Estimation and Inference with the Efficient Method of Moments: With Applications to Stochastic Volatility Models and Option Pricing
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Chapter 8
Summary and Further Research

This chapter provides a brief summary of the thesis and some suggestions for further research.

8.1 Summary

The purpose of this thesis has been: (i) to provide a reliable estimation technique for Stochastic Volatility (SV) models, (ii) to provide reliable hypothesis tests and test for mis-specification for SV models, (iii) to investigate option pricing under stochastic volatility and (iv) to analyse volatility-forecasting performance of SV models. Below the main results are recapitulated.

Chapter 2 briefly discusses the models for financial time series that have been proposed in the literature and provides some context for these models. This chapter also introduces the standard SV models and some non-Gaussian, asymmetric and multivariate extensions that are analyzed in the thesis. Furthermore recent estimation techniques for SV models are briefly reviewed. This chapter concludes with a brief discussion of option pricing under stochastic volatility.

Chapter 3 contains the theory of the Efficient Method of Moments (EMM). EMM is a moment-based technique that for a specific choice of the moments provides first-order asymptotically efficient estimators. The moments are chosen from the score of an auxiliary model (score generator) that converges asymptotically to the true probability density of the data. For SV models we employ an EGARCH model with an expansion in terms of Hermite polynomials as auxiliary model. We also discuss reprojection which is a recent extension of EMM which in this context enables us to obtain a representation of the latent volatility series from the SV model. The semblance to other moment-based techniques is exploited for generalisation of hypothesis tests. The efficiency claim is corroborated for finite-samples through a Monte Carlo study in the context of SV models. From the Monte Carlo
study we learn that for SV models using the specific score generator chosen here
the efficiency claim of EMM is supported in finite samples. Replacing the Hermite
expansion with a Student $t$-distribution improves the small-sample estimation per­
formance in this context, but the Hansen $J$-test for overidentifying restrictions will
have less alternative directions. Several univariate SV models are fitted to daily re­
turns of the S&P500 for the period 1963–1993 using a variety of score generators.
For this series we find that an asymmetric SV with Student-$t$ errors is preferred
over the symmetric and Gaussian alternatives.

Chapter 4 deals with tests for structural stability with known breakpoint for
EMM. We discuss three equivalence classes of tests, viz. the $LM/LR/Wald$-tests,
the Hansen tests, and the Prediction (or PSP) tests, each being asymptotically lo­
cally most powerful for a specific alternative. Only one of these three classes,
namely the class of Prediction tests, is computationally attractive in the sense that
only one EMM estimator is needed. Therefore we propose computationally attrac­
tive modifications for the other two classes that retain the property of being asymp­
totically locally most powerful. As an illustration of these tests we employ first-
order linearized EMM estimators. A Monte Carlo study investigates the small-
sample properties of the computationally attractive tests in the context of univari­
ate SV models. The Monte Carlo study reveals: (i) The computationally attractive
tests and first-order linearized estimators seem to have encouraging properties, ex­
cept for very small sample and post-samples where the first-order linearized es­
timators react quite heavily on a contrast in the parameter values, and the level
of the test is not 5%, but much larger. (ii) The $PSP$-test is in terms of perfor­
mance always between the computationally attractive tests, so there are better tests
than the $PSP$-test which do not require estimates of the structural model for the
post-sample and combination of sample and post-sample and are thus computa­
tionally attractive test statistics. This only holds for detecting parameter variation.
For detection of violation of the moment conditions we find that a computa­tionally attractive Hansen test for structural stability outperforms a computationally attractive Wald-type test for structural stability and the $PSP$-test. (iii) Detecting
of a change in the volatility-of-volatility parameter in the SV model is more dif­
ficult than it is for the other parameters. Further Monte Carlo studies are needed
to pass judgement on the small-sample properties of the tests. In particular, in the
EMM framework it may increase the power of a test to use as many as possible
post-sample data. Next the tests are applied to SV models for daily exchange-rate
movements of the British Pound versus the Canadian Dollar 1988–1996 and daily
returns of the S&P500 index 1981-1993. We set the breakpoint for the exchange-
rate movements to Black Wednesday, when Britain left the ERM. Here we find that
the stability hypothesis is rejected. For the S&P500 index we set the breakpoint at
Black Monday 1987. There seems to be no parameter variation and violation of
the EMM moment conditions before and after Black Monday 1987.
Chapter 5 deals with tests for structural stability with unknown breakpoint for EMM. As in Chapter 4 the tests fall apart into three equivalence classes, where each class contains tests that consider a specific aspect of mis-specification of the structural model. Since the breakpoint is treated here as unknown, the asymptotic distribution of the tests cannot be derived by standard theory. As suggested in the literature exponentially weighted test statistics, arithmetically weighted test statistics and the supremum of the test statistics are considered. The generalization of the Hansen test for structural stability with known breakpoint to the case of unknown breakpoint is a novelty in the literature of moment-based inference. Therefore the asymptotic distribution of this test is derived. The theory is applied to an asymmetric stochastic volatility model for thirty years of daily data of the S&P500 index ranging from 1963 to 1993. All tests indicate rejection of the null hypothesis of structural stability. From the movements of the test-statistics we can see aspects of the data we could not see by eyeballing the levels or the returns. The supremum tests give an estimate of the breakpoint at the first half of 1970.

