Queensland University of Technology

DISCUSSION PAPERS IN ECONOMICS, FINANCE AND INTERNATIONAL COMPETITIVENESS

Modelling the Intraday Return Volatility Process In The Australian Equity Market: An Examination Of The Role Of Information Arrival In S&P/Asx 50 Stocks

Andrew C. Worthington
and
Helen Higgs

Discussion Paper No. 150, July 2003

Series edited by
Associate Professor Andrew Worthington

School of Economics and Finance

ISSN 1324-5910

All correspondence to:

Associate Professor Andrew C. Worthington
Editor, *Discussion Papers in Economic, Finance and International*
School of Economics and Finance
Queensland University of Technology
GPO Box 2434, BRISBANE QLD 4001, Australia

Telephone: 61 (0)7 3864 2658
Facsimilie: 61 (0) 7 3864 1500
Email: a.worthington@qut.edu.au

MODELLING THE INTRADAY RETURN VOLATILITY PROCESS IN THE AUSTRALIAN EQUITY MARKET: AN EXAMINATION OF THE ROLE OF INFORMATION ARRIVAL IN S&P/ASX 50 STOCKS

Andrew C. Worthington & Helen Higgs

School of Economics and Finance, Queensland University of Technology, Brisbane, QLD 4001, Australia

Abstract

This paper examines the intraday return volatility process in Australian company stocks. The data set employed consists of five-minute returns, trading volumes and bid-ask spreads over the period 31 December 2002 to 4 March 2003 for the fifty national and multinational stocks comprising the S&P/ASX 50 index. GARCH is used to model the time-varying variance in the intraday return series and the inclusion of news arrival as proxied by the contemporaneous and lagged volume of trade and bid-ask spread is used as an exogenous explanatory variable. The results indicate strong persistence in volatility for the fifty stocks even with the contemporaneous and lagged volume of trade and bid-ask spread included as explanatory variables in the models. Overall, while there is much variation among the stocks included in terms of the role of the irregular arrival of new information in generating GARCH effects and the degree of persistence, all of the volatility processes are mean reverting.

JEL classification: C22; C512 ; G12 ; G14

Keywords: return volatility; trading volume; bid-ask spread; GARCH

1. Introduction

It goes without saying that knowledge of stock return volatility is important. In any number of asset pricing and portfolio management problems this knowledge, as encapsulated in volatility models, is used to make predictions that help market actors make better financial decisions. And already a number of stylised facts are known about stock return volatility and the best models to capture and reflect these stylised facts. In the first instance, these include volatility clustering, persistence and mean reversion whereby volatility shocks today will influence the expectation of volatility in the future, though with some more normal level to where it will eventually return. In the second instance, the autoregressive conditional heteroskedasticity (ARCH) model and its various extensions has been shown to provide a good fit for many financial return series where an autoregressive structure is imposed on the conditional variance. These allow the volatility shocks to persist over time and to revert to that more normal level. It also captures both the propensity of returns to cluster in time and helps explain the well-documented non-normality and non-stability of stock return distributions.

The empirical literature underlying this knowledge of stock return volatility is voluminous. Unfortunately, much of this knowledge has been garnered from just a few contexts. First and foremost, most of what we know about financial return volatility in general has been based on studies employing interday returns. Given that financial markets display high speeds of adjustment, studies based on daily (or longer) observations may fail to capture critical information contained in intraday price movements. Moreover, of that small number of studies that are concerned with intraday data, almost all addresses foreign exchange or futures market volatility [see, for instance, Baillie and Bollerslev (1990), Locke and Sayers (1993), Andersen and Bollerslev (1997) and Tse (1999)] and much less in stock markets. Second, within the small intraday stock return volatility literature, most studies have concentrated on indexes or index futures contracts with less attention directed to the intraday return volatility of individual securities [see, for instance, Baillie and DeGennaro (1990), Kim and Kon (1994) and Kyriacou and Sarno (1999)]. Because it is likely that volatility effects vary across individual securities in much the same manner as they do across markets, the analysis of stock return volatility at the company level would throw light on the characteristics of volatility within a single market.

Third, the bulk of volatility modelling has been concerned with univariate characteristics such that the volatility of a return series is related only to information in its own history. As Bollerslev et al. (1992: 32) notes: "the widespread existence of ARCH effects and the persistence of stock return volatility have led researchers to search for it origin(s). [Since] the GARCH(p,q) model can be viewed as a reduced form of a more complicated dynamic structure for the time-varying conditional second-order moments…interpretations and explanatory variables for the observed ARCH effects have been proposed both on the micro and macro level…". However, while the macro level has received a good deal of attention, including the influence of other financial assets and exogenous deterministic events such as macroeconomic and company announcements on the volatility process, much less has been directed to micro level influences [for exceptions, see Lamoureux and Lastrapes (1990), Kim and Kon (1994) and Rahman et al. (2002)]. Finally, only a few ARCH-type studies of stock return volatility have been undertaken in Australia, and as far as the authors are aware, none using intraday data at the individual security level. Following Bollerslev's et al. (1992: 31) suggestion it would "…be interesting to use different data sets to further assess the degree of persistence on stock return volatility [since] with very few exceptions, most current studies use data from the US stock market".

Accordingly, the purpose of this paper is to investigate the intraday return volatility process in Australian stocks. The remainder of the paper is divided into four sections. The second section explains the data employed in the analysis and presents some brief summary statistics. The third section discusses the methodology employed. The results are dealt with in the fourth section. The paper ends with some brief concluding remarks.

2. Data and summary statistics

The data employed in the study consists of last price, trading volumes and bid-ask spreads for the five-minute intervals from 31 December 2002 to 4 March 2003 for the national and multinational stocks included in the S&P/ASX 50 index. The S&P/ASX 50 index comprises the fifty largest stocks by market capitalization in Australia and currently accounts for some seventy-five percent of the market capitalization of domestic equities listed on the Australian Stock Exchange (ASX). The criteria for inclusion in the index place an emphasis on liquidity and investability and together the high frequency of information arrivals and volume of trading in these securities are likely to reduce measurement error problems. All data is obtained electronically from Bloomberg. Each of the trading days in the analysis is portioned into five-minute intervals beginning with the opening of the market at 9:00 a.m. Australian Eastern Standard Time (AEST). The natural log of the relative price is computed for the five-minute intervals to produce a time series of continuously compounded five-minute returns, such that $r_t = \log(p_t/p_{t-1})\text{x}100$, where p_t and p_{t-1} represent the stock price at time t and t-1, respectively. By way of comparison, Chan et al. (1995) and Rahman et al. (2002) also specified five-minute returns when modelling intraday return volatility in US listed stocks.

Table 1 presents the summary of descriptive statistics of the five-minute returns for the fifty stocks. Sample means, medians, maximums, minimums, standard deviations, skewness, kurtosis and the Jacque-Bera statistic and first-order autocorrelation coefficient and their *p*-values are reported. It should first be noted that over the relatively short sample period the Australian equity market generally declined, with forty-four of the stocks (eight-eight percent) producing negative mean returns. The lowest mean returns were for ALL and AMP with -0.0300 and -0.0161 percent, respectively. However, six stocks had positive average returns over this same period ranging from 0.0005 (WOW) to 0.0029 (CCL). The largest five-minute returns were for CCL (0.0209) and MBL (0.0017). The standard deviations of returns range from 0.144 (MGR) to 1.053 (ALL). On this basis, of the fifty stocks AGL, CBA, MGR, NAB, SGB and SGP are the least volatile, with ALL, SRP and MIM being the most volatile.

<TABLE 1 HERE>

By and large, the distributional properties of all fifty return series appear non-normal. Twenty-seven of the return series are negatively skewed, ranging from -0.1297 (STO) to -35.1062 (ALL), indicating the greater probability of large deceases in returns than rises. The remaining return series are positively skewed, also suggestive of volatility clustering in intraday stock returns. The asymptotic sampling distribution of skewness is normal with mean 0 and standard deviation of $\sqrt{6/T}$, where T is the sample size. Since the sample size for all the return series is 3,215 then the standard error under the null hypothesis of normality is 0.0432: all estimates of skewness are significant at the .10 level or higher. The kurtosis, or degree of excess, in all stock returns is also large, ranging from 5.6283 for MIM to1647.6950 for ALL, thereby indicating leptokurtic distributions. Given the sampling distribution of kurtosis is normal with mean 0 and standard deviation of $\sqrt{24/T} = 0.0864$, then all estimates are once again statistically significant at any conventional level.

