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Guest editorial

Econometric methods for derivative securities and risk management

Derivative securities pose many challenges to the financial community. To econometricians they do so as well. The area of empirical modeling and applications of financial derivatives is an extremely fertile ground for research. It is what econometrics is all about. The theory of derivative security pricing in the now commonly used continuous-time setting dates back to Black and Scholes (1973) and Merton (1993). We have discrete-time observations of the underlying fundamental asset and option pricing formulas which typically are derived under assumptions which imply the existence of a continuous-time arbitrage-free world. Already at this stage, there are a lot of tensions between theory and reality. The fact that financial assets feature volatility clustering, a departure from the Black–Scholes economy assumptions, adds another layer of complexity. Some of these issues have been addressed. Notably, the fact that volatility is not constant has a number of implications both for the pricing formulas and econometric estimation. The pricing formulas of Hull and White (1987), Chesney and Scott (1989) and Heston (1993), among others, deal with derivative securities when volatility is random while the econometric analysis of financial time series with conditional heteroskedasticity is surveyed for instance by Bollerslev et al. (1994), Ghysels et al. (1996), Renault (1997) and Tauchen (1997).

In this Annals issue we bring together a collection of eight papers on the subject of *Econometric Methods for Derivative Securities and Risk Management*. The first four papers have a common feature. They examine various nonparametric estimation schemes to enhance risk management, hedging and pricing of derivatives. The first paper is by Yacine Aït-Sahalia and Andrew Lo. Both have been at the forefront of nonparametric analysis applied to derivatives (see for instance Aït-Sahalia (1996a, b) and Hutchinson et al. (1994) as well as the discussion in Ghysels et al. (1998)). In their paper they revisit Value at Risk (VaR) measures, which are confidence intervals of how much one can lose from holding a risky portfolio of assets over a set horizon. The methods used by practitioners are based on the statistical distributions of market prices, i.e. the objective or physical measure of the portfolio of asset price processes. Aït-Sahalia and Lo argue that statistical VaR measures, which they call S-VaR, lack economic evaluation of risk exposure. They note that since Arrow–Debreu

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prices have a probability-like interpretation, such prices can be used as a basis for measuring economic risk. The authors propose to use Arrow–Debreu prices, or equivalently, state-price densities to measure Value at Risk, an approach they coin E-VaR. Nonparametric methods are used to obtain estimates of the densities, those pertaining to S-VaR as well as those pertaining to E-VaR. Then, the authors propose to compare the densities underlying the alternative value at risk measures to extract an aggregate measure of risk aversion, which they call implied risk aversion as it is extracted from traded financial assets. The empirical implementation, which involves S&P500 options data, shows that implied risk aversion varies considerably and in a nonlinear way across states and maturities.

The second paper is by Mark Broadie, Jérôme Detemple, Eric Ghysels and Olivier Torrés and deals with American type options. The early excercise feature of these contracts considerably complicates their valuation. Even the relatively simple case where the underlying asset features constant volatility typically requires numerical algorithms to value the option. The authors first discuss at length pricing of American options when there is stochastic volatility and dividend payments are random as well. A general equilibrium representation is provided and risk premia as well as contingent claims pricing formula are derived, including those for American and European type options. These pricing formula are, not surprisingly, even more complex than the existing results for Black–Scholes economies. The paper does not propose to address these highly complex pricing schemes with numerical algorithms. Instead it takes advantage of nonparametric methods to derive pricing formula as well as excercise boundaries. The OEX options contract is used for the empirical implementation. The authors use both call prices and excercise data, the latter being provided by the Options Clearing Corporation. The OEX contract with the S&P100 index as the underlying asset, is supported by an extremely liquid market which in many regards surpasses its European counterpart based on the S&P500. The abundance of data, including observations on excercise decisions, justifies the use of nonparametric methods. The authors propose to use kernel regressions involving measures of the latent spot volatility as well as dividend series, which are both related to the state variables of the theoretical model. The use of proxies for latent volatility in a nonparametric setting like this raises several technical issues, which are discussed in the paper. The kernel regressions are applied to both the pricing of calls as well as the characterization of the excercise boundary. Instead of a single excercise boundary, which is obtained for constant volatility models, the authors find a boundary which is conditional on volatility and dividends. They find that call prices and excercise decisions are relatively insensitive to volatility except for the upper quartile of the volatility distribution. The paper concludes with a comparison between pricing errors obtained from parametric constant volatility option pricing formula, from binomial trees and finally from nonparametric schemes.

