MATHEMATISCHES FORSCHUNGSINSTITUT OBEFRWOLFACH

T a g u n g s b e r i c h t 38/1997

Stochastic Analysis in Finance and Insurance

14. 9. – 20. 9. 1997

This meeting was organised jointly by Darrell Duffie (Stanford), Paul Embrechts (Zürich) and Hans Föllmer (Berlin). In 28 talks and many informal discussions, it covered a wide range of problems in finance and insurance which involve advanced methods of stochastic analysis. Key topics included:

- incomplete financial markets, in particular stochastic volatility, equilibrium analysis, stochastic optimisation problems, and applications in insurance,
- hedging strategies in the presence of transaction costs and constraints,
- financial versus actuarial pricing principles, asset liability modelling, default risk, and insurance derivatives,
- new approaches to the modelling of asset price dynamics,
- stochastic dynamics of the term structure of interest rates, in particular geometric aspects, interest rate derivatives, and extremes,
- theoretical problems in stochastic analysis motivated by applications in finance, in particular martingale inequalities, backward stochastic differential equations and the structure of Brownian filtrations.

The meeting had 49 participants.

Abstracts

Knut Aase

A new equilibrium asset pricing model based on Lévy processes

The talk presented some security market pricing results in the setting of a security market equilibrium in continuous time. The model consists in relaxing the distributional assumptions of asset returns to a situation where the underlying random modelling the spot prices of assets are exponentials of Lévy processes, the latter having normal inverse Gaussian marginals, and where the aggregate consumption is inverse Gaussian. Normal inverse Gaussian distributions have proved to fit stock return remarkably well in empirical investigations. Within this framework we demonstrate that contingent claims can be priced in a preference-free manner, a concept defined in the paper. Our results can be compared to those emerging from stochastic volatility models, although these two approaches are very different. Equilibrium equity premiums are derived and calibrated to the data in the Mehra and Prescott (1985) study. The model gives a possible resolution of the equity premium puzzle. The "survival" hypothesis of Brown, Goetzmann and Ross (1995) is also investigated within this model, giving a very low crash probability of the market.

Ole E. Barndorff-Nielsen

Some thoughts on statistical modelling in finance

There are striking similarities between finance and turbulence as regard to some of the most essential empirical features that relate to logarithmic asset prices on the one hand and streamwise velocities on the other. After a discussion of these similarities, the talk concentrated on the problems of constructing tractable stochastic processes that exhibit the type of (quasi) long-range dependence or scaling/selfsimilarity behaviour observed in both of the two fields of study. In particular, a method of setting up selfsimilar processes, with second order stationary increments and driven by bivariate Lévy processes, was discussed.

Tomas Björk

Forward rate models and invariant manifolds

We investigate when the dynamics of a given forward rate model is consistent with a given finitely parameterized family of forward rate curves.

Consistency, in this context, simply means that the forward rate model actually is able to produce forward rate curves belonging to the parameterized family. Mathematically this leads to the question when a finite-dimensional manifold in C-space is invariant under the action of the (C-valued) infinite-dimensional forward rate process. We give necessary and sufficient conditions for consistency, and apply the results to some concrete examples. We also propose a new parameterized family and give conditions for the existence of a consistent forward rate model.

Rainer Buckdahn

Viability for BSDE and associated PDE

Let $K \subset \mathbb{R}^N$ be a nonempty and closed set and let F be a progressively measurable $\mathbb{R}^N$-valued function such that the BSDE

$$Y_t = \xi + \int_t^T F(s, Y_s, Z_s)\, ds - \int_t^T Z_s\, dW_s, \qquad 0 \le t \le T,$$

has a unique solution $(Y, Z) \in B^2$ for each $\xi \in L^2(\Omega, \mathcal{F}_T^W, \mathbb{P}, \mathbb{R}^N)$, where W is a d-dimensional standard Brownian motion defined on $(\Omega, \mathcal{F}, \mathbb{P})$. The talk studies a minimal assumption on F, under which the BSDE enjoys the viability property with respect to K. The talk is based on a joint work with Marc Quincampoix (Brest) and Aurel Rascanu (Iaşi).