The calculated Jarque-Bera statistics and corresponding *p*-values in Table 1 are used to test the null hypotheses that the five-minute distribution of stock returns is normally distributed. All *p*-values are smaller than the .01 level of significance suggesting the null hypothesis can be rejected. These stock returns are then not well approximated by the normal distribution. To test for the presence of autocorrelation in the five-minute interval series, the first order autocorrelation coefficients are also calculated and presented in Table 1 along with their corresponding *p*-values. The asymptotic distribution of $\hat{\rho}_1$ is normally distributed with a mean of 0 and a standard error of$1/\sqrt{3126} = 0.0176$. On this basis, first-order autocorrelation is evident in the intraday return series for the Australian stocks selected at the .05 level or higher, with the exception of CSL, QBE, RMD and WPL.

3. Model specification

The distributional properties of Australian company intraday stock returns indicates that generalized autoregressive conditional heteroskedastistic (GARCH) models can be used to examine the dynamics of the return volatility process. Autoregressive conditional heteroscedasticity (ARCH) models [as introduced by Engle (1982)] and generalised ARCH (GARCH) models [as presented by Bollerslev (1986)] that take into account the time-varying variances of financial time series data have already been widely employed. Suitable surveys of ARCH modeling in general and/or its widespread use in finance applications may be found in Bera and Higgins (1993) and Bollerslev et al. (1992; 1994). Pagan (1996) also contains discussion of developments in this ever-expanding literature.

The first methodological requirement is to remove the predictable component of returns so as to produce a return innovation, e_t, with a conditional mean of zero before a GARCH equation is specified for the variance. One common method to produce an uncorrelated process in the five-minute returns is to assume that the level of returns follow an AR(1) process. The following conditional expected returns equation accommodates each stock's own returns and its returns lagged one period:

$$r_t = \alpha_0 + \alpha_1 r_{t-1} + e_t \tag{1}$$

where r_t is the return for each stock in the current period and r_{t-1} an n x 1 vector of the returns lagged one period, α_0 represents the long-term drift coefficient and α_1 is the degree of mean spillover effect across time, or put differently, whether the lagged return can be used to predict the current return and e_t, the random error or innovation at time t, is approximately distributed $e_t \sim (0, h_t)$.

The second methodological requirement is to model the variance of the return innovation itself. A GARCH process of orders p and q, denoted as GARCH(p,q), for the conditional variance (volatility) of e_t at time t can then be represented as:

$$h_t = \beta_0 + \beta_i \sum_{i=1}^{p} e_{t-i}^2 + \gamma_i \sum_{i=1}^{q} h_{t-i} \tag{2}$$

where h_t is the conditional variance volatility of e_t at time t, β_0 is a constant, β_i and γ_i are coefficients that are associated with the past values of innovation and volatility spillovers e_{t-i}^2 to the current volatility, and thereby represent news about the degree of innovation from previous periods (ARCH terms) and previous period's forecast volatility spillover effects (GARCH terms), and all other variables are as previously defined.

One important and well-founded characteristic of stock returns is the tendency for volatility clustering to be found, such that large changes in returns are often followed by other changes, and small changes in returns are often followed by yet more small changes. The implication of such volatility clustering is that volatility shocks today will influence the expectation of volatility many periods in the future. The aggregation of β_i and γ_i coefficients measures this degree of continuity or persistence in volatility. If the degree of persistence is close to one, this implies that the current volatility of intraday returns is affected by past volatility that tends to persist over time. Further, volatility clustering also implies that volatility will come and go. Accordingly, a period of high volatility in stock returns will eventually give way to a more normal (lower) level of volatility and a lower period of volatility will be replaced with a more normal (higher) level of volatility. This process of reversion to a normal or mean level of volatility implies that even if volatility persistence exists, so long as the sum of the β_i and γ_i coefficients is significantly less than one the volatility process, while having a long memory, will still be mean reverting or stationary.

A concern with the volatility generation process as defined is that current volatility is only related to the past values of innovation and volatility spillovers from previous periods. It is likely that variables other than these may contain information relevant for the volatility of stock returns and a possibility is that the incidence of time varying conditional heteroskedasticity could be due instead to an increase in the variability in returns following the arrival of new and irregular information. This is important because the GARCH effects often observed in stocks returns is likely the outcome of the stochastic properties of these factors. Lamoureux and Lastrapes (1990) and Rahman et al. (2002), for example, argue that an appealing explanation for the presence of GARCH effects is that the rate of information arrival is the stochastic mixing variable that generates stock returns. For daily, weekly and monthly data, variables such as macroeconomic and company announcements may be major influences. However, for high-frequency intraday data the variables likely to be of most influence relate to trade information. Fortunately, features such as day-of-the-week and holiday effects that characterize interday patterns are also clearly less significant and critical for high frequency analysis and this helps simplify the analysis of intraday data (Andersen and Bollerslev 1997).

One means of proxying the arrival of this trade information is to introduce the volume of trade into the conditional variance equation. Lamoureux and Lastrapes (1990), for example, showed that with the introduction of the contemporaneous and lagged volume of trade (indicating a greater amount of information) the GARCH effect in US stock returns became insignificant for the majority of securities, with the estimated coefficients on trade volume being significant, though small. Alternatively, Najand and Yung (1991), Foster (1995) Rahman et al. (2002) found that the GARCH effects remained strongly significant with the inclusion of the current volume of trade in the conditional variance equation. Another way of including this information arrival follows past evidence of a high correlation between intraday return volatility and intraday variation of bid-ask spreads (Copeland and Galai, 1983; Grossman and Miller, 1988; McInish and wood, 1992; Walsh and Quek, 1999 and Wang and Yau 2000). For instance, Rahman et al. (2002) introduced the bid-ask spread as a measure of information that flows into the market with the argument that bid-ask spreads narrow when information flow increases and widen when information flow decreases.

The final methodological requirement is then to incorporate the arrival of exogenous information in the volatility return generating process in Equation (2). Since the incidence of the time varying conditional heteroskedasticity could be due to an increase in the contemporaneous and/or lagged volume of trading and/or bid-ask spread following the simultaneous arrival of new information, the conditional variance equation is reformulated as:

$$h_t = \beta_0 + \beta_1 e_{t-1}^2 + \gamma_1 h_{t-1} + \delta_1 v_t + \delta_2 v_{t-1} + \delta_3 s_t + \delta_4 s_{t-1} \tag{3}$$

where v_t and v_{t-1} and s_t and s_{t-1} represent the volume of trade (v) and bid-ask-spreads (s) in period t and t-1 and all other variables are as previously defined.

4. Empirical results

The estimated coefficients and standard errors for the conditional mean return equations are presented in Table 2. Different GARCH(p,q) models were initially fitted to the data (results not shown) and compared on the basis of the Akaike and Schwarz Information Criteria (AIC and SIC) from which a GARCH(1,1) model was deemed most appropriate for modelling the five-minute return process for all fifty stocks. All the same, Rahman et al. (2002: 165) confined "…estimation to the GARCH(1,1) specification since it has been shown to be a parsimonious representation of conditional variance that adequately fit many high-frequency time series". Of the fifty stocks, thirty-nine (seventy-eight percent) exhibit a significant own mean spillover from their own lagged return. In all significant cases, the mean spillovers are negative with the sole exception of WES. For example, and during this particular sample period, a 1.00 cent increase in MIM's own return will Granger cause a decrease of 0.36 cents in its return over the next five-minutes. Likewise, a 1.00 cent increase in returns for WES will Granger cause a 0.05 cent increase over the next five-minutes. The finding that lagged intraday returns in Australian stocks Granger-cause current returns is conventionally suggestive of a violation of weak-form market efficiency.

<TABLE 2 HERE>

Also included in Table 2 are details for AIC and SIC comparing the performance of GARCH(1,1) models including information arrival as exogenous variables in the variance equation (columns 10 and 11 and 21 and 22) with those obtained from a simple GARCH(1,1) process (columns 8 and 9 and 19 and 20). These model selection criteria are used to test the proposition that the occurrence of time-dependent conditional heteroskedasticity could be due, at least in part, to an increased volume of trading and/or variability of prices following the arrival of new information in the market. In the current analysis, the arrival of new information is proxied by including trading volume and bid-ask spread in the variance equation.

The values for AIC and SIC in Table 2 indicate that in thirty of the stocks the intraday return volatility process could be appropriately modelled employing a simple GARCH process, whereas in the remaining twenty stocks the rate of information arrival has some significant role in generating intraday returns. For example, for WOW the lower values for AIC and SIC (-0.7882 and -0.7788) compared to AIC(δ) and SIC(δ) (-0.2130 and -0.1960) indicate that a GARCH model with no allowance for exogenous variables is a more comprehensive and parsimonious representation of the return generation process, whereas for NCP the lower values for AIC(δ) and SIC(δ) (-0.7027 and -0.6857) as compared to AIC and SIC (0.0819 and 0.0913) indicate the reverse. By way of comparison, Lamoureux and Lastrapes (1990) found that that GARCH effects found in their US actively traded securities were due to time dependencies in the process generating information flows, whereas Rahman et al. (2002) concluded that even after proxying information arrival, GARCH effects prevailed in NASDAQ stock returns. The results in Table 2 indicate that, at least for actively traded Australian stocks, there is much variation in the role of information arrival as a means of generating the commonly found GARCH effects with it having a critical role for some stocks but not for others.

