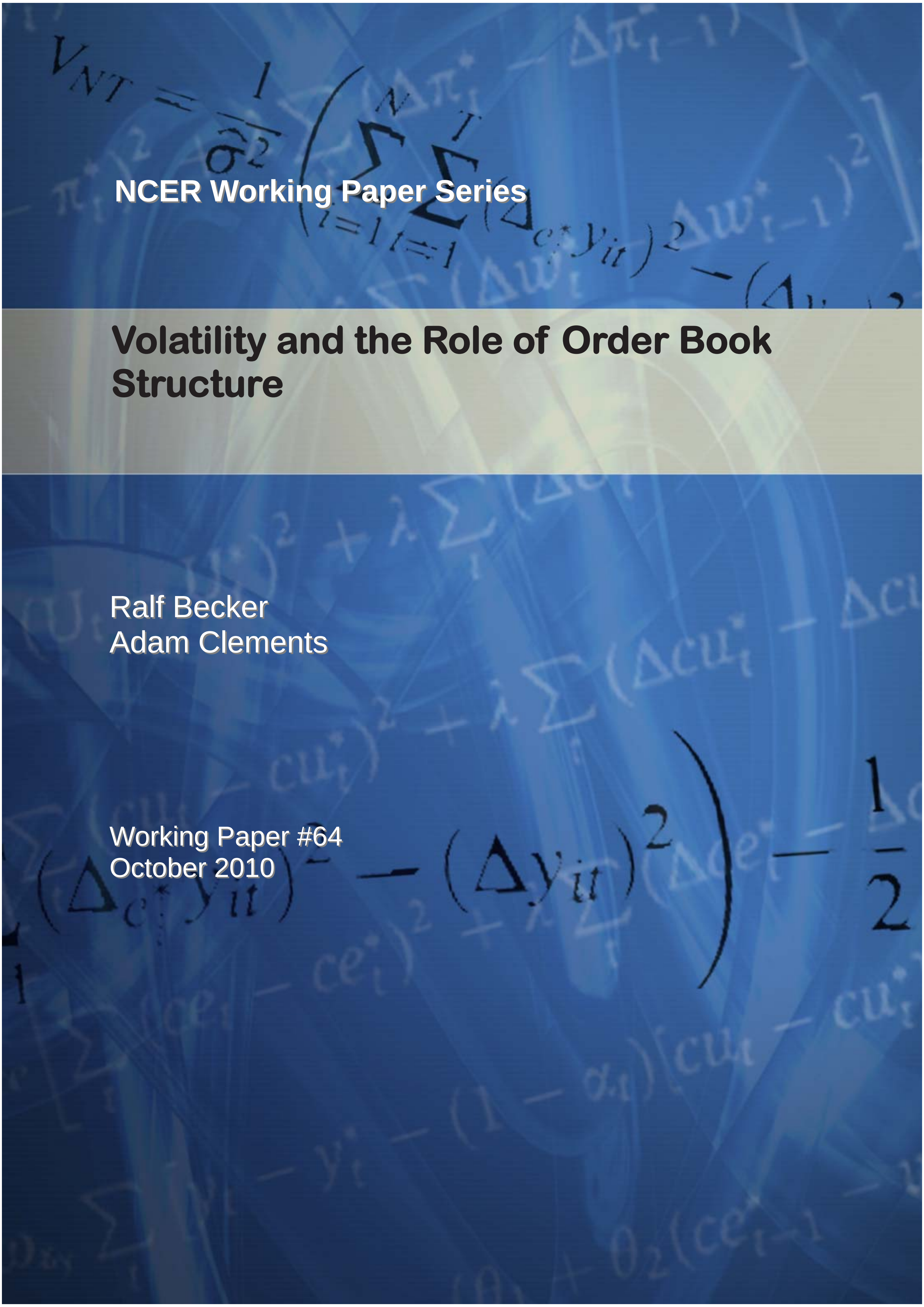

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Volatility and the Role of Order Book Structure

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Volatility and the role of order book structure

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Abstract

There is much literature that deals with modeling and forecasting asset return volatility. However, much of this research does not attempt to explain variations in the level of volatility. Movements in volatility are often linked to trading volume or frequency, as a reflection of underlying information flow. This paper considers whether the state of an open limit order book influences volatility. It is found that market depth and order imbalance do influence volatility, even in the presence of the traditional volume related variables.