The next paper is by René Garcia and Ramazan Gençay and deals with pricing and hedging of derivatives using neural networks and what the authors call a homogeneity hint. In nonparametric models of option pricing functions, it is often assumed that the function is homogeneous of degree one in the underlying stock price and the strike price. A first reason is that it reduces the number of inputs in learning the nonparametric pricing function. This parsimony is an advantage since the rate of convergence of nonparametric estimators slows down considerably as the number of inputs increases. A second invoked reason is the nonstationarity of option and stock prices. While justified, this homogeneity assumption is not always consistent with the underlying asset price dynamics. Merton (1973) shows that serial independence of asset returns for the data generating process is a sufficient condition for homogeneity. In a non-arbitrage context, Garcia and Renault (1995) establish that conditional independence under the pricing probability measure between future returns and the current price is a necessary and sufficient condition for homogeneity of the option pricing function. Similar conditions are also derived in the paper by Mark Broadie, Jérôme Detemple, Eric Ghysels and Olivier Torrés appearing in this issue. For processes which obey these objective or risk-neutral distributional assumptions, the option pricing formula is homogeneous and can be characterized as a generalized Black–Scholes formula where the normal distribution function is replaced by another distribution function in an otherwise similarly shaped formula which stems from the convexity of the terminal payoff. In their paper, Garcia and Gencay show that pricing accuracy gains can be made by exploiting the implications of this homogeneity property in terms of functional shape. They break down the pricing function into two parts, one controlled by the stock price to the strike price ratio, the other by a function of time to maturity. In each part, a neural network learning network is fit with these variables as inputs. Both in a simulation setting and with several years of data on European call options on the S&P 500 index, they show that the two-part network based on homogeneity always reduces the out-of-sample mean-squared prediction error compared with a simple feedforward neural network. Garcia and Gencay also investigate the relative delta-hedging performance of both feedforward network models. The homogeneity-based networks provide more stable average delta hedging errors.

The final paper involving nonparametric methods is written by Emmanuelle Clément, Christian Gouriéroux and Alain Monfort. It deals with the statistical analysis of risk neutral densities. The non-arbitrage condition implies that there is a unique measure. This result has very strong implications regarding the inference of parameters, implications which are in fact at odds with statistical analysis of option price data. The authors provide a motivating example involving a European call option and the Black–Scholes formula and show how in principle one observation on the underlying stock, the interest rate and a call price suffices to uncover the volatility. This example alludes to the common practice of computing implied volatilities, which are treated as random despite the fact that the Black–Scholes formula is derived under constant volatility. The authors introduce the notion of a stochastic risk neutral measure and make a distinction between information held by market participants and information available to econometricians who estimate risk neutral densities. To the econometrician, who has less information, the risk neutral measure used to price derivatives is stochastic due to the asymmetry of information. This randomness permits the authors to derive the population moments of derivative security prices and suggest statistical estimation procedures. When the risk neutral measure is a Gamma process the authors derive an extended Black–Scholes model which yields the standard formula as the population mean and a full characterization of the call price densities. This analysis has immediate implications for proper statistical inference and sets the stage for several extensions involving multihorizon contracts as well as path-dependent cash flows. The actual implementation and performance of the methods is appraised by a Monte Carlo study.

The next paper by Eric Jacquier and Robert Jarrow also deals with the issue of how to treat observational errors to reconcile options data with theoretical models. Jacquier and Jarrow take the view that the options pricing model contains an additional error term and therefore that there is some departure from the completer market hypothesis. Based on a distributional assumption about the pricing error, they develop a maximum likelihood Bayesian estimator to assess the effect of model error on inference. They assume that the error term builds additively or multiplicatively onto a basic reference model or a nonparametric extended model. Moreover, they allow for heteroskedasticity in the errors. The Bayesian estimator does not have an analytical solution even for the Black–Scholes and simple pricing error structures. To contravene this problem, they propose a hierarchical Markov Chain Monte Carlo estimator. This simulation-based estimator provides exact inference for any non linear function of the parameter instead of relying on the usual combination of delta method and normality assumption. The empirical analysis reveals the non-normality of the posterior densities. It also shows that tests of the Black–Scholes model and its extension which are based only on the fit density do not give a reliable view of the pricing uncertainty to be expected out-of-sample. The use of the predictive density markedly improves the quality of the forecasts. The authors also show that the nonparametric extended models improved on the basic model specification in sample, but fail to provide a better out-of-sample performance than Black–Scholes. This remains true even for the heteroskedastic models.