Table 3 presents the estimated coefficients for the conditional variance equations in the GARCH models. The coefficients of the conditional variance equations are all significant at the 0.01 level or lower for the innovations and volatility spillovers for the fifty stock markets, indicating the presence of strong ARCH and GARCH effects. The own-innovation spillovers in all stocks are significant indicating the presence of strong ARCH effects. These own-innovation spillover effects range from 0.0360 in MIM to 0.2069 in LLC. In the GARCH set of parameters, all fifty of the estimated coefficients are also significant. The lagged volatility spillover effects range from 0.2090 for ALL to 0.7507 for MIM. This implies that the past volatility shocks in MIM have the greatest effect on its future volatility shocks than for any other stocks included in the analysis during the sample period.

<TABLE 3 HERE>

The sum of the ARCH and GARCH coefficients measures the overall persistence in each market's own and lagged conditional volatility. All fifty stocks display strong own persistence volatility: ranging from 0.3236 for ALL to 0.8397 for LLC. Thus, LLC has the highest lead-persistence volatility spillover effect as compared to the other stocks included in the analysis. The average persistence across the stocks is 0.7307 and this implies a volatility half-life (*HL*), defined as the time taken for the volatility to move halfway back towards it unconditional mean following a deviation from it, of 2.2092 periods or about 11 minutes, where $HL = -\log(2)/\log(\beta_1 + \gamma_0)$. This impact decays geometrically and is essentially zero after 243 minutes. This implies that for many of the stocks included in the analysis volatility shocks will tend to persist over what seems only a relatively short period of time.

By way of comparison, the volatility half-life for the stock with the longest lead-persistence is nearly 20 minutes and that for the shortest is just 3 minutes, while for a comparable international study Rahman et al. (2000) provided tables suggesting a mean volatility half-life of 13 minutes in a sample of NASDAQ stocks (as calculated by the authors). Other stocks that have a relatively higher level of persistence in volatility over time (and their half-lives) include MIM (0.7868 and 14 minutes), AMC (0.7979 and 15 minutes) and MIG (0.7645 and 13 minutes) while those with a lower level of persistence include NPD (0.6304 and 7 minutes), FXJ (0.6800 and 9 minutes) and CLS (0.6672 and 8 minutes). Nonetheless, although the returns volatility in these stocks appears to have a quite long memory, at least in terms of high frequency data, they are still mean reverting. One-sided *t*-tests that the sum of ARCH and GARCH effects is greater than or equal to one are rejected for all stocks at the .05 level or higher, suggesting although it may take a long time, the volatility process does return to its mean.

Table 3 also includes the estimated coefficients, standard errors and p-values for the variables used to proxy the irregular arrival of new information: namely, contemporaneous and lagged volume of trade and contemporaneous and lagged bid-ask spread. To start with, there is a significant, and almost always positive, relationship between the return volatility and the contemporaneous volume of trade for forty-one of the stocks (some eight-two percent). As expected, this would indicate the increase of new information, as proxied by trade volume, is associated with an increase in return volatility. This at once lies counter to early work by Lamoureux and Lastrapes (1990) who found that the introduction of contemporaneous volume into the conditional variance equations made the GARCH effects disappear for the majority of US securities or Lee et al. (2001) who found that daily trading volume used as proxy for information arrival had no significant explanatory power for the conditional volatility of Chinese daily returns. They are, however, broadly comparable to work by Najand and Yung (1991), Foster (1995) and Rahman et al. (2002).

At the same time, there is a significant negative relationship between return volatility and lagged volume for forty-six of the stocks (some ninety-two percent). This would suggest that following the role of new information in the current period to increase return volatility; information in the lagged period has the role of reducing return volatility. This is perhaps an indication of the ability of the equity market to process high-frequency information whereby adjustments are made to over and under-reaction in the current period on the basis of historical information. Nevertheless, the magnitude of all contemporaneous and lagged volume coefficients, whether positive or negative, is relatively small, and their impact on the GARCH effect is minimal.

With the inclusion of contemporaneous bid-ask spread as yet another measure of information flow, the estimated coefficients for twenty-eight of the stocks (approximately fifty-six percent) are significant. All of the significant coefficients indicate a negative relationship between return volatility and contemporaneous bid-ask spread with the exception of ALL and CBA. For the most part, this would suggest that as bid-ask spreads widen (less new information) return volatility will decrease, while a narrowing of bid-ask spreads (more new information) is associated with an increase in return volatility. Seventeen stocks (thirty-four percent) also show a significant relationship between return volatility and lagged bid-ask spread of which eleven cases are positive. Interestingly, while the coefficients for the contemporaneous and lagged bid-ask spreads remain numerically small, and their impact on the GARCH effects is therefore minimal, they are nevertheless larger in magnitude than the coefficients for either the contemporaneous or lagged volume of trade. These results would lead us to suspect that bid-ask spread may be a more appropriate proxy for information arrival, at least for a select number of stocks. However, information arrival as proxied by the volume of trade is spread across almost all of the stocks, indicating the information proxied by the volume of trade is more general than specific than that provided by bid-ask spread. Moreover, the fact that most of the estimated coefficients are significant indicates that the simultaneity problem between volume and bid-ask spread though present, is not too serious.

5. Concluding remarks

This study presents an analysis of the distributional and time-series properties of intraday returns in the Australian equity markets. The data employed for this study consists of five-minute returns for the large capitalization, high liquidity stocks comprising the S&P/ASX 50 stock index over the period 31 December 2002 to 4 March 2003. The results indicate that intraday return volatility in the Australian market is best described by a GARCH(1,1) specification and that the inclusion of the contemporaneous and lagged volume of trade and bid-ask spread in the conditional variance equations account, at least in part, for some of the GARCH effects observed in stock returns. However, the GARCH effects remain strongly significant for all securities even after the introduction of trade volume and bid-ask spreads as proxies for the irregular arrival of new information, suggesting that the GARCH effects commonly found ins security returns are not solely due to time dependence in the process generating information flows.

The most important result of this study is that there is much variation in the time-series properties among the stocks included in the sample, despite the fact that they are drawn from a relatively homogenous subset of the Australian equity market. While all of the stocks exhibit the volatility clustering and predictability expected in intraday equity returns, the persistence of this volatility varies markedly with half-lives anywhere between three and twenty minutes. Likewise, the role of trading volume and bid-ask spreads as proxies for information arrival in producing these volatility effects also varies, with the effect of contemporaneous and lagged volume being general but relatively small, while the influence of contemporaneous and lagged bid-ask is relatively larger but more specific. Nonetheless, though the degree of volatility clustering and its persistence varies across the sample, in all of the stocks it is nonetheless mean-reverting, indicating that after departure to some higher or lower level of volatility there will be an eventual return to some more normal level.

Of course, there are several ways in which this work could be extended, especially considering the dearth of literature concerning intraday returns and/or volatility in the Australian equity markets at the micro level. One possibility is to examine the behaviour of return volatility during the day following some US evidence that volatility is high at the open and close of trading and low in the middle of the day (Bollerslev et al. 1992). Another is to use intraday data in conjunction with daily and weekly data to examine the role sampling frequency has on the observed significance of GARCH effects in stock level data. While it is generally thought that GARCH effects are less common as sampling frequency falls, there is nothing in the equity literature, in Australia or elsewhere, that parallels Andersen’s and Bollerslev’s (1997) wide-ranging analysis of the influence of sampling frequency in foreign exchange markets.

Finally, there is the prospect of examining the asymmetric response of Australian equity market volatility to the flow of information into the market. If, and as hypothesised by Antoniou et al. (1998) and Rahman et al. (2002) amongst others, positive news causes a different volatility response than negative news, a more comprehensive understanding of Australian intraday stock return volatility would result from the application of the Threshold

ARCH (TARCH) model as first proposed by Glosten et al. (1993) and/or Nelson's (1991) Exponential GARCH (EGARCH) model.

References

Andersen, T.G. (1996) Return volatility and trading volume: An information flow interpretation of stochastic volatility, Journal of Finance, 51(1), 169-204.

Andersen, T. and Bollerslev, T. (1997) Intra-day periodicity and volatility persistence in financial markets, *Journal of Empirical Finance*, 4(1), 115-158.