Keywords
Realized volatility, bi-power variation, limit order book, market microstructure, order imbalance

JEL Classification Numbers G10, G12

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1 Introduction

Understanding the dynamics of financial asset return volatility is of central importance when making many financial decisions. There is a vast financial econometrics literature that address the question of modeling and forecasting volatility. Surveys of this area can be found in Campbell, Lo and MacKinlay (1997), Gourieroux and Jasiak (2001) and Andersen, Davis and Kreiß (2009). Much of this literature has stemmed from the development of the GARCH class of models attributable to Engle (1982) and Bollerslev (1986). The majority of this research does not attempt to explain the fundamental determinants of volatility and simply focuses on forecasting.

There is also a strand of literature that attempts to explain variation in volatility. Broadly speaking, volatility reflects information arrival which is captured by trading volume or frequency, or order flow (imbalance). Theoretically, Clark (1973), Tauchen and Pitts (1983) and Andersen (1996) among others relate volatility and trading volume jointly to the process of information arrival. From an empirical perspective, the volume volatility relationship has attracted a great deal of interest. A number of studies find that the number of trades is dominant factor in explaining volatility, see for instance Jones, Kaul and Lipson (1994) and Chan and Fong (2006). The evidence is mixed in relation to the importance of variables such as trading volume and order flow. Berger, Chaboud and Hjalmarsson (2009) link movements in volatility to order flow and market's sensitivity to the order flow. Giot, Laurent and Petitjean (2009) examine the volume volatility relationship from the perspective of the components of realized volatility. They find that the number of trades influences both the continuous diffusion (positive relationship) and jump (negative relationship) components of total realized volatility.

Little research has examined the relationship between order book structure and asset return volatility, certainly in the context of the volume volatility relationship. Pascual and Veradas (2010) consider the link between order book structure and the volatility of the unobserved efficient price. This paper examines the link between volatility and trade frequency and volume variables, along with a number of variables that reflect the structure of an open limit order book. In the context of a number of stocks trading on the Australian Stock Exchange (ASX), it is found that market depth and order imbalance significantly influence volatility, even in the presence of trading volume and frequency variables. These results represent an important contribution to our understanding of the fundamental source of volatility, market trading conditions.

The paper proceeds as follows. Section 2 outlines the manner in total volatility is decomposed into its constituent components. Section 3 outlines the data upon which the study is based and how the relevant explanatory variables are constructed. Section 4 describes the analysis conducted here along with the empirical results. Section 5 provides concluding comments.

2 Methodology

To obtain a proxy for the underlying latent volatility, we utilise the realized volatility (RV) estimator of Andersen and Bollerslev (1998). To briefly outline this approach, begin by defining the continuous time jump-diffusion process for the logarithm of an asset price, $p(t)$,

$$dp(t) = \mu(t)dt + \sigma(t)dW(t) + \kappa(t)dq(t), \tag{1}$$

where $\mu(t)$ is a drift process, $\sigma(t)$ is a stochastic volatility process, $W(t)$ is a standard Brownian motion and $q(t)$ is a pure jump process with intensity $\lambda(t)$ and jump size $\kappa(t)$.

The original RV estimator of Andersen and Bollerslev (1998) generates an estimate of total volatility for day t

$$RV_t(\Delta) \equiv \sum_{j=1}^{1/\Delta} r^2_{t+j\Delta,\Delta} \rightarrow \int_{t-1}^{t} \sigma^2(s)ds + \sum_{j=1}^{N_t} \kappa^2_{t,j} \tag{2}$$

where $r_{t+j\Delta,\Delta} = p(t) - p(t-\Delta)$ is a $\Delta-$period return with $1/\Delta$ number of intraday periods, N_t is the number of jumps and $\kappa_{t,j}$ is the $j-$th jump on day t.