Rüdiger Frey

Superreplication under stochastic volatility

Stochastic volatility models have been developed in order to cope with the well-known empirical deficiencies of the standard Black–Scholes model of geometric Brownian motion. In this class of models the asset price follows an SDE of the form $dS_t = \sigma_t S_t\, dW_t$, where σ_t is not adapted to the filtration generated by the Brownian motion W. Therefore these models are incomplete such that there are “many” equivalent (local) martingale measures for S. We show that for unbounded σ_t and for a European call option the quantities

$$\bar{C}_K = \sup\{\mathbb{E}^Q[(S_T - K)^+] \colon Q \text{ equivalent martingale measure}\}$$

and

$$\underline{C}_K = \inf\{\mathbb{E}^Q[(S_T - K)^+] \colon Q \text{ equivalent martingale measure}\}$$

are given by $\bar{C}_K = S_0$ and $\underline{C}_K = (S_0 - K)^+$. Hence it follows from the optional decomposition theorems of Delbaen, El-Karoui and Quenez or Kramkov that there is no nontrivial super- or subreplication strategy for the options. We go on and determine "meaningful" superhedging strategies under the additional assumption that σ_t is a bounded process. In both cases the principal tool is the result that every continuous local martingale can be represented as time-changed Brownian motion. We close by discussing the relation of our results to the PDE characterisation of superhedging strategies. The first part of the talk is based on joint work with C. Sin.

Marco Frittelli

Valuation principles in incomplete financial markets

We describe a general principle for the valuation problem in incomplete markets that reconciles the "utility" and "martingale" approaches. We provide a general criterion for selecting one equivalent martingale measure that requires minimising an appropriate functional which depends on investors utility. We give sufficient conditions for the existence of the martingale measure that minimises this functional. We then show that most existing financial criteria for pricing in incomplete markets are particular cases of our approach. The results are derived by applying duality theory and Legendre transforms.

Hélyette Geman

Transaction clock, asset price dynamics and volatility estimates

Normality of asset returns is a central assumption in a number of fundamental problems in finance such as portfolio theory, the capital asset pricing model or the Black–Scholes option pricing. In the measurement of value at risk, the tails of the distribution obviously play a key role. In order to address the issue of non-normality of asset returns, which has been documented in a vast number of empirical studies in finance, this paper proposes to represent as in Clark (1973) the price process as a subordinated process. At variance with Clark however, no a priori distribution is imposed on the subordinator. Using the number of trades as the stochastic clock, a quasi perfect normality of returns is exhibited on a high frequency data base of S&P 500 future contracts. Moreover, we are able to construct an activity-related volatility which reveals to be a better estimator of the volatility to incorporate in the Black–Scholes formula (in a stochastic volatility framework) than the historical volatility, the implied volatility or the Garman–Klass volatility.

Hansueli Gerber

From ruin theory to option pricing

We examine the joint distribution of the time of ruin, the surplus immediately before ruin, and the deficit at ruin. The time of ruin is analysed in terms of its Laplace transform, which can naturally be interpreted as discounting. We show how to calculate an expected discounted penalty, which is due at ruin, and may depend on the deficit at ruin and the surplus immediately before ruin. The expected discounted penalty, considered as a function of the initial surplus, satisfies a certain renewal equation. By replacing the penalty at ruin with a payoff at exercise, these results can be applied to pricing a perpetual American put option on a stock, where the logarithm of the stock price is a shifted compound Poisson process. Because of the stationary nature of the perpetual option, its optimal option-exercise boundary does not vary with respect to the time variable. We have derived an explicit formula for determining the optimal boundary. (This is joint work with Elias S. W. Shiu.)

Farshid Jamshidian

Libor and swap derivatives

A general model for arbitrage-free movements of term structure of forward Libor and swap rates is presented within the framework of a finite-dimensional securities market model, and applied to evaluate common swap derivatives such as European and Bermudian swaptions. Appropriate numeraires and measures are identified for construction of such models from the specification of any volatility function. For the lognormal case the construction is explicit. This is of special importance in practice as it corresponds to the way cap and European swaptions are evaluated in the market place.

Monique Jeanblanc

Incomplete markets, range of prices, informed agent

We study an incomplete market where two assets are traded: a riskless asset with constant interest rate r and a risky asset whose dynamics is

$$dS_t = S_{t-}(\mu\, dt + \sigma\, dW_t + \varphi(dN_t - \lambda\, dt)), \qquad S_0 = x,$$

where W is a Brownian motion and N a Poisson process with constant intensity λ. In a first part (joint work with N. Bellamy) we study the set $\mathcal{Q}$ of equivalent martingale measures and establish that

$$\left\{\mathbb{E}_Q[e^{-rT}(S_T-K)^+] \colon Q \in \mathcal{Q}\right\} =]\mathcal{BS}(x), x[,$$

where $\mathcal{BS}$ is the Black–Scholes function, i. e.,

$$\mathcal{BS}(x) = \mathbb{E}\left[\left(x \exp((r-\sigma^2/2)T + \sigma W_T) - K\right)^+\right], \qquad x > 0.$$