Antoniou, A. Holmes, P. and Priestley, R. (1998) The effects of stock index futures trading on stock index volatility: An analysis of the asymmetric response of volatility to news, *Journal of Futures Markets*, 18(1), 151-166.

Baillie, R. and Bollerslev, T. (1990) Intraday and inter-market volatility in foreign exchange rates, *Review of Economic Studies*, 58(3), 565-585.

Baillie, R. and DeGennaro, R. (1990) Stock returns and volatility, *Journal of Financial and Quantitative Analysis*, 25(?), 203-214.

Bera, A.K. and Higgins, M.L. (1993) ARCH models: properties, estimation and testing, *Journal of Economic Surveys*, 7(4), 305-366.

Bollerslev, T. (1990) Modelling the coherence in short-run nominal exchange rates: a multivariate generalized ARCH model, *Review of Economics and Statistics*, 73(3), 498-505.

Bollerslev, T. Chou, R.Y. and Kroner, K.F. (1992) ARCH modeling in finance: a review of the theory and empirical evidence, *Journal of Econometrics*, 52(1), 5-59.

Chan, K. Christie, W. and Schultz, P. (1995) Market structure and intraday pattern of bid-ask spreads for NASDAQ securities, *Journal of Business*, 68(1), 35-60.

Copeland, T. and Galai, D. (1983) Information effects on bid-ask spread, *Journal of Finance*, 38(5), 1457-1469.

Engle, R.F. and Ng, V.K. (1993) Measuring and testing the impact of news on volatility, Journal of Finance, 48(5), 1749-1778.

Foster, A. (1995) Volume volatility relationships for crude oil futures markets, *Journal of Futures Markets*, 15(8), 929-951.

Grossman, S. and Miller, M. (1988) Liquidity and market structure, *Journal of Finance*, 43(3), 617-633.

Kim, D. and Kon, S. (1994) Alternative models for the conditional heteroskedasticity of stock returns, *Journal of Business*, 67(4), 563-598.

Lamoureux, C. and Lastrapes, W. (1990) Heteroskedasticity in stock return data: Volume verses GARCH effects, *Journal of Finance*, 45(1), 221-229.

Lee, C.F. Chen,G.M. and Rui, O.M. (2001) Stock returns and volatility on China's stock markets, *Journal of Financial Research*, 24(4), 523-543.

Locke, P. and Sayers, C. (1993) Intraday futures price volatility: Information effects and variance persistence, *Journal of Applied Econometrics*, 8(1), 15-30.

McInish, T. and Wood, R. (1992) An analysis of intraday patterns in bid-ask spreads for NYSE stocks, *Journal of Finance*, 47(2), 753-764.

Najand, M. and Yung, K. (1991) A GARCH examination of the relationship between volume and price volatility in futures markets, *Journal of Futures Markets*, 11(5), 613-621.

Pagan, A. (1996) The econometrics of financial markets, *Journal of Finance*, 3, 15-102.

Rahman, S. Lee, C.F. and Ang, K.P. (2002) Intraday return volatility process: Evidence from NASDAQ stocks, *Review of Quantitative Finance and Accounting*, 19(1), 155-180.

Smith, B.F. White, R. Robinson, M. and Nason, R. (1997) Intraday volatility and trading volume after takeover announcements, *Journal of Banking and Finance*, 21(2), 337-368.

Tse, Y. (1999) Price discovery and volatility spillovers in the DJIA and futures markets, *Journal of Futures Markets*, 19(8), 911-930.

Wang, G. and Yau, J. (2000) Trading volume, bid-ask spread, and price volatility in future markets, *Journal of Future Markets*, 20(10), 943-970.

TABLE 1. Sample statistics for intraday returns

Stock	Mean	Maximum	Minimum	Standard Deviation	Skewness	Kurtosis	Jarque-Bera statistic	JB p-value	ρ	ρ p-value	Stock	Mean	Maximum	Minimum	Standard Deviation	Skewness	Kurtosis	Jarque-Bera statistic	JB p-value	ρ	ρ p-value
AWC	-0.0028	0.0222	-0.0365	0.2544	-1.5784	35.3343	1.41E+05	0.0000	-0.1420	0.0000	MGR	-0.0005	0.0149	-0.0147	0.1438	0.1549	14.9219	1.91E+04	0.0000	-0.2110	0.0000
AMC	-0.0011	0.0182	-0.0189	0.1822	0.0277	22.8430	5.27E+04	0.0000	-0.1100	0.0000	NAB	-0.0028	0.0291	-0.0169	0.1563	1.3717	54.9297	3.62E+05	0.0000	-0.0810	0.0000
AMP	-0.0161	0.0323	-0.0590	0.3232	-3.6319	75.0244	7.02E+05	0.0000	-0.0560	0.0015	NCP	-0.0040	0.0360	-0.0469	0.2624	-2.2323	83.1695	8.64E+05	0.0000	-0.0680	0.0001
ALL	-0.0300	0.0899	-0.5037	1.0534	-35.1062	1647.6950	3.63E+08	0.0000	-0.1600	0.0000	NCPD	-0.0041	0.0371	-0.0489	0.2765	-1.7918	80.0484	7.97E+05	0.0000	-0.0820	0.0000
ANZ	-0.0014	0.0350	-0.0247	0.1852	1.0622	66.1539	5.35E+05	0.0000	-0.0610	0.0005	PBL	-0.0034	0.0392	-0.0273	0.2214	0.7320	55.8832	3.75E+05	0.0000	-0.1300	0.0000
AGL	0.0009	0.0124	-0.0134	0.1537	0.0168	13.7098	1.54E+04	0.0000	-0.1760	0.0000	QAN	-0.0050	0.0293	-0.0265	0.2662	0.3142	18.6494	3.29E+04	0.0000	-0.1200	0.0000
AXA	-0.0027	0.0385	-0.0218	0.3444	0.5043	14.9333	1.92E+04	0.0000	-0.1710	0.0000	QBE	0.0003	0.0532	-0.0168	0.1952	5.7296	180.6841	4.25E+06	0.0000	-0.0190	0.2814
BHP	-0.0026	0.0246	-0.0395	0.1874	-4.6813	138.4846	2.47E+06	0.0000	-0.0790	0.0000	RMD	-0.0028	0.0333	-0.0269	0.2692	0.2254	27.8439	8.27E+04	0.0000	-0.0320	0.0696
BSL	0.0016	0.0347	-0.0242	0.2907	0.4156	20.4454	4.09E+04	0.0000	-0.1750	0.0000	RIO	-0.0001	0.0252	-0.0404	0.1720	-4.1217	169.9978	3.74E+06	0.0000	-0.0660	0.0002
BIL	-0.0024	0.0831	-0.0252	0.2959	6.2336	211.5728	5.85E+06	0.0000	-0.0970	0.0000	STO	-0.0027	0.0201	-0.0184	0.1972	-0.1297	15.8851	2.22E+04	0.0000	-0.1330	0.0000
CCL	0.0029	0.0209	-0.0311	0.2062	-0.7445	34.5710	1.34E+05	0.0000	-0.1190	0.0000	SRP	-0.0121	0.0600	-0.2029	0.5197	-19.4697	757.4267	7.64E+07	0.0000	-0.1250	0.0000
CML	-0.0030	0.0182	-0.0208	0.2211	-0.3259	14.7018	1.84E+04	0.0000	-0.1170	0.0000	SGB	-0.0002	0.0109	-0.0115	0.1469	-0.2765	12.6650	1.26E+04	0.0000	-0.1270	0.0000
CBA	-0.0029	0.0257	-0.0303	0.1572	-0.7850	76.4857	7.24E+05	0.0000	-0.1040	0.0000	SGP	0.0008	0.0223	-0.0223	0.1586	0.2774	32.8650	1.20E+05	0.0000	-0.2180	0.0000
CSL	-0.0144	0.0313	-0.0510	0.3405	-1.5351	40.4158	1.89E+05	0.0000	0.0000	1.0000	SUN	-0.0028	0.0447	-0.0495	0.2637	-1.5477	81.1620	8.20E+05	0.0000	-0.1380	0.0000
CSR	0.0014	0.0187	-0.0236	0.2083	-0.0823	22.2873	4.98E+04	0.0000	-0.0760	0.0000	TAH	-0.0031	0.0262	-0.0309	0.2020	-0.8720	39.7503	1.81E+05	0.0000	-0.0290	0.1001
FGL	-0.0026	0.0141	-0.0268	0.1918	-1.2637	21.9899	4.92E+04	0.0000	-0.2810	0.0000	TEL	-0.0019	0.0308	-0.0235	0.2266	0.3391	33.2644	1.23E+05	0.0000	-0.0970	0.0000
GPT	-0.0011	0.0197	-0.0197	0.2102	0.2435	10.8363	8.26E+03	0.0000	-0.2610	0.0000	TLS	-0.0018	0.0239	-0.0397	0.2147	-1.4705	46.1490	2.51E+05	0.0000	-0.2460	0.0000
IAG	0.0030	0.0543	-0.0233	0.3102	1.9399	42.8019	2.14E+05	0.0000	-0.2290	0.0000	WES	-0.0028	0.0400	-0.0475	0.2386	-1.9808	103.3812	1.35E+06	0.0000	0.0460	0.0090
JHX	-0.0022	0.0172	-0.0230	0.2470	-0.3013	14.0797	1.65E+04	0.0000	-0.0520	0.0032	WFA	-0.0020	0.0120	-0.0336	0.2495	-0.7489	14.3935	1.77E+04	0.0000	-0.2580	0.0000
FXJ	-0.0017	0.0509	-0.0405	0.2838	0.7756	56.3056	3.81E+05	0.0000	-0.1950	0.0000	WSF	-0.0007	0.0439	-0.0162	0.2561	3.0662	53.7464	3.50E+05	0.0000	-0.0550	0.0018
LLC	-0.0030	0.0434	-0.0687	0.2671	-4.7446	170.2667	3.76E+06	0.0000	-0.0790	0.0000	WFT	-0.0019	0.0091	-0.0383	0.1770	-3.2750	72.9883	6.62E+05	0.0000	-0.2310	0.0000
MBL	0.0017	0.0248	-0.0195	0.1857	0.3970	31.9205	1.12E+05	0.0000	-0.0570	0.0012	WBC	0.0002	0.0287	-0.0160	0.1779	1.1522	42.2319	2.07E+05	0.0000	-0.0710	0.0001
MIG	-0.0006	0.0191	-0.0191	0.2556	0.1167	9.0691	4.94E+03	0.0000	-0.2380	0.0000	WMR	-0.0011	0.0158	-0.0403	0.3032	-2.2419	33.4281	1.27E+05	0.0000	-0.1570	0.0000
MAY	-0.0015	0.0329	-0.0284	0.3086	0.0310	18.7165	3.31E+04	0.0000	-0.2110	0.0000	WPL	-0.0044	0.0223	-0.0369	0.2338	-1.5611	40.1305	1.86E+05	0.0000	-0.0330	0.0613
MIM	-0.0015	0.0299	-0.0274	0.4262	0.1377	5.6283	9.36E+02	0.0000	-0.3290	0.0000	WOW	0.0005	0.0284	-0.0131	0.1853	1.0947	31.5185	1.10E+05	0.0000	-0.1210	0.0000