It is widely acknowledged that RV is a more accurate and less noisy estimate of the unobserved volatility process than squared daily returns (see amongst others, Poon and Granger 2003). Barndorff-Nielsen and Shephard (2004) proposed a refinement to RV, realized bi-power variation (BPV) as an estimator of the continuous component of volatility even in the presence of jumps

$$BPV_t(\Delta) \equiv \mu_1^{-2} \sum_{j=2}^{1/\Delta} |r_{t+j\Delta,\Delta}||r_{t+(j-1)\Delta,\Delta}| \rightarrow \int_{t-1}^{t} \sigma^2(s)ds \tag{3}$$

where $\mu_1 = \sqrt{2/\pi}$. The difference between realized volatility and bi-power variation consistently estimates the contribution to total volatility from jump activity, $RV_t(\Delta) - BPV_t(\Delta) \rightarrow \sum_{j=1}^{N_t} \kappa^2_{t,j}$ as $\Delta \rightarrow 0$.

To select statistically significant jump contribution, as opposed to all jumps we employ the methodology of Huang and Tauchen (2005) and Andersen, Bollerslev and Diebold (2007). To begin, compute the Z statistic

$$Z_t(\Delta) \equiv \Delta^{-1/2} \frac{[RV_t(\Delta) - BPV_t(\Delta)]RV_t(\Delta)^{-1}}{[(\mu_1^{-4} + 2\mu_1^{-2} - 5)\max\{1, TQ_t(\Delta)BPV_t(\Delta)^{-2}\}]^{1/2}} \tag{4}$$

where $TQ_t(\Delta)$ is the tri-power quarticity[1].

Given a level of significance, α significant jumps are given by

$$J_{t,\alpha}(\Delta) = I_{t,\alpha}(\Delta)[RV_t(\Delta) - BPV_t(\Delta)] \tag{5}$$

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[1] An expression for $TQ_t(\Delta)$ can be found in Andersen, Bollerslev and Diebold (2007) or Giot *et al.* (2009)

where $I_{t,\alpha}(\Delta)$ is an indicator taking the value of one if $Z_t(\Delta) > \Phi_\alpha$, with Φ_α being the relevant critical value from the standard normal. To ensure that the continuous and jump components sum to total realized volatility, the continuous component is defined as

$$C_{t,\alpha}(\Delta) = [1 - I_{t,\alpha}(\Delta)]RV_t(\Delta) + I_{t,\alpha}(\Delta)BPV_t(\Delta). \tag{6}$$

Giot *et al.* (2009) examine the relationship between trading volume and frequency, and total RV along with both the continuous ($C_{t,\alpha}(\Delta)$ from equation 6) and jump components ($J_{t,\alpha}(\Delta)$ from equation 5). In contrast to Giot *et al.* (2009) we find that $J_{t,\alpha}(\Delta)$ is not significantly related to any of the variables considered, for values of α ranging from 0.9 to 0.995. Hence, we have not reported any results pertaining to the jump component below. The additional variables beyond those considered by Giot *et al.* (2009) relate to order book structure. The data upon which these variables are based, along with the volatility components will be described in the following section.

3 Data and variables of interest

This study is based on data pertaining to six of the largest stocks trading on the Australian Securities exchange. Two banking stocks, National Australia Bank (NAB) and Commonwealth Bank of Australia (CBA), two resource stocks, BHP Billiton (BHP) and Rio Tinto (RIO), QANTAS (QAN) are utilised. The period under consideration is 1 May 2009 to 30 April 2010, representing 253 trading days. For each of these days, all transaction and quote arrivals were obtained for each of the stocks. Quotes arrivals at the first five levels of the order book (both bid and ask sides) were obtained. Due to the market opening process, data is only collected after 10.10am for each trading day.

Mid-quote prices are computed (based on most recent quotes) at one-minute intervals throughout the trading day. These prices that are used to compute the total RV from equation 2, and its constituent continuous components from equation 6. To do so, prices and returns sampled at 15 minutes have been used. Subsequent empirical results are based on $\alpha = 0.99$ in the computation of C_t (dependence on α and Δ are suppressed from herein).