The paper by David Bates is a first of two papers in this Annals issue examining jump option pricing models. In his paper, David Bates examines the post-crash negative skewness in the distributions inferred from S&P500 future option prices and proposes two models, stochastic volatility with and without jumps, as alternative explanations for this phenomenon. The author proposes two diagnostics to appraise which volatility process is the better one. A first diagnostic exploits the differences in predictions regarding the relationship between time to maturity and implicit skewness. A nonlinear generalized least-squares approach combined with Kalman filtering is proposed to uncover implicit parameters and assessing the specification error. The second diagnostic relies on comparisons of distributions recovered from cross sections of options with distributions obtained from the time-series properties of the underlying. The author's overall conclusion is that the stochastic volatility/jump-diffusion model is more compatible with observed option prices. Yet, the author also points out that the implicit distributions from this model predict far too many large stock moves over the 1988–1993 period which is incompatible with the observed data.

Nicolas Bollen, Stephen Gray and Robert Whaley provide another approach to characterize the occurrence of jumps in security prices. They show that regime-switching models capture well the time-series properties of foreign exchange rates. A model with independent mean and variance shifts provides a tighter in-sample fit and more accurate variance forecasts than competing GARCH models. However, the original contribution of the paper is to investigate whether regime-switching models provide more accurate option valuation than standard models such as Black–Scholes. Using exchange-traded option prices, they infer regime-switching parameters and show that these implied parameters are consistent with those of the time series analysis of the underlying exchange rates. However, option prices generated from the time-series estimates are significantly different from market option prices. They interpret these results as evidence that market prices fail to incorporate regime-switching information fully. To confirm this interpretation, they provide a trading strategy experiment. To evaluate competing option valuation models, they assess the risk-adjusted profits associated with alternative trading strategies. A strategy based on a regime-switching model with constant within-regime volatility is shown to provide higher profits than strategies using Black–Scholes with implied volatilities recovered from option prices of the previous day or with a time series estimate of volatility using the past year's data. The trading strategies are used on options on the British Pound, the Japanese Yen and the Deutsche Mark. The conclusion are robust to the inclusion of transaction costs.

The final paper is written by Gurdip Bakshi, Charles Cao and Zhiwu Chen. They rely on long-term options, the so called LEAP (Long-term Equity Anticipation Securities) contracts written on the S&P500 contract, to revisit model specification issues in options pricing. When comparing the hedge ratios and option deltas for stochastic volatility, stochastic volatility/stochastic interest rates and stochastic volatility/jump diffusions models, the differences are only marginal when short-term (i.e. regular) options data are used. Long-term contracts, feature far greater discriminatory power across the candidate model specifications. The authors take advantage of this long horizon pricing problem to compare models. Estimation of the parameters is based on a simulated method of moments approach. Like Bates, they also find evidence in support of the jump model for the purpose of pricing, although in pricing long term puts the stochastic volatility model performs the best. They also find that adding stochastic interest rate does not seem to be much helpful. For the hedging excercise, it appears that deep in-the-money LEAPS puts yield the lowest hedging error on average. For the purpose of hedging it also appears that stochastic volatility and stochastic volatility/jump diffusions models lead to similar errors.

To conclude, we would like to take this opportunity to thank all the referees who helped us with the tedious task of reviewing the papers and providing us with timely and insightful reports which greatly improved the quality of the contributions to this volume. This Annals issue started when the three of us were all in one place, the CIRANO research center in Montréal. We would like to acknowledge the continued financial support from CIRANO for this project. Last, but absolutely not least, we would also like to thank the Editors of the *Journal of Econometrics* for their support.

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