Notes: This table provides measures of central tendency, dispersion and shape for the five-minute returns on the stocks included in the S&P/ASX 50 index, namely: AWC – Alumina, AMC – Amcor, AMP – AMP, ALL – Aristocrat Leisure, ANZ – Australia and New Zealand Banking Group, AGL – Australian Gas Light Company, AXA – AXA Asia Pacific Holdings, BHP – BHP Billiton, BSL – BHP Steel, BIL – Brambles, CCL – Coca-Cola Amatil, CML – Coles Myer, CBA – Commonwealth Bank of Australia, CSL – CSL, CSR – CST, FGL – Fosters Group, GPT – General Property Trust, IAG – Insurance Australia Group, JHX – James Hardie Industries, KXJ – John Fairfax Holdings, LLC – Lend Lease Corp, MBL – Macquarie Bank, MIG – Macquarie Infrastructure Group, MAY – Mayne Group, MIM – MIM Holdings, MGR – Mirvac Group, NAB – National Australia Bank, NCP – News Corp, NCPDP – News Corp, PBL – Publishing and Broadcasting, QAN – Qantas Airways, QBE – QBE Insurance, RMD – Resmed, RIO – Rio Tinto, STO – Santos, SRP – Southcorp, SGB – St. George Bank, SGP – Stockland, SUN – Suncorp-Metway, TAH – TABCORP Holdings, TEL – Telecom Corp of New Zealand, TLS – Telstra, WES – Wesfarmers, WFA – Westfied America Trust, WSF – Westfield Holdings, WFT – Westfied Trust, WBC – Westpac Banking Corp, WMC – WMC Resources, WPL – Woodside Petroleum, WOW – Woolworths. The sample period is from 31 December 2002 – 4 March 2003 with 3,215 observations. The critical values of skewness and kurtosis are 0.0432 and 0.0864, respectively, JB – Jarque-Bera, ρ – first-order autocorrelation coefficient, ρ p-value – one-tailed test of significance of first-order autocorrelation coefficient.

TABLE 2. Estimated coefficients for conditional mean return equations

Stock	Coefficient (α_0)	Standard error (α_0)	p-value (α_0)	Coefficient (α_1)	Standard error (α_1)	p-value (α_1)	AIC	SIC	AIC(δ)	SIC(δ)	Stock	Coefficient (α_0)	Standard error (α_0)	p-value (α_0)	Coefficient (α_1)	Standard error (α_1)	p-value (α_1)	AIC	SIC	AIC(δ)	SIC(δ)
AWC	-0.0034	0.0121	0.7768	-0.1418	0.0588	0.0158	-0.0320	-0.0226	0.4234	0.4404	MGR	-0.0006	0.0070	0.9268	-0.2105	0.0607	0.0005	-1.1432	-1.1337	-0.7112	-0.6942
AMC	-0.0010	0.0023	0.6771	-0.1391	0.0249	0.0000	-0.7099	-0.7004	-0.9215	-0.9045	NAB	-0.0030	0.0075	0.6922	-0.0808	0.0603	0.1805	-1.1630	-1.1536	-0.5677	-0.5507
AMP	-0.0034	0.0028	0.2250	-0.0644	0.0240	0.0074	0.4070	0.4165	-0.1442	-0.1272	NCP	-0.0003	0.0022	0.8730	-0.0890	0.0262	0.0007	0.0819	0.0913	-0.7027	-0.6857
ALL	0.0010	0.0045	0.8299	-0.0274	0.0182	0.1329	2.9445	2.9540	0.9740	0.9910	NCPD	0.0022	0.0025	0.3670	-0.0547	0.0231	0.0179	0.2124	0.2219	-0.4927	-0.4757
ANZ	-0.0015	0.0082	0.8534	-0.0612	0.0733	0.4041	-0.8683	-0.8588	-0.2320	-0.2150	PBL	-0.0039	0.0091	0.6690	-0.1299	0.0503	0.0098	-0.5445	-0.5350	0.1014	0.1184
AGL	0.0010	0.0074	0.8903	-0.1759	0.0587	0.0027	-1.0585	-1.0490	-0.5808	-0.5638	QAN	-0.0057	0.0129	0.6575	-0.1188	0.0459	0.0096	-0.0007	0.0088	0.5210	0.5380
AXA	-0.0032	0.0162	0.8441	-0.1711	0.0595	0.0040	0.5679	0.5774	1.0493	1.0663	QBE	0.0003	0.0113	0.9781	-0.0191	0.0644	0.7664	-0.4941	-0.4847	-0.0837	-0.0667
BHP	-0.0031	0.0042	0.4655	-0.0793	0.0616	0.1981	-0.5315	-0.5221	-0.4536	-0.4366	RMD	-0.0028	0.0121	0.8193	-0.0310	0.0588	0.5982	0.1069	0.1163	0.4976	0.5146
BSL	-0.0019	0.0037	0.6032	-0.2790	0.0206	0.0000	0.2561	0.2655	0.0962	0.1132	RIO	0.0005	0.0037	0.8937	-0.0659	0.0471	0.1622	-0.7031	-0.6937	-1.2126	-1.1956
BIL	0.0002	0.0034	0.9496	-0.2557	0.0217	0.0000	0.3071	0.3166	-0.1497	-0.1327	STO	-0.0025	0.0025	0.3053	-0.1397	0.0199	0.0000	-0.5777	-0.5682	-0.7366	-0.7195
CCL	0.0032	0.0091	0.7242	-0.1186	0.0631	0.0602	-0.4744	-0.4649	-0.0105	0.0065	SRP	-0.0051	0.0035	0.1473	-0.1272	0.0207	0.0000	1.4591	1.4685	0.0254	0.0424
CML	-0.0011	0.0025	0.6606	-0.1442	0.0200	0.0000	-0.3493	-0.3398	-0.5188	-0.5018	SGB	-0.0002	0.0072	0.9789	-0.1265	0.0517	0.0145	-1.1785	-1.1691	-0.6630	-0.6460
CBA	-0.0002	0.0015	0.8782	-0.1051	0.0221	0.0000	-1.1592	-1.1497	-1.4359	-1.4189	SGP	0.0010	0.0022	0.6486	-0.2171	0.0249	0.0000	-1.1190	-1.1095	-1.1508	-1.1338
CLS	-0.0016	0.0035	0.6550	-0.0193	0.0244	0.4301	0.4612	0.4707	0.0409	0.0579	SUN	-0.0032	0.0119	0.7854	-0.1379	0.0500	0.0058	-0.3320	-0.3226	0.4382	0.4552
CSR	0.0033	0.0028	0.2365	-0.0773	0.0223	0.0005	-0.4572	-0.4477	-0.5954	-0.5784	TAH	-0.0033	0.0103	0.7477	-0.0291	0.0544	0.5934	-0.5238	-0.5143	-0.0378	-0.0208
FGL	-0.0032	0.0027	0.2228	-0.3414	0.0191	0.0000	-0.6251	-0.6157	-0.7371	-0.7201	TEL	-0.0063	0.0037	0.0879	-0.0997	0.0274	0.0003	-0.2180	-0.2086	-0.4906	-0.4736
GPT	0.0005	0.0030	0.8617	-0.2640	0.0230	0.0000	-0.3676	-0.3581	-0.4353	-0.4183	TLS	-0.0024	0.0107	0.8232	-0.2461	0.0624	0.0001	-0.4529	-0.4434	0.0442	0.0612
IAG	-0.0005	0.0037	0.8919	-0.3308	0.0199	0.0000	0.3083	0.3178	0.0410	0.0580	WES	0.0009	0.0027	0.7485	0.0452	0.0245	0.0656	-0.3592	-0.3497	-0.8568	-0.8398
JHX	-0.0023	0.0119	0.8435	-0.0516	0.0515	0.3168	-0.0889	-0.0795	0.3905	0.4076	WFA	-0.0025	0.0111	0.8231	-0.2576	0.0540	0.0000	-0.0655	-0.0560	0.3529	0.3699
FXJ	0.0023	0.0031	0.4517	-0.2165	0.0253	0.0000	0.0903	0.0997	-0.1316	-0.1146	WSF	-0.0010	0.0139	0.9428	-0.0547	0.0582	0.3477	-0.1656	-0.1562	0.4460	0.4630
LLC	-0.0029	0.0023	0.2069	-0.1012	0.0225	0.0000	-0.0168	-0.0074	-0.4063	-0.3893	WFT	0.0001	0.0023	0.9676	-0.2617	0.0217	0.0000	-0.7220	-0.7125	-0.8399	-0.8229
MBL	0.0021	0.0016	0.1943	-0.0573	0.0227	0.0115	-0.7107	-0.7012	-1.0231	-1.0061	WBC	-0.0002	0.0017	0.8916	-0.0719	0.0187	0.0001	-0.9886	-0.9791	-1.2555	-1.2385
MIG	-0.0019	0.0038	0.6258	-0.2905	0.0219	0.0000	-0.0107	-0.0013	-0.0538	-0.0368	WMR	-0.0033	0.0032	0.2987	-0.1831	0.0203	0.0000	0.3151	0.3246	0.0007	0.0177
MAY	-0.0030	0.0038	0.4397	-0.2691	0.0186	0.0000	0.3656	0.3751	0.1596	0.1766	WPL	-0.0031	0.0019	0.0953	-0.0350	0.0220	0.1113	-0.2934	-0.2839	-0.7128	-0.6958
MIM	-0.0038	0.0063	0.5438	-0.3569	0.0190	0.0000	1.0016	1.0111	0.9393	0.9563	WOW	0.0006	0.0089	0.9509	-0.1205	0.0563	0.0322	-0.7882	-0.7788	-0.2130	-0.1960

