Journal of Banking & Finance 34 (2010) 871–881

Contents lists available at ScienceDirect

Journal of Banking & Finance

journal homepage: www.elsevier.com/locate/jbf

# The information content of implied volatilities and model-free volatility expectations: Evidence from options written on individual stocks

Stephen J. Taylor [a], Pradeep K. Yadav [a,b,c], Yuanyuan Zhang [a,d,*]

[a] Department of Accounting and Finance, Lancaster University, UK
[b] Price College of Business, University of Oklahoma, USA
[c] Center of Financial Research, University of Cologne, Germany
[d] Department of Finance and Insurance, Lingnan University, Hong Kong

ARTICLE INFO

*Article history:*
Received 4 September 2008
Accepted 23 September 2009
Available online 27 September 2009

*JEL classification:*
C22
C25
G13
G14

*Keywords:*
Volatility
Stock options
Information content
Implied volatility
Model-free volatility expectations
ARCH models

ABSTRACT

We measure the volatility information content of stock options for individual firms using option prices for 149 US firms and the S&P 100 index. We use ARCH and regression models to compare volatility forecasts defined by historical stock returns, at-the-money implied volatilities and model-free volatility expectations for every firm. For 1-day-ahead estimation, a historical ARCH model outperforms both of the volatility estimates extracted from option prices for 36% of the firms, but the option forecasts are nearly always more informative for those firms that have the more actively traded options. When the prediction horizon extends until the expiry date of the options, the option forecasts are more informative than the historical volatility for 85% of the firms. However, at-the-money implied volatilities generally outperform the model-free volatility expectations.



## 1. Introduction

Volatility forecasts extracted from option prices are often compared with forecasts calculated from historical asset prices.[1] For US stock indices in particular, most of the empirical evidence shows that option prices provide more accurate volatility forecasts than historical methods which rely on daily returns; see, for example, Christensen and Prabhala (1998), Fleming (1998) and Ederington and Guan (2002). Furthermore, option-based forecasts often rank highly against forecasts obtained from the high-frequency realized volatility measures of Andersen et al. (2001, 2003); see Blair et al. (2001), Jiang and Tian (2005) and Giot and Laurent (2007) for US stock indices.[2] In contrast, comparisons of volatility forecasts for the stock prices of individual firms are rare, the most notable being the study of 10 US firms by Lamoureux and Lastrapes (1993). Our first contribution is a comparison of historical and option-based predictors of future volatility for a large sample of US firms, namely all 149 firms that have sufficient option price data included in an OptionMetrics database.

The most recent important innovation in research into volatility forecasts exploits combinations of option prices that do not rely on any pricing formula. These model-free forecasts apply the theoretical results of Carr and Madan (1998), Demeterfi et al. (1999) and Britten-Jones and Neuberger (2000), which we outline in Section 2. For the S&P 500 index, Jiang and Tian (2005) show that the model-free volatility expectation is more highly correlated with future realized volatility than either the at-the-money implied volatility or the latest measurement of realized volatility calculated from 5-min returns; furthermore, in multivariate regressions only the model-free variable has a significant coefficient. Lynch and Panigirtzoglou (2004) also compare the model-free volatility expectation with historical volatility measured by intraday returns. Their results, for the S&P 500 index, the FTSE 100 index, Eurodollar futures and short sterling futures, show that the model-free volatility

* Corresponding author. Address: Department of Finance and Insurance, Lingnan University, Hong Kong. Tel.: +852 2616 8158; fax: +852 2462 1073.
*E-mail addresses:* s.taylor@lancaster.ac.uk (S.J. Taylor), pyadav@ou.edu (P.K. Yadav), zhangy@ln.edu.hk (Y. Zhang).

[1] Poon and Granger (2003) and Taylor (2005) provide surveys for equity, foreign exchange and commodity markets. Yu et al. (2009) is a recent relevant study of non-US stock indices.

[2] High-frequency methods rank more highly, however, in recent papers by Bali and Weinbaum (2007), Becker et al. (2007) and Martin et al. (2009).

0378-4266/$ - see front matter © 2009 Elsevier B.V. All rights reserved.
doi:10.1016/j.jbankfin.2009.09.015

expectation is more informative than high-frequency returns, but it is a biased estimator of future realized volatility. Our second contribution is a comparison of model-free and at-the-money predictors for individual firms. We provide an empirical strategy which is able to extract model-free information from the few traded strikes that are usually available for firms.

Model-free volatility expectations have two potential advantages compared with Black–Scholes implied volatilities. Firstly, they do not depend on any option pricing formula so they do not require assumptions about the volatility dynamics. Secondly, they avoid relying on a single strike price which is problematic because implieds are far from constant across strikes. The early version of the VIX volatility index is investigated by Blair et al. (2001) and uses a few near-the-money option prices. The CBOE replaced this index in 2003 by the model-free volatility expectation. Both versions of the VIX index and relevant theory are discussed by Carr and Wu (2006). In related research, Carr and Wu (2009) synthesize variance swap rates, which are equivalent to model-free variance expectations, and show these swap rates are significant when explaining the time-series movements of realized variance.[3]

We compare the information content of three types of volatility forecasts for 149 US firms: historical ARCH forecasts obtained from daily stock returns, the at-the-money (hereafter ATM) implied volatility and the model-free volatility expectation. We initially focus on a 1-day-ahead forecast horizon and subsequently evaluate forecasts whose horizons match the relevant option expiry dates, which we choose to be 1 month into the future on average. Our sample also includes the S&P 100 index, to provide comparisons with the results for our firms and also with previous literature about indices.