Simple total daily volume (*vol*) and number of trades (*ntrades*) are recorded for each stock. Daily order flow (*orflow*) was determined by the absolute value of the sum of volume of buy (positive) and sell (negative) volume where the direction of each trade was classified using the approach of Lee and Ready (1991). This is equivalent to the variable denoted as order imbalance by Giot *et al.* (2009). Beyond the variables reflecting trading activity, and following Pascual and Veradas (2010), a number of measures capturing the state of the order book are also considered.

The first variables are the displayed depth in the order book at the best bid (D^b) and ask (D^a) quotes. Next, depth beyond the best quotes is considered. Following Pascual and Veradas (2010) define this as the accumulated depth up to k ticks from the quote mid-point on both the bid ($D^b(k)$) and ask ($D^a(k)$) sides of the market. Order imbalance in the best quotes is given by $OI = |D^a - D^b|$, and beyond the best quotes, $OI(k) = |D^a(k) - D^b(k)|$. Depth and imbalance variables are taken as the average within each trading day.

Table 1 reports basic descriptive statistics for the market trading variables and volatility components respectively. RV and C_t obviously show very similar characteristics. BHP and RIO returns are somewhat more volatile than those of CBA and NAB. In all cases, there is a degree of positive skew associated with the volatility estimates. The next panels show that BHP has the highest combined volume and number of trades, with little association between the number of trades and volume across the other stocks in the sample. BHP also exhibits the greatest mean level, and volatility of order flow, with a great deal of positive skewness across all stocks. For each of the stocks, the depths at the best bid and ask quotes are very similar (BHP showing the greatest depth and RIO the least). This pattern shows that on average, the order book is balanced at the best quotes. Setting $k = 2$, shows that on average, the order book for each stock is less balanced than at the best quotes[2]. In all cases, OI and $OI(k)$ exhibit a degree of positive skewness.

4 Empirical analysis

We begin by examining the simple volume volatility relationship. In this case RV_t and C_t will be regressed against *vol*, *ntrades* and *orflow*. Parameters are estimated via OLS regression with Newey-West standard errors. To start, the relationship between the volume variables and the volatility components will be examined by estimating

$$RV_t \,\text{or}\, C_t = \alpha + \beta\, x_t + \varepsilon_t \tag{7}$$

where x_t represent *vol*, *ntrades* or *orflow*.

Results from these regressions are reported in Tables 2 for x_t given by *vol*, *ntrades* and *orflow* respectively. It is clear from the top two panels, that both total RV and the associated diffusion component, C_t exhibit significantly positive relationships with *vol* and *ntrades*. Overall, these results are consistent with Giot *et al.* (2009). While Giot *et al.* (2009) also find that *orflow* has a significant effect on volatility, the results reported here show that this is not the case for the stocks considered here.

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[2] Subsequent empirical results were also generated based on $k = 4$. Results remain unchanged.

	BHP	CBA	NAB	RIO
RV				
Mean	6.92×10^{-5}	1.06×10^{-4}	1.12×10^{-4}	9.92×10^{-5}
SDev	4.04×10^{-5}	5.57×10^{-5}	5.51×10^{-5}	5.93×10^{-5}
Skew	1.10	0.665	0.648	0.808
$C_{t,\alpha}(\Delta)$				
Mean	6.58×10^{-5}	9.96×10^{-5}	1.05×10^{-4}	9.30×10^{-5}
SDev	4.00×10^{-5}	5.31×10^{-5}	5.58×10^{-5}	5.80×10^{-5}
Skew	1.08	0.695	0.746	0.952
vol				
Mean	1.07×10^{7}	3.54×10^{6}	6.36×10^{6}	2.92×10^{6}
SDev	4.05×10^{6}	1.41×10^{6}	4.18×10^{6}	1.76×10^{6}
Skew	1.34	1.59	7.19	2.73
$ntrades$				
Mean	1.31×10^{4}	1.04×10^{4}	9.74×10^{3}	1.06×10^{4}
SDev	2.98×10^{3}	2.78×10^{3}	2.91×10^{3}	3.31×10^{3}
Skew	0.413	0.222	0.667	1.08
$orflow$				
Mean	8.35×10^{5}	3.71×10^{5}	6.25×10^{5}	3.38×10^{5}
SDev	1.01×10^{6}	5.09×10^{5}	7.54×10^{5}	5.28×10^{5}
Skew	3.48	5.14	4.84	6.55
D^b				
Mean	6.45×10^{3}	2.15×10^{3}	5.39×10^{3}	1.27×10^{3}
SDev	3.42×10^{3}	6.73×10^{2}	2.73×10^{3}	4.65×10^{2}
Skew	3.33	1.42	6.05	1.77
D^a				
Mean	6.97×10^{3}	2.12×10^{3}	5.68×10^{3}	1.49×10^{3}
SDev	4.10×10^{3}	7.38×10^{2}	2.94×10^{3}	6.52×10^{2}
Skew	4.15	2.33	5.47	2.84
OI				
Mean	7.11×10^{3}	2.18×10^{3}	4.93×10^{3}	1.56×10^{3}
SDev	3.83×10^{3}	6.85×10^{2}	2.24×10^{3}	5.28×10^{2}
Skew	3.47	2.23	5.35	1.37
$OI(k)$				
Mean	2.29×10^{4}	6.81×10^{3}	1.69×10^{4}	5.26×10^{3}
SDev	1.01×10^{4}	2.65×10^{3}	8.48×10^{3}	2.55×10^{3}
Skew	2.60	3.33	2.38	3.03