We establish similar results for the values $\mathbb{E}_Q[(S_T-K)^+ \,|\, \mathcal{F}_t]$, where $\mathcal{F}_t = \sigma(W_s, N_s; s \le t) = \sigma(S_s; s \le t)$, and for American and Asian options. In a second part (work in progress with R. Elliott) we address the problem of range of prices/optimisation for an “informed” agent who knows N_T. For this agent the dynamics of the asset's price is

$$dS_t = S_{t-}\left([\mu + \varphi(\Gamma_t - \lambda)]\,dt + \varphi\,dM_t^* + \sigma\,dW_t\right)$$

where

$$M_t^* = N_t + \int_0^t (\Gamma_s - \lambda)\,ds \quad \text{and} \quad \Gamma_s = \frac{N_T - N_{s-}}{T-s}.$$

Yuri Kabanov

Hedging and liquidation under transaction costs

We study a problem of initial endowment needed to hedge a contingent claim in various currencies (or other assets). Being inspired by the recent papers by Cvitanič and Karatzas, we derive a duality description for this set and apply the result to a problem of optimal control with a terminal functional. The main message of the talk is that a partial ordering induced by the solvency cone provides a convenient tool and elucidates many aspects of the theory of markets with transaction costs.

Claudia Klüppelberg

Extremal behaviour of term structure diffusion models

We investigate the extremal behaviour of diffusions given by the SDE

$$dX_t = \mu(X_t)\,dt + \sigma(X_t)\,dB_t, \qquad t > 0,\ X_0 = 0,$$

where μ is the drift term, σ the volatility and B standard Brownian motion. Examples which have been considered as term structure models include the Vasicek model, the Cox–Ingersoll–Ross model and generalisations. Under suitable conditions the extremes of X have the same asymptotic behaviour as the extremes of i. i. d. random variables with a well-specified distribution function, which we derive for the above examples. (This is joint work with Milan Borkovec.)

Ralf Korn

Some applications of optimal impulse control in mathematical finance

Applications of optimal stochastic control in the idealised situation of continuous trading typically result in optimal trading strategies that require trading at every time instant. However, under imperfections of real security markets (such as the occurrence of transaction costs) it is impossible to follow such strategies. The appropriate mathematical setting that is able to cope with the presence of transaction costs is given by the impulse control framework. We show how it can be applied to three different problems of mathematical finance: the optimal cash management in equity index tracking, portfolio selection under transaction costs and the optimal control of the exchange rate. To all these problems different solution methods (such as an optimal stopping method, the quasi-variational inequalities approach, and an asymptotic analysis of the problem) are given.

Dmitrii Kramkov/Walter Schachermayer

A growth condition for utility functions and its relevance in duality theory

We consider the classical utility maximisation problem

$$u(x) = \sup_H \mathbb{E}[U(x + (H \cdot S)_T], \qquad x \in \mathbb{R}_+,$$

where $U : \mathbb{R}_+ \to \mathbb{R}$ is a utility function with $U'(0) = \infty$, $U'(\infty) = 0$, $S = (S_t)_{0 \le t \le T}$ is a semimartingale taking its values in $\mathbb{R}^d_+$, modelling the discounted price process of d stocks, and H ranges through the admissible predictable trading strategies. We analyse under which assumptions the value function $u(x)$ again is a utility function. Under the standard assumptions $u(x) < \infty$ and $\mathcal{M}^{\mathrm{e}}(S) \neq \emptyset$, where $\mathcal{M}^{\mathrm{e}}(S)$ denotes the equivalent local martingale measures for the process, we find that a necessary and sufficient condition is the requirement that $U(x)$ is *asymptotically elastic,* i. e.,

$$\limsup_{x \to \infty} \frac{U'(x) \cdot x}{U(x)} < 1.$$

Defining the Legendre transforms

$$V(y) = \sup_{x>0} \{U(x) - xy\} \qquad \text{and} \qquad v(y) = \sup_{x>0} \{u(x) - xy\},$$

we also find that a necessary and sufficient condition for the duality formula

$$v(y) = \inf_{Q \in \mathcal{M}^e(S)} \mathbb{E}\Big[V\Big(y\frac{dQ}{d\mathbb{P}}\Big)\Big]$$

to hold true again is the asymptotic elasticity of U.