Notes: This table provides the estimated coefficients, standard errors and p-values from the conditional mean return in Equation (1) for the fifty stocks included in the S&P/ASX 50 index, namely: AWC – Alumina, AMC – Amcor, AMP – AMP, ALL – Aristocrat Leisure, ANZ – Australia and New Zealand Banking Group, AGL – Australian Gas Light Company, AXA – AXA Asia Pacific Holdings, BHP – BHP Billiton, BSL – BHP Steel, BIL – Brambles, CCL – Coca-Cola Amatil, CML – Coles Myer, CBA – Commonwealth Bank of Australia, CSL – CSL, CSR – CST, FGL – Fosters Group, GPT – General Property Trust, IAG – Insurance Australia Group, JHX – James Hardie Industries, KXJ – John Fairfax Holdings, LLC – Lend Lease Corp, MBL – Macquarie Bank, MIG – Macquarie Infrastructure Group, MAY – Mayne Group, MIM – MIM Holdings, MGR – Mirvac Group, NAB – National Australia Bank, NCP – News Corp, NCPDP – News Corp, PBL – Publishing and Broadcasting, QAN – Qantas Airways, QBE – QBE Insurance, RMD – Resmed, RIO – Rio Tinto, STO – Santos, SRP – Southcorp, SGB – St. George Bank, SGP – Stockland, SUN – Suncorp-Metway, TAH – TABCORP Holdings, TEL – Telecom Corp of New Zealand, TLS – Telstra, WES – Wesfarmers, WFA – Westfied America Trust, WSF – Westfield Holdings, WFT – Westfied Trust, WBC – Westpac Banking Corp, WMC – WMC Resources, WPL – Woodside Petroleum, WOW – Woolworths. AIC and SIC are the Akaike Information Criterion and Schwartz Information Criterion respectively for the simple GARCH (1,1) model in Equation 2. AIC(δ) and SIC(δ) are the Akaike Information Criterion and Schwartz Information Criterion respectively from the GARCH (1,1) model in Equation 3 including exogenous variables in the conditional variance equation. AIC and SIC represent the trade-off between goodness-of-fit and model complexity with a lower value for the AIC or SIC indicating the more appropriate model.