Table 1: Descriptive statistics for all variables.

	BHP	CBA	NAB	RIO
		$x_t : vol$		
RV_t				
$\widehat{\beta}$	0.0166	0.1475	0.0316	0.1083
t-stat	1.9312	4.7736	2.2253	3.7294
R^2	0.0276	0.1397	0.0574	0.1036
C_t				
$\widehat{\beta}$	0.0150	0.1389	0.0298	0.1121
t-stat	1.9034	4.8808	2.2626	4.0782
R^2	0.0232	0.1364	0.0498	0.1159
		$x_t : ntrades$		
RV_t				
$\widehat{\beta}$	0.5631	0.4139	0.8589	0.7409
t-stat	6.2448	1.8204	4.8194	5.7814
R^2	0.1721	0.0428	0.2052	0.1706
C_t				
$\widehat{\beta}$	0.5350	0.3505	0.7669	0.7583
t-stat	6.1342	1.8299	4.1629	6.4081
R^2	0.1584	0.0337	0.1599	0.1867
		$x_t : orflow$		
RV_t				
$\widehat{\beta}$	-0.0029	0.0037	0.0233	-0.0444
t-stat	-0.1455	0.0546	0.3572	-0.4797
R^2	0.0001	0.0000	0.0010	0.0016
C_t				
$\widehat{\beta}$	-0.0057	0.0085	0.0264	-0.0298
t-stat	-0.2921	0.1397	0.4137	-0.3010
R^2	0.0002	0.0001	0.0013	0.0007

Table 2: Regression results for x_t given by *vol* (top panel), *ntrades* (middle panel) and *orflow* (bottom panel). Both *vol* and *ntrades* are scaled by 1×10^6 and *ntrades* is scaled by 1×10^4

.

	BHP	CBA	NAB	RIO
RV_t				
$\widehat{\beta}_1$	-0.1627	-0.6772	0.2049	1.2399
t-stat	-1.1101	-1.0370	0.7820	0.8946
$\widehat{\beta}_2$	-0.2521	-1.4301	-0.4438	-2.3395
t-stat	-1.6159	-2.3102	-2.0035	-3.3870
R^2	0.1499	0.0563	0.0242	0.0411
C_t				
$\widehat{\beta}_1$	-0.1370	-0.9141	0.1158	1.2354
t-stat	-0.9345	-1.8253	0.4468	0.9010
$\widehat{\beta}_2$	-0.2640	-1.1632	-0.3990	-2.0846
t-stat	-1.6552	-2.1063	-1.6855	-3.0312
R^2	0.1457	0.0562	0.0266	0.0327

Table 3: Regression results for equation 8. Both D_t^b and D_t^a are scaled by 1×10^4.

