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The dynamics of stochastic volatility: evidence from underlying and options markets

Christopher S. Jones*

Marshall School of Business, University of Southern California, Los Angeles, CA 90089, USA

Abstract

This paper proposes and estimates a more general parametric stochastic variance model of equity index returns than has been previously considered using data from both underlying and options markets. I conclude that the square root stochastic variance model of Heston (Rev. Financial Stud. 6 (1993) 327) is incapable of generating realistic returns behavior, and that the data are better represented by a stochastic variance model in the CEV class or a model with a time-varying leverage effect. As the level of market variance increases, the volatility of market variance increases rapidly and the leverage effect becomes substantially stronger. The heightened heteroskedasticity in market variance that results causes returns to display unconditional skewness and kurtosis much closer to their sample values, while the model falls short of explaining the implied volatility smile for short-dated options and conditional higher moments in returns.

JEL classification: G12; C11

Keywords: Continuous-time estimation; Stochastic volatility; Option pricing; Bayesian analysis; Stock market crashes

1. Introduction

The dynamic nature of asset price volatility has long been a popular subject in the empirical finance literature, and even greater interest in volatility dynamics has followed the development of stochastic volatility models of option pricing. These models attribute the higher prices of options far from "at-the-money" to return non-normality generated

* Corresponding author.
E-mail address: christopher.jones@marshall.usc.edu (C.S. Jones).

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by time-varying volatility. Because much of the interest in options focuses on the options that are furthest from at-the-money and therefore have positive payoffs only in extremely rare circumstances, precise characterizations of volatility dynamics are particularly important.

While the need to better model extreme events for the purposes of option pricing made the task of understanding volatility more exacting, the existence of options has made the researcher's data set much richer, so that more finely tuned models may be investigated with greater hope of obtaining accurate results.

Traditionally, volatility dynamics in asset prices have been explored using the time series of returns on the assets being studied. Following the work of Engle (1982) and Bollerslev (1986), models in the ARCH class have been studied extensively for this purpose and remain popular today. Perhaps because of the rapid growth in derivatives markets, continuous-time stochastic volatility models have recently become popular as well, and a growing body of research is concerned with fitting these models to asset returns. Two recent examples are the papers by Gallant and Tauchen (1997) and Andersen et al. (2002).

An alternative approach is to infer the risk-neutralized volatility dynamics from the prices of options. While methods of inferring risk-neutral returns probabilities from the cross section of options prices are well-known following the seminal work of Breeden and Litzenberger (1978), more recent studies such as Bates (2000) and Bakshi et al. (1997) fit parametric stochastic volatility models to option prices to learn about the parameters of these models.

But since the risk-neutral and objective measures are not wholly dissimilar, there must be an advantage to using both sets of data (the time series of the underlying's prices and the prices of options on it) to infer both measures simultaneously, a point made forcefully by Chernov and Ghysels (2000a). In addition, since it is the difference between the two measures that defines risk premia, it may further be advantageous to estimate the two measures together so that estimation errors relating to these differences can be treated in a sensible way. In fact, a number of recent papers have pursued this idea. Pan (2002), Poteshman (1998), and Chernov and Ghysels (2000a) all use some combination of a time series of the underlying price and one or more time series of liquid, short-term, near-the-money option prices to infer the dynamics of the underlying volatility process under both the objective and risk-neutral measures. [1]

In its use of option implied volatilities for the purpose of estimating more realistic volatility dynamics, the paper is related to a growing literature on alternative volatility proxies. The use of high-frequency realized volatilities (often calculated at 5-min intervals) is increasingly popular, pursued by Andersen and Bollerslev (1997) and Andersen et al. (2001) among many others. The range, or the high price minus the low price over some interval, has been employed recently by Gallant et al. (1999) and Alizadeh et al. (2001) for similar purposes. It is possible that implied volatility provides a proxy that is less noisy than the range and easier to work with

[1] Studies by Benzoni (2001) and Jiang and van der Sluis (1998) have similar objectives, but both use options data only to estimate the parameters that are not identified by data on the underlying. Additional literature is reviewed in Chernov and Ghysels (2000b).