TABLE 3. Estimated coefficients for conditional variance equations

	Constant			ARCH			GARCH			Contemporaneous (v_t) and lagged (v_{t-1}) volume						Contemporaneous (s_t) and lagged (s_{t-1}) bid-ask spread						Persistence	
Stock	Coefficient (β_0)	Standard error (β_0)	p-value (β_0)	Coefficient (β_1)	Standard error (β_1)	p-value (β_1)	Coefficient (γ_0)	Standard error (γ_0)	p-value (γ_0)	Coefficient (δ_1)	Standard error (δ_1)	p-value (δ_1)	Coefficient (δ_2)	Standard error (δ_2)	p-value (δ_2)	Coefficient (δ_3)	Standard error (δ_3)	p-value (δ_3)	Coefficient (δ_4)	Standard error (δ_4)	p-value (δ_4)	$\beta_1 + \gamma_0$	p-value
AWC	0.0627	0.0018	0.0000	0.1500	0.0295	0.0000	0.5999	0.0157	0.0000	-3.38E-08	1.97E-09	0.0000	-1.23E-08	9.72E-09	0.2047	5.46E-06	1.44E-01	1.0000	5.71E-06	9.70E-02	1.0000	0.7499	0.0000
AMC	0.0012	0.0002	0.0000	0.1389	0.0097	0.0000	0.6590	0.0169	0.0000	4.63E-07	2.05E-08	0.0000	-2.12E-07	1.91E-08	0.0000	-3.72E-02	3.27E-03	0.0000	2.77E-02	7.38E-03	0.0002	0.7979	0.0000
AMP	0.0004	0.0003	0.1395	0.1494	0.0112	0.0000	0.5915	0.0209	0.0000	5.20E-07	1.02E-08	0.0000	-2.27E-07	1.56E-08	0.0000	-9.28E-03	3.81E-03	0.0150	6.07E-03	1.41E-02	0.6661	0.7409	0.0000
ALL	0.0256	0.0010	0.0000	0.1146	0.0093	0.0000	0.2090	0.0209	0.0000	3.00E-06	7.48E-09	0.0000	-5.79E-07	6.71E-08	0.0000	8.86E-02	1.43E-02	0.0000	-7.35E-02	4.67E-03	0.0000	0.3236	0.0000
ANZ	0.0341	0.0063	0.0000	0.1500	0.0210	0.0000	0.6000	0.0743	0.0000	-1.51E-08	1.03E-08	0.1441	-1.88E-08	5.45E-09	0.0006	2.22E-08	4.75E-02	1.0000	2.80E-08	3.12E-02	1.0000	0.7500	0.0006
AGL	0.0229	0.0048	0.0000	0.1500	0.0412	0.0003	0.6000	0.0829	0.0000	-4.21E-08	1.80E-08	0.0190	-1.80E-08	1.51E-08	0.2325	2.98E-07	1.90E-02	1.0000	2.95E-07	4.16E-02	1.0000	0.7500	0.0035
AXA	0.1151	0.0312	0.0002	0.1500	0.0537	0.0052	0.6000	0.1114	0.0000	-1.66E-08	8.43E-08	0.8439	-1.63E-07	6.31E-08	0.0100	1.20E-06	7.97E-01	1.0000	1.30E-06	6.46E-01	1.0000	0.7500	0.0216
BHP	0.0244	0.0018	0.0000	0.1495	0.0187	0.0000	0.5987	0.0261	0.0000	2.32E-08	1.78E-09	0.0000	-7.61E-09	1.43E-09	0.0000	-1.54E-03	6.44E-04	0.0172	-9.80E-04	4.60E-04	0.0330	0.7483	0.0000
BSL	0.0053	0.0009	0.0000	0.1050	0.0102	0.0000	0.6412	0.0345	0.0000	8.39E-07	2.85E-08	0.0000	-4.91E-07	3.65E-08	0.0000	-1.81E-01	1.30E-02	0.0000	7.28E-02	5.05E-02	0.1497	0.7462	0.0000
BIL	0.0038	0.0005	0.0000	0.0671	0.0045	0.0000	0.6390	0.0185	0.0000	5.23E-07	7.55E-09	0.0000	-2.45E-07	1.47E-08	0.0000	-9.29E-04	5.58E-03	0.8677	9.89E-03	8.12E-03	0.2231	0.7061	0.0000
CCL	0.0419	0.0077	0.0000	0.1500	0.0205	0.0000	0.6000	0.0704	0.0000	-1.48E-08	5.85E-09	0.0115	-7.87E-08	4.52E-09	0.0000	5.85E-07	1.68E-03	0.9997	1.01E-07	3.52E-02	1.0000	0.7500	0.0003
CML	0.0013	0.0001	0.0000	0.1504	0.0124	0.0000	0.6050	0.0213	0.0000	7.01E-07	3.32E-08	0.0000	-3.13E-07	3.10E-08	0.0000	-2.76E-02	2.43E-02	0.2556	-9.41E-03	3.28E-02	0.7742	0.7554	0.0000
CBA	0.0002	0.0001	0.0142	0.1493	0.0067	0.0000	0.5982	0.0178	0.0000	2.15E-07	7.52E-09	0.0000	-9.41E-08	7.01E-09	0.0000	1.26E-03	7.35E-05	0.0000	-1.13E-03	4.06E-04	0.0056	0.7475	0.0000
CLS	0.0022	0.0003	0.0000	0.1265	0.0077	0.0000	0.5408	0.0144	0.0000	5.18E-06	1.03E-07	0.0000	-1.89E-06	1.17E-07	0.0000	-6.12E-03	1.88E-03	0.0012	3.45E-02	4.18E-03	0.0000	0.6672	0.0000
CSR	0.0027	0.0003	0.0000	0.1580	0.0106	0.0000	0.6040	0.0155	0.0000	3.83E-07	2.68E-08	0.0000	-1.18E-07	2.28E-08	0.0000	-2.72E-02	7.23E-03	0.0002	6.39E-04	9.40E-03	0.9458	0.7620	0.0000
FGL	0.0043	0.0006	0.0000	0.0589	0.0134	0.0000	0.6471	0.0331	0.0000	5.88E-08	7.25E-09	0.0000	-5.87E-09	6.76E-09	0.3849	-1.04E-01	1.08E-02	0.0000	1.10E-01	2.99E-02	0.0002	0.7060	0.0000
GPT	0.0083	0.0014	0.0000	0.0946	0.0135	0.0000	0.6050	0.0533	0.0000	2.01E-07	1.16E-08	0.0000	-1.15E-07	1.44E-08	0.0000	-1.14E-02	3.18E-04	0.0000	2.27E-02	3.27E-03	0.0000	0.6995	0.0000
IAG	0.0065	0.0012	0.0000	0.0997	0.0128	0.0000	0.6248	0.0381	0.0000	5.95E-07	2.33E-08	0.0000	-3.31E-07	2.90E-08	0.0000	-8.78E-02	5.07E-02	0.0832	6.70E-03	1.19E-01	0.9551	0.7245	0.0000
JHX	0.0608	0.0122	0.0000	0.1500	0.0338	0.0000	0.6000	0.0827	0.0000	-8.96E-08	3.20E-08	0.0051	-7.66E-08	3.41E-08	0.0249	1.06E-06	1.16E-01	1.0000	1.23E-06	9.29E-02	1.0000	0.7500	0.0026
FXJ	0.0047	0.0004	0.0000	0.1330	0.0069	0.0000	0.5469	0.0188	0.0000	1.24E-06	5.81E-08	0.0000	-5.29E-07	4.60E-08	0.0000	-1.94E-02	8.94E-04	0.0000	2.54E-02	1.04E-02	0.0143	0.6800	0.0000
LLC	0.0019	0.0002	0.0000	0.2069	0.0069	0.0000	0.6328	0.0110	0.0000	1.18E-06	2.18E-08	0.0000	-6.31E-07	2.76E-08	0.0000	-3.31E-02	3.13E-03	0.0000	5.26E-02	9.52E-03	0.0000	0.8397	0.0000
MBL	-0.0003	0.0000	0.0000	0.1568	0.0065	0.0000	0.6028	0.0111	0.0000	2.30E-06	2.87E-08	0.0000	-1.13E-06	3.93E-08	0.0000	-1.24E-02	1.59E-03	0.0000	-3.25E-03	1.24E-03	0.0087	0.7596	0.0000
MIG	0.0097	0.0006	0.0000	0.1246	0.0123	0.0000	0.6399	0.0292	0.0000	4.29E-08	1.17E-08	0.0002	5.50E-08	1.33E-08	0.0000	-1.33E-01	3.92E-02	0.0007	5.52E-02	4.90E-02	0.2603	0.7645	0.0000
MAY	0.0066	0.0009	0.0000	0.0853	0.0104	0.0000	0.6214	0.0346	0.0000	2.15E-06	6.07E-08	0.0000	-1.29E-06	9.49E-08	0.0000	-4.97E-02	3.76E-03	0.0000	-1.41E-02	4.53E-02	0.7552	0.7067	0.0000
MIM	0.0210	0.0083	0.0111	0.0360	0.0070	0.0000	0.7507	0.0777	0.0000	1.95E-07	1.86E-08	0.0000	-1.35E-07	2.25E-08	0.0000	-2.37E-01	1.27E-01	0.0618	-6.85E-02	2.33E-01	0.7692	0.7868	0.0031
MGR	0.0198	0.0059	0.0008	0.1500	0.0542	0.0057	0.6000	0.1155	0.0000	-7.75E-09	6.19E-11	0.0000	-7.12E-09	4.29E-09	0.0973	1.48E-08	6.41E-02	1.0000	1.84E-08	3.77E-02	1.0000	0.7500	0.0251
NAB	0.0243	0.0016	0.0000	0.1500	0.0153	0.0000	0.6000	0.0280	0.0000	-3.44E-09	8.63E-09	0.6906	-2.18E-08	4.97E-09	0.0000	2.34E-08	2.39E-02	1.0000	3.03E-08	1.49E-02	1.0000	0.7500	0.0000
NCP	0.0000	0.0001	0.8149	0.1436	0.0073	0.0000	0.5613	0.0264	0.0000	3.84E-07	5.70E-09	0.0000	-2.07E-07	1.14E-08	0.0000	-1.51E-02	2.83E-03	0.0000	-9.17E-04	8.77E-03	0.9167	0.7050	0.0000
NPD	-0.0003	0.0001	0.0180	0.1343	0.0083	0.0000	0.4962	0.0132	0.0000	6.89E-07	9.08E-09	0.0000	-2.60E-07	9.72E-09	0.0000	-1.99E-02	1.03E-03	0.0000	-6.69E-02	9.09E-03	0.0000	0.6304	0.0000
PBL	0.0471	0.0005	0.0000	0.1500	0.0190	0.0000	0.5999	0.0175	0.0000	-8.84E-08	1.62E-08	0.0000	-5.82E-08	6.65E-09	0.0000	2.23E-05	7.35E-02	0.9998	2.33E-05	9.38E-02	0.9998	0.7499	0.0000