Shigeo Kusuoka

Replication costs for American securities with transaction costs

We first think of a discrete-time complete stochastic finance market with time unit h, and introduce transaction costs. We also define superreplication costs for American securities with transaction costs. Our concern is the limit theorem for the superreplication costs as $h \downarrow 0$. We prove the limit theorem and show that the limit is described by the solution of a certain "supermartingale problem." Finally we define "supermartingale problem" and discuss about it.

David Lando

Term structures of credit spreads with incomplete accounting information

Two approaches to modelling default risk are unified in the following sense: It is shown that a "structural model"—in which the assets of a defaultable issuer of bonds are modelled as a diffusion process and default is a first hitting time of this diffusion of a given boundary—becomes a "reduced-form" model—in which default is modelled through a stochastic intensity—if the assets in the structural model are observed with noise. As an application of this we study the implications of imperfect accounting information for the term structure of credit spreads. Leland's 1994 model is extended by an assumption that bond investors cannot observe the issuer's assets directly and receive instead only periodic and imperfect accounting reports.

Ragnar Norberg

Topics in insurance mathematics

This talk reviews some selected basic areas of insurance mathematics and discusses their relations—factual and potential—to mathematical finance. Special emphasis is laid on life insurance mathematics and the probability of ruin. Some pieces of technical progress are reported, in particular on a Poisson-driven Ornstein–Uhlenbeck process and its applications to insurance and finance. A brief introduction to actuarial notation like

$${}_{m|n}(I\ddot{a})_x^{(k)} \qquad \text{and} \qquad {}_{m|n}(D\bar{A})_{\underset{1}{x_1}\overset{2}{x_2}x_3}$$

seemed to amuse the audience.

Bernt Øksendal

The Wick product and the Donsker delta function: How to hedge a discontinuous claim

We use the white noise calculus, including the Wick product and the Donsker delta function, to find explicit formulae for the replicating portfolios in a Black–Scholes market for a class of contingent T-claims, including claims of the form $f(X_T(\omega))$, where $(X_t)_{0\leq t\leq T}$ is an Itô diffusion and $f : \mathbb{R} \to \mathbb{R}$ is a bounded measurable function. Our results apply to cases which are not covered by the Black–Scholes partial differential equation approach or by the Clark–Ocone formula. The talk is based on work from a current project with K. Aase and J. Ubøe.

Eckhard Platen

Modelling the dynamics of financial markets

The talk described an approach to the modelling of financial markets. Starting from two working principles, a non-linear stochastic volatility dynamics and a short-term forward rate dynamics were derived. The drift of a stock was specified in a linear mean-reverting way. Furthermore a notion of market risk as an average of squared returns or cost increments was introduced. Then the dynamics of stochastic volatility and short-term forward rate followed from the minimisation of market risk. Many stylised empirical facts about these market characteristics can be explained by the result. The minimisation of an analogous market risk for a mixed derivatives and insurance market resulted in prices for contingent claims that are based on the minimal equivalent martingale measure. The approach naturally allows the inclusion of transaction costs and constraints. As typical for local risk minimisation, the cumulative cost process represents a martingale under the given objective probability measure.

Philip Protter

Complete markets with a discontinuous price process

We propose a parametrised family of financial market models. These models have jumps in the price process yet are complete with equivalent martingale measures and no arbitrage. For each β with $-2 \leq \beta < 0$ the model generalises the standard model (with Brownian motion) which corresponds to $\beta = 0$. Moreover, as β converges to 0, the models converge weakly to the standard model. A hedging result is also presented. The models rely on the Emery–Azéma martingales, whose development was originally motivated by quantum probability. (Based on joint work with Michael Dritschel.)

Uwe Schmock

Estimating the value of the WinCat coupons of the Winterthur Insurance convertible bond

The three annual $2\,{}^{1}\!/_{4}\%$ interest coupons of the Winterthur Insurance convertible bond (face value Chf 4 700) will only be paid out if during their corresponding observation periods no major storm or hail storm on one single day damages more than 6 000 motor vehicles insured with Winterthur Insurance. Data for events, where storm or hail damaged more than 1 000 insured vehicles, are available for the last ten years. Using a constant-parameter model, the estimated discounted value of the three Wincat coupons together is Chf 263.29. A conservative evaluation, which accounts for the standard deviation of the estimate, gives a coupon value of Chf 238.25. However, fitting a model, which admits a trend in the expected number of events per observation period, leads to substantially higher knock-out probabilities of the coupons. The estimated discounted value of the coupons drops to Chf 214.44; a conservative evaluation as above leads to substantially lower values. Hence, the model uncertainty is in this case substantially higher than the standard deviations of the used estimators.

