Chapter 7

Conclusion

7.1 Summary of Results and Conclusion

This study deals with the modeling of financial data for volatility forecasting in the context of volatility forecasting. The empirical performance of GARCH(1,1), GARCH-KF and SV models from both estimation and forecasting perspective was investigated through state space and Kalman filtering techniques. Comparison with the widely established GARCH based models were applied to analyze the time-varying relationship in volatility forecasting in Indian stock market scenario. The major research objectives are addressed:

- A detailed study of the basic properties for all available techniques for modeling volatility by analyzing the work done and contributions made by Financial econometricians thus far.

- To improve upon the different models and to investigate efficient way to recover estimates of volatility parameters using numerical techniques.

- To analyze the alternative methodology Stochastic Volatility(SV). Comparison of SV and the well established GARCH will be done on the same data sets, as far as the prediction performance is concerned.

- To study the techniques for computing efficient estimates using Kalman filtering i.e. to estimate the optimal filter to a desired level of accuracy using computational tools such as MATLAB® (from Mathworks®).
This final chapter reviews the main results and aims to highlight the possible future directions to continue research connected to the findings presented in this thesis.

In the theoretical part of this thesis, the methodology to analyze the GARCH model through state space and kalman filter representation were introduced. The econometric toolbox provided by MATLAB were used with a range of functions written specifically to implement numerical techniques for estimation, model evaluation and forecasting. The modeling techniques for improvement of GARCH model like Linear Gaussian state space models and the Kalman filter and stochastic volatility models were established.

With the sound theoretical foundation of how these techniques can be employed to the models, a empirical research was carried out to model the volatility on real data of Sensex index. The steps in conducting empirical test were the following. First, to decide on how a problem should be approached. Second, to perform the selection and specification of a model. Third, to perform the model estimation and forecasts. Finally, the results of out-of sampling forecasts were summarized based on the evaluation measures.

7.1.1 Findings of the Study

- A review of the SENSEX series major empirical properties illustrates the distributions of the return series are found to be highly leptokurtic, the squared return series are significantly autocorrelated, and exhibit a leverage effect and volatilities.

- The empirical properties, especially with regard to the observed volatility clustering, imply that the degree of the linear association between returns is not constant but changing over time. This has been confirmed by a formal testing procedure using ACF, PACF and other statistical tests.

- State Space models were employed to capture the volatility and other stylized properties of a series. In the context of a state space framework, it was established that the volatility process can be estimated efficiently via the Kalman Filtering techniques.

- The comparison of the results of symmetric and asymmetric GARCH models, indicate that the models fit data comparably for the sensex index. However, the specification tests generate some interesting findings. We cannot reject any of the GARCH
models for the in-sample forecast, but the asymmetric models do not perform significantly better than the standard GARCH model. The standard GARCH model delivers the best performance among the selected GARCH model variants.

- The analysis of out-of-sample estimates suggests that Sensex volatility as modeled by one of the proposed Kalman filter approaches are superior to the considered alternatives. It seems that stochastic volatility model estimated through Kalman filter based Quasi Maximum likelihood approach has more appropriate forecast as it has lesser residual errors then the competing models GARCH(1,1) and GARCH(1,1)-KF model.

### 7.1.2 Result of the comparative performance of various models used

Compared to similar studies, the state space modeling techniques employed here was applied to the two competing models i.e. GARCH, and stochastic volatility model that was estimated via Kalman filtering techniques. A GARCH-KF model was proposed to deal with heteroskedasticity in the context of improvement of estimation procedure of standard GARCH model. Compared to standard GARCH model, Kalman filtering approach delivered superior out-of-sample forecasting results. This implies that the Kalman filter based estimation model offers relatively best predictive performance.

In the theoretical part of this thesis, the methodology of Linear State space gaussian model was discussed. In the course of this study, many features, starting from basic state space representations, estimation and forecasting procedures were discussed. Linkages between the different concepts were emphasized: the introduction of linear Gaussian state space model, GARCH model estimation using the Kalman filter and also laid the ground for the state space modeling of stochastic volatility models. The ARMA specification was closely followed and compared with the proposed linearized stochastic volatility model. Unsatisfactory out-of-sample results were obtained by the ARMA models when the estimation was performed on price series as compared to the SV model.

A linearized GARCH-KF model was proposed to deal with heteroskedasticity in the context of effective estimation procedure for GARCH models. The out-of-sample results suggested that returns can be better explained when estimated using KF methods. Com-
pared to standard GARCH model, GARCH-KF approach delivered superior out-of-sample forecasting results. This also implies confirmation to the improvement of the standard GARCH model commonly used in practice.

The empirical investigation in Chapter 6 adds to the literature a comprehensive analysis and comparison between GARCH(1,1), GARCH-KF and SV models. Compared to earlier studies for other regions of the world, an evaluation of the various modeling techniques and ability to produce out-of-sample forecasts revealed that the Kalman filter based model offers relatively best predictive performance. The results revealed that fitting the GARCH models by Kalman filter was an effective strategy for estimation and forecasting. In fact, the Quasi maximum-likelihood version of the SV volatility model did particularly well. It outperformed all the other models, producing one-step-ahead forecasts whose mean absolute errors and root mean squared errors are superior.

7.1.3 Conclusion

The preliminary analysis of data set suggested that volatility in the Indian stock market is time varying in nature, persist to form clusters and has a heteroskedastic process. These findings of the data justified the application of GARCH, Stochastic Volatility and State Space models for this case. It is concluded that volatility of Indian stock market can be best described as a stochastic process. The finding that the state space model, which has been introduced to take explicitly into account the volatility clustering and kalman filter estimates can outperform the traditional GARCH model estimation. It also suggests that the corresponding Kalman Filter based estimator was well applicable in the presence of heteroskedasticity.

Many econometricians, agree to the fact that all models are just approximations to the unknown true data generating process. Though, it cannot be assumed implicitly that only one of the models has to be the correct one. This fact is very useful, as the estimation of parameters of GARCH, SV or other volatility models was not easy, and one would better want to know if the estimated and forecasted parameters are optimal. Within the proposed KF framework it was possible to achieve the best performance of any of the considered model. Considering the models that we have studied by applying the kalman filter based
forecasting techniques to Sensex returns, it is indicated that the SV-model is preferred to the GARCH-model.

The analysis with computational tools explored in this thesis also agrees with the documented statistical superiority of Kalman Filter estimates. The superior performance of Kalman filter based method can be further utilized because of higher degree of flexibility offered by Kalman filter which particularly pays off during the inherent robustness of the model. It indicates that, everything else being equal, improved return predictions can be obtained by modeling the time-varying nature of volatility using the proposed techniques.

7.1.4 Directions for Future Research

- While answering the question which of the selected modeling approaches is most suitable to predict the volatility, many interesting challenges are open for future research. The performance of the Kalman Filter could be further improved by adding additional states and considering other nonlinear models as well.

- If questioned, whether the best model for volatility forecasting can be extended to other fields, it cannot be answered right away, more effort is needed for clarification. As volatility estimation plays such an important role in option trading and portfolio risk management, the application of our model to these two fields should be further studied.

- In this study the comparative performance of stock market volatility in India only has been studied. In future, the study on the same subject can be undertaken for various stocks, options and portfolios.