	Constant			ARCH			GARCH			Contemporaneous (v_t) and lagged (v_{t-1}) volume						Contemporaneous (s_t) and lagged (s_{t-1}) bid-ask spread						Persistence	
Stock	Coefficient (β_0)	Standard error (β_0)	p-value (β_0)	Coefficient (β_1)	Standard error (β_1)	p-value (β_1)	Coefficient (γ_0)	Standard error (γ_0)	p-value (γ_0)	Coefficient (δ_1)	Standard error (δ_1)	p-value (δ_1)	Coefficient (δ_2)	Standard error (δ_2)	p-value (δ_2)	Coefficient (δ_3)	Standard error (δ_3)	p-value (δ_3)	Coefficient (δ_4)	Standard error (δ_4)	p-value (δ_4)	$\beta_1 + \gamma_0$	p-value
QAN	0.0698	0.0085	0.0000	0.1500	0.0260	0.0000	0.6000	0.0535	0.0000	1.31E-08	1.11E-08	0.2364	-4.55E-08	7.13E-09	0.0000	1.34E-08	3.37E-01	1.0000	1.38E-08	3.10E-01	1.0000	0.7500	0.0000
QBE	0.0381	0.0100	0.0001	0.1500	0.0456	0.0010	0.6000	0.1023	0.0000	3.14E-08	1.13E-09	0.0000	-6.52E-08	1.06E-08	0.0000	1.19E-07	1.79E-01	1.0000	1.41E-07	1.22E-01	1.0000	0.7500	0.0128
RMD	0.0646	0.0079	0.0000	0.1497	0.0280	0.0000	0.5985	0.0461	0.0000	-4.58E-08	5.45E-08	0.4007	-1.73E-07	1.24E-09	0.0000	1.58E-05	1.93E-01	0.9999	2.79E-05	1.89E-01	0.9999	0.7482	0.0000
RIO	0.0053	0.0005	0.0000	0.1492	0.0175	0.0000	0.5984	0.0349	0.0000	1.71E-07	3.42E-09	0.0000	-4.55E-08	1.09E-08	0.0000	-5.75E-03	1.65E-03	0.0005	-6.50E-03	3.00E-03	0.0300	0.7476	0.0000
STO	0.0030	0.0003	0.0000	0.1418	0.0110	0.0000	0.6178	0.0195	0.0000	7.06E-07	3.88E-08	0.0000	-3.71E-07	3.56E-08	0.0000	-2.74E-02	4.95E-03	0.0000	2.64E-02	9.09E-03	0.0037	0.7596	0.0000
SRP	0.0103	0.0002	0.0000	0.1568	0.0098	0.0000	0.4808	0.0156	0.0000	7.39E-07	3.67E-09	0.0000	-3.36E-07	1.64E-08	0.0000	-6.64E-03	5.28E-03	0.2079	-1.61E-02	5.49E-03	0.0033	0.6376	0.0000
SGB	0.0211	0.0022	0.0000	0.1500	0.0284	0.0000	0.6000	0.0359	0.0000	-5.54E-08	9.74E-09	0.0000	-3.70E-08	6.52E-09	0.0000	1.51E-06	3.04E-02	1.0000	1.70E-06	2.32E-02	0.9999	0.7500	0.0000
SGP	0.0040	0.0003	0.0000	0.1498	0.0111	0.0000	0.6012	0.0193	0.0000	1.85E-07	8.59E-09	0.0000	-1.14E-07	6.17E-09	0.0000	-9.05E-03	3.46E-03	0.0088	-6.08E-03	8.89E-03	0.4939	0.7511	0.0000
SUN	0.0682	0.0056	0.0000	0.1500	0.0236	0.0000	0.6000	0.0319	0.0000	-9.33E-08	9.00E-08	0.2998	-1.12E-07	6.56E-08	0.0878	7.66E-07	9.28E-02	1.0000	7.22E-07	7.51E-02	1.0000	0.7500	0.0000
TAH	0.0407	0.0099	0.0000	0.1500	0.0344	0.0000	0.6000	0.0955	0.0000	-1.20E-08	2.81E-08	0.6683	-7.25E-08	1.49E-08	0.0000	1.26E-07	4.27E-02	1.0000	1.32E-07	4.45E-02	1.0000	0.7500	0.0069
TEL	0.0065	0.0006	0.0000	0.1206	0.0095	0.0000	0.5970	0.0247	0.0000	1.93E-06	5.67E-08	0.0000	-1.16E-06	5.94E-08	0.0000	-1.00E-01	1.56E-03	0.0000	7.09E-03	1.84E-02	0.6999	0.7175	0.0000
TLS	0.0432	0.0121	0.0003	0.1500	0.0411	0.0003	0.6000	0.1056	0.0000	6.28E-09	2.45E-09	0.0103	-1.27E-08	3.79E-09	0.0008	7.42E-09	2.47E-01	1.0000	7.97E-09	1.76E-01	1.0000	0.7500	0.0137
WES	0.0024	0.0002	0.0000	0.1474	0.0075	0.0000	0.5923	0.0165	0.0000	1.21E-06	1.81E-08	0.0000	-4.91E-07	3.51E-08	0.0000	-8.99E-03	8.08E-04	0.0000	1.14E-02	2.17E-03	0.0000	0.7398	0.0000
WFA	0.0581	0.0183	0.0015	0.1500	0.0474	0.0016	0.6000	0.1148	0.0000	-1.80E-08	6.33E-09	0.0044	-2.15E-08	4.58E-09	0.0000	1.55E-08	1.11E+00	1.0000	1.60E-08	7.13E-01	1.0000	0.7500	0.0221
WSF	0.0651	0.0112	0.0000	0.1500	0.0292	0.0000	0.6000	0.0683	0.0000	-3.50E-08	1.07E-07	0.7447	-1.65E-07	6.59E-08	0.0122	1.09E-06	9.50E-02	1.0000	1.38E-06	8.54E-02	1.0000	0.7500	0.0004
WFT	0.0037	0.0005	0.0000	0.0749	0.0125	0.0000	0.6278	0.0478	0.0000	3.95E-07	8.55E-09	0.0000	-2.45E-07	1.98E-08	0.0000	-8.66E-02	2.65E-03	0.0000	9.61E-02	1.30E-02	0.0000	0.7027	0.0000
WBC	0.0005	0.0001	0.0000	0.1515	0.0097	0.0000	0.5988	0.0249	0.0000	1.90E-07	6.86E-09	0.0000	-9.92E-08	6.12E-09	0.0000	-5.09E-03	2.08E-03	0.0145	-2.41E-03	1.27E-03	0.0588	0.7503	0.0000
WMR	0.0011	0.0003	0.0010	0.1071	0.0102	0.0000	0.6335	0.0223	0.0000	1.02E-06	3.41E-08	0.0000	-5.63E-07	4.09E-08	0.0000	-7.99E-02	4.17E-02	0.0555	-4.05E-02	4.66E-02	0.3847	0.7406	0.0000
WPL	-0.0002	0.0000	0.0000	0.1452	0.0069	0.0000	0.5984	0.0100	0.0000	1.77E-06	3.49E-08	0.0000	-8.18E-07	1.09E-08	0.0000	-8.79E-03	5.34E-03	0.0998	8.44E-03	5.77E-03	0.1433	0.7436	0.0000
WOW	0.0338	0.0001	0.0000	0.1500	0.0171	0.0000	0.6000	0.0206	0.0000	-1.72E-08	1.43E-08	0.2277	-2.13E-08	1.43E-08	0.1367	9.72E-08	7.63E-02	1.0000	1.18E-07	7.26E-02	1.0000	0.7500	0.0000

Notes: This table provides the estimated coefficients, standard errors and p-values for the conditional covariance equation in Equation (3) for the fifty stocks included in the S&P/ASX 50 index, namely: AWC – Alumina, AMC – Amcor, AMP – AMP, ALL – Aristocrat Leisure, ANZ – Australia and New Zealand Banking Group, AGL – Australian Gas Light Company, AXA – AXA Asia Pacific Holdings, BHP – BHP Billiton, BSL – BHP Steel, BIL – Brambles, CCL – Coca-Cola Amatil, CML – Coles Myer, CBA – Commonwealth Bank of Australia, CSL – CSL, CSR – CST, FGL – Fosters Group, GPT – General Property Trust, IAG – Insurance Australia Group, JHX – James Hardie Industries, KXJ – John Fairfax Holdings, LLC – Lend Lease Corp, MBL – Macquarie Bank, MIG – Macquarie Infrastructure Group, MAY – Mayne Group, MIM – MIM Holdings, MGR – Mirvac Group, NAB – National Australia Bank, NCP – News Corp, NCPDP – News Corp, PBL – Publishing and Broadcasting, QAN – Qantas Airways, QBE – QBE Insurance, RMD – Resmed, RIO – Rio Tinto, STO – Santos, SRP – Southcorp, SGB – St. George Bank, SGP – Stockland, SUN – Suncorp-Metway, TAH – TABCORP Holdings, TEL – Telecom Corp of New Zealand, TLS – Telstra, WES – Wesfarmers, WFA – Westfied America Trust, WSF – Westfield Holdings, WFT – Westfied Trust, WBC – Westpac Banking Corp, WMC – WMC Resources, WPL – Woodside Petroleum, WOW – Woolworths. Persistence is the sum of the estimated ARCH and GARCH coefficients. The p-value for persistence is obtained from a one-tailed t-test that the persistence is less than one.