Martin Schweizer

From actuarial to financial valuation principles

A valuation principle is a mapping that assigns a number (value) to a random variable (payoff). We construct a transformation on valuation principles by embedding them in a financial environment. Given an a priori valuation rule u, we define the associated a posteriori valuation rule h on payoffs as follows by an indifference argument: The u-value of optimally investing in the financial market alone should equal the u-value of first selling the payoff at its h-value and then choosing an investment strategy that is optimal inclusive of the payoff. In an L^2-framework, we explicitly obtain the financial transforms of the variance principle and the standard deviation principle. The resulting financial valuation rules involve the expectation under the variance-optimal martingale measure and the intrinsic financial risk of the payoff.

Elias S. W. Shiu

Deferred annuities: Equity-indexed annuities

The purpose of the talk is to point out applications of modern financial theory to the life insurance business. It explains the various options granted by an insurance company in its assets and liabilities. Such options need to be priced and reserved properly. A dominant segment of the U. S. life insurance business is the deferred annuities, which consists of the fixed-rate annuities, variable annuities and equity-indexed annuities. These deferred annuities are investment products with (exotic) options which should be priced and reserved using modern option-pricing theory.

Steven E. Shreve

Hedging under portfolio constraints

Consider a European call which knocks-out (falls to zero value) if the underlying stock crosses a barrier B prior to expiration. We assume B exceeds the strike price. The classical Black–Scholes value $v(t,x)$ at time t if the stock price is x has large negative "delta" $v_x(t,x)$ and "gamma" $v_{xx}(t,x)$ near the barrier. In practice, these large derivatives prevent traders from implementing the "delta-hedging" strategy. To overcome this difficulty, there are three possible approaches:

(1) Artificially increase the barrier, and price and hedge the option as if the higher barrier were the contracted one;
(2) Impose a transaction cost in the model to cover the close-out of the short position mandated by "delta-hedging" when the option knocks out;
(3) Price and hedge the option subject to a constraint that the ratio of the value of the stock shorted by the hedging portfolio to the total value of the hedging portfolio cannot exceed a prespecified bound.

It is shown that approaches (2) and (3) are equivalent, and (1) is a first-order approximation to them.

Mete Soner

Option pricing in incomplete markets

In this talk, I consider two different examples of incomplete markets and outlined two approaches to pricing. In the first example, I used the approach of superreplication to price a European call option with portfolio constraints. I showed that the minimal price is the Black–Scholes price of an adjusted claim. (This is joint work with N. Broadie and J. Cvitanič of Columbia University.) The second example was a model with proportional transaction costs. I used the utility maximisation approach of Hodges–Neuberger and Davis–Panas–Zariphopoulou and asymptotic analysis to derive a nonlinear Black–Scholes equation. (This is joint work with G. Barles of University of Tours.)

Christophe Stricker

Some inequalities in mathematical finance

This talk is based on two joint papers with T. Choulli and L. Krawczyk. We give some extensions of the well-known Doob and Burkholder–Davis–Gundy inequalities to more general processes than martingales. Such an extension is crucial for the closedness of some spaces of stochastic integrals arising in mathematical finance.

Nizar Touzi

Closed form solution to the super-replication problem under stochastic volatility, portfolio constraints and transaction costs

We study the problem of finding the minimal initial amount which allows to hedge a European-type contingent claim. We use a previously known dual representation of the minimal price as a supremum of the prices in some corresponding shadow markets. Although the Hamilton–Jacobi–Bellman equation is not satisfied by the value function of the dual problem, an explicit closed-form solution is derived using only the supersolution property.

Marc Yor

Weakly and strongly Brownian filtrations

In this lecture, I presented some recent results due to B. Tsirel'son, the most striking being: *The filtration of Walsh's Brownian motion with at least three rays is a weakly Brownian, but not a strongly Brownian filtration.* More explicitly: Although all martingales in this filtration can be written as stochastic integrals with respect to a given Brownian motion, the filtration is not the natural filtration of a Brownian motion. The method used helped to solve two other open problems, one about the minimum of three harmonic measures for Brownian motion, the other one about the difference between $\mathcal{F}_{L+}$ and $\mathcal{F}_L$, where L is the end of a predictable set. The answer is: Given any such L, $\mathcal{F}_{L+}$ differs from $\mathcal{F}_L$ by at most the adjunction of one set (M. Barlow's conjecture). The results of B. Tsirel'son should appear in GATA and also in a presentation by Barlow–Emery–Knight–Song–Yor in Séminaire XXXII, Lecture Notes in Mathematics, Springer-Verlag (1998).

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For a TEX-version of the report see
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