Our empirical results show that both the model-free volatility expectation and the ATM implied volatility do contain relevant information about the future volatility of stock prices. In contrast to most previous studies about stock index options, our research into individual stocks shows that for 1-day-ahead prediction neither the ATM implied volatility nor the model-free volatility expectation is consistently superior to a simple ARCH model for all firms. It is often best to use an asymmetric ARCH model to estimate the next day's volatility, particularly for firms with few traded strikes. However, when the estimation horizon extends until the end of the option lives, both the volatility estimates extracted from option prices outperform the historical volatility for a substantial majority of our sample firms.

The ATM implied volatility outperforms the model-free volatility expectation for 87 out of 149 firms when predicting volatility 1-day-ahead, and for 89 firms when the forecast horizon equals the remaining time until the options expire. The relatively unsuccessful performance of the model-free volatility expectation is not explained by either selected properties of the available option data, such as the number of option observations or the range of option moneyness, or by the trading volume of ATM options compared with all other options.

Section 2 introduces three types of volatility forecasts and explains how the model-free volatility expectation is calculated. Section 3 describes the data. Section 4 explains the ARCH and regression methodologies that we use to compare the information content of the historical and option-based volatility estimates. Section 5 presents the empirical results for 1-day-ahead forecasts and option-life forecasts. Section 6 provides cross-sectional comparisons, which identify firm-specific variables which are associated with the best volatility prediction method. Section 7 contains our conclusions.

[3] For some recent empirical studies of the VIX index, see Becker et al. (2007, 2009), Konstantinidi et al. (2008) and Martin et al. (2009).

## 2. The volatility forecasting instruments

ARCH models provide a vast variety of historical volatility forecasts, obtained from information sets $I_t$ that contain the history of asset prices up to and including time $t$; Lamoureux and Lastrapes (1993), Blair et al. (2001) and Ederington and Guan (2005) provide examples. The conditional variance of the next asset return, $r_{t+1}$, denoted by $h_{t+1} = \mathrm{var}(r_{t+1}|I_t)$, is a forecast of the next squared excess return. An advantage of the ARCH framework is that maximum likelihood methods can be used to select a specification for $h_{t+1}$ and to estimate the model parameters. However, historical forecasts rely on past information and are not forward-looking.

Option implied volatilities are forward-looking and essentially contain all the information, including the historical information, required to infer the market's risk-neutral expectation of future volatility. For the risk-neutral measure $Q$, suppose the price of the underlying asset $S_t$ follows a diffusion process, $dS = (r - q)Sdt + \sigma SdW$, where $r$ is the risk-free rate, $q$ is the dividend yield, $W_t$ is a Wiener process and $\sigma_t$ is the stochastic volatility. The integrated squared volatility of the asset from time 0 until the forecast horizon $T$ is defined as $V_{0,T} = \int_0^T \sigma_t^2\,dt$; it equals the quadratic variation of the logarithm of the price process because we are here assuming there are no price jumps.[4] The theoretical analysis of Carr and Wu (2006) and Carr and Lee (2008) shows that the Black–Scholes ATM implied volatility for expiry time $T$ represents an accurate approximation of the risk-neutral expectation of the realized volatility over the same time period, namely $E^Q\left[\sqrt{V_{0,T}}\right]$. Consequently, although the ATM implied volatility is model-dependent it has an economic interpretation as an approximation to the volatility swap rate.

The concept of the model-free variance expectation is developed in Carr and Madan (1998), Demeterfi et al. (1999), Britten-Jones and Neuberger (2000) and Carr and Wu (2009), motivated by the development of variance swap contracts. At time 0 a complete set of European option prices is assumed to exist for an expiry time $T$; the call and put prices are, respectively, denoted by $c(K,T)$ and $p(K,T)$ for a general strike price $K$. Britten-Jones and Neuberger (2000) show that the risk-neutral expectation of the integrated squared volatility is given by the following function of the continuum of European out-of-the-money (hereafter OTM) option prices:

$$E^Q[V_{0,T}] = 2e^{rT}\left[\int_0^{F_{0,T}} \frac{p(K,T)}{K^2}\,dK + \int_{F_{0,T}}^{\infty} \frac{c(K,T)}{K^2}\,dK\right], \tag{1}$$

where $F_{0,T}$ is the forward price at time 0 for a transaction at the expiry time $T$. We refer to the right-hand side (RHS) of (1) as the *model-free variance expectation* and its square root as the *model-free volatility expectation*. Dividing, as appropriate, by either $T$ or $\sqrt{T}$ defines the annualized versions of these quantities. As the volatility expectation does not rely on a specific option pricing formula, the expectation is "model-free", in contrast to the Black–Scholes implied volatility.

The key assumption required to derive (1) is that the stochastic process for the underlying asset price is continuous. When there are relatively small jumps in the stock price process, Jiang and Tian (2005) and Carr and Wu (2006, 2009), show that the RHS of (1) is an excellent approximation to the risk-neutral, expected quadratic variation of the logarithm of the stock price. However, if there is an appreciable risk of an extreme jump, in particular of default, then the approximation error can be very large.

As the model-free expectation defined by (1) is a function of option prices for all strikes, a potential problem arises from the limited number of option prices observed in practice. This is an

[4] The quadratic variation of log($s$) during a time interval is defined as the integrated squared volatility plus the sum of the squared jumps in log($s$) during the interval.