Chapter 6 discusses the pricing of options with EMM. We use a series of daily US 3-month Treasury-bill rates and daily 3Com Corporation stock prices. The data covers the period from March 12, 1986 to August 18 1997. Option prices are computed using both reprojected underlying historical volatilities and implied stochastic volatility risk to gauge each model’s performance through direct comparison with observed market option prices. The option pricing formulae are tested using option prices on the same underlying stock for the period June 19, 1997 through August 18, 1997. The major empirical findings are summarized as follows. First, while theory predicts that the short-term interest rates are strongly related to the systematic volatility of the consumption process, the estimation results suggest that the short-term interest rate fails to be a good proxy of the systematic volatility factor. Second, while allowing for stochastic volatility can reduce the pricing errors and allowing for asymmetric volatility or “leverage effect” does help to explain the skewness of the volatility “smile”, we find that allowing for stochastic interest rates has minimal impact on option prices. Third, our empirical findings strongly suggest the existence of a non-zero risk premium for stochastic volatility of stock returns. Based on implied volatility risk, the SV models can largely reduce the option pricing errors, suggesting the importance of incorporating the information in the options market in pricing options. Finally, both the model diagnostics and option pricing errors in our study suggest that the Gaussian SV model is not satisfactory for modelling short-term kurtosis of asset returns, and hence a SV model with fatter-tailed noise or jump components may have better explanatory power.

Chapter 7 evaluates the performance of volatility forecasting based on univariate and multivariate stochastic volatility models. The data consists of the daily returns of four technology stocks: 3Com, Applied Material, Cisco, and Oracle
which are all traded at Nasdaq, over the period from February 16, 1990 to January 5, 1997. Part of the data was treated as \textit{ex-post} in volatility forecasting. It is shown that the choice of the squared asset return or squared return residual with mis-specified trend as proxy of \textit{ex-post} volatility directly leads to the extremely low explanatory power of the common regression analysis. It is argued that since the measure of volatility is always model-dependent, the volatility-forecasting performance should be evaluated in a consistent model framework. The main contribution of this chapter is that we illustrate that the volatility-forecasting performance based on reprojected volatility series can be substantially improved. We also show that the volatility-forecasting performance based on multivariate SV models is better than that of univariate SV models due to the statistical correlation between asset-return volatility.

Appendix A contains a manual of the Ox computer code for conducting EMM written by the author and gives explicit expressions for the score generators that have been used in this thesis.

8.2 Outlook for Further Research

The SV models that were studied in this thesis can be extended into several directions that are motivated by both econometrics and financial theory: (i) SV models with endogenous variables, such as trading volume, in the volatility process. These type of models fall into Case 3 in Table 3.1 and can thus be estimated with EMM using the methods outlined in this thesis. (ii) SV models with a factor structure for the volatility; see e.g. Kim \textit{et al.} (1998), Jacquier \textit{et al.} (1998), Gallant and Long (1997), Mahieu and Schotman (1998) and Shephard and Pitt (1998). The feasibility of EMM for these type of SV models is under study. (iii) Stochastic volatility in mean, parallelling the ARCH-in-mean models; see Bollerslev \textit{et al.} (1994) for references on ARCH in mean models. The feasibility of EMM for these types of models is also under study. (iv) Stochastic volatility models that can be used for modelling interest rates and consequently pricing of fixed-income derivatives. In Andersen and Lund (1997) a specific SV model for interest rates has been estimated by EMM. In this paper an AR-EGARCH score generator was used, where “AR” means that an AR model is used to model the mean $m_t(\beta)$ of $z_t(\beta)$ in (3.18). (v) Stochastic volatility with jump diffusions; see Bates (1996a). This extension was motivated by our results in Chapter 6. EMM-estimation of SV models with jumps is under study. (vi) SV models using very high frequency data and continuous-time SV models. Estimation of SV models at higher frequencies than the daily and in continuous time can clearly be done with EMM, see Section 3.2.2. (vii) Fractionally integrated SV models; see Harvey (1993), Comte and Renault (1998) and Breidt \textit{et al.} (1998). EMM-estimation of these models could also be possible...
and this would probably require a fractionally integrated (E)GARCH as the leading term in the score generator.

Whether these extensions can be estimated with EMM has to be determined. Alternatives are other recent simulation-based econometric estimation techniques such as MCMC methods, see Kim et al. (1998), particle filtering see Pitt and Shephard (1999), or extended Kalman filter approaches see Sandmann and Koopman (1998). A second issue is the pricing of derivatives under these extended SV models and the volatility-forecasting performance of these models. In addition to derivatives pricing under stochastic volatility we could also study the hedging of derivatives under stochastic volatility as in Bakshi, Cao and Chen (1998). Furthermore we could also use SV models for the pricing of other types of contracts such as long-term options (e.g. LEAPS\(^1\)) or interest-rate derivatives. It would also be interesting to see whether the EMM technique could further be improved by studying auxiliary models that are based on non-parametric expansions other than the SNP density.
6.2 Outlook for Further Research

The SV models that were studied in this thesis can be extended into several different areas that are motivated by both econometrics and financial theory. (i) SV models with endogenous variables, next trading volume. In trend. These type of models fall into Case 2 in Table 3.1, and can thus be estimated with EMM using the methods outlined in this thesis. (ii) SV models with a factor structure for the volatility process. These type of models fall into Case 3 in Table 3.1 and can thus be estimated with EMM using the methods outlined in this thesis. (iii) SV models with ARMA-in-mean models, see Bollerslev et al. (1994), for instance on ARCH-in-mean models. The feasibility of EMM for these type of models is also under study. (iv) ARCH-like volatility models that can be used for modelling interest rates and consequently pricing of fixed-income derivatives. In Andersen and Lund (1997) a specific SV model for interest rates has been estimated by EMM. In this paper an AR(2)GARCH x the mean model was used, where "AR" means that an AR model is used to model the mean, and (v) SV models with jumps. Jumps and SV models with jumps and SV models with jumps. Jumps and SV models with jumps. Jumps and SV models with jumps. Jumps and SV models with jumps.