In analysing the influence of the order book variables on volatility, we begin by estimating the following regression based on depth at the best quotes,

$$RV_t \,\mathrm{or}\, C_t = \alpha + \beta_1 \, D_t^b + \beta_2 \, D_t^a + \varepsilon_t. \tag{8}$$

The results from this regression for both total volatility and the continuous component are reported in Table 3. In virtually all cases, the coefficient on bid depth (β_1) for either RV_t or C_t are insignificant. However, the coefficient on ask depth (β_2) is significantly negative in most cases. Greater depth leads to lower volatility as greater trading volume can be executed with lower impacts on prices. This result indicates that the state of the ask side of the market is responsible for the greatest variation in volatility.

The role of order imbalance (asymmetry in the order book) is examined in the context of the following regression

$$RV_t \,\mathrm{or}\, C_t = \alpha + \beta_1 \, OI_t + \beta_2 \, OI(k)_t + \varepsilon_t. \tag{9}$$

Results from this regression are reported in Table 4. Given either RV_t or C_t, there appears to be little evidence to support the importance of OI, the imbalance at the best quotes. In this case, β_1 is only significant for BHP. However, imbalance at quotes beyond the best, $k = 2$, $OI(k)$ is found to be significantly negatively to related to both RV_t or C_t for all stocks. This is an interesting finding in that it reveals that when depth in the order book, further from the best quotes is heavily skewed toward either the buy or sell side volatility is lower on average. This indicates that heavier activity in either direction reduces volatility.

Finally, the role of the order book variables deemed to be significant above, D_t^a and $OI(k)$ are

	BHP	CBA	NAB	RIO
RV_t				
$\widehat{\beta_1}$	-0.0215	0.0160	0.0250	0.1642
t-stat	-2.8215	0.2715	0.8159	1.4145
$\widehat{\beta_2}$	-0.0087	-0.0364	-0.0192	-0.0670
t-stat	-3.0127	-2.2061	-3.1398	-4.2094
R^2	0.1513	0.0260	0.0587	0.0433
C_t				
$\widehat{\beta_1}$	-0.0204	-0.0086	0.0192	0.1925
t-stat	-2.7143	-0.1494	0.6083	1.6222
$\widehat{\beta_2}$	-0.0087	-0.0284	-0.0180	-0.0651
t-stat	-3.1584	-1.8960	-2.9089	-3.8929
R^2	0.1471	0.0222	0.0537	0.0398

Table 4: Regression results for equation 4. Both OI and $OI(k)$ are scaled by 1×10^3.

examined in the presence of the volume and trade frequency, *vol* and *ntrades*. This is achieved in the context of the following regression,

$$RV_t \,\text{or}\, C_t = \alpha + \beta_1\, vol_t + \beta_2\, ntrades_t + \beta_3\, D^a_t + \beta_4\, OI(k)_t + \varepsilon_t, \tag{10}$$

the results for these regressions are reported in Table 5. Given either RV_t or C_t, both *vol* and *ntrades* generally continue to be significant. Depth at the best ask quotes continues to be significant for only BHP and NAB. Order imbalance away from the best quotes, $OI(k)$ continues to be highly significant for across all stocks considered.

Overall, these results extend the findings of Jones, Kaul and Lipson (1994) and Chan and Fong (2006) and Giot *et al.* (2009) in showing that volatility is not only related to volume and frequency of trades but also to measures capturing the structure of the open limit order book. Volatility (and its associated diffusive component) is found to be significantly related to order imbalance away from the best quotes. Greater imbalance leads to lower volatility on average. Depth on the ask side of the market shows a similar effect, however it is somewhat less significant than order imbalance. In contrast to Giot *et al.*(2009), none of the variables considered here were found to be significantly related to the presence of jump activity.

5 Conclusion

From a theoretical perspective, movements in volatility are often linked to information arrival. Empirically, the relationship between volatility and volume has attracted a great deal of atten-

	BHP	CBA	NAB	RIO
RV_t				
$\widehat{\beta}_1$	0.0262	0.2044	0.0467	0.0493
t-stat	2.8715	3.8565	3.0583	1.4586
$\widehat{\beta}_2$	0.3436	-0.2310	0.6246	0.6266
t-stat	3.1376	-0.8660	3.4106	4.1002
$\widehat{\beta}_3$	-0.0105	-0.0127	-0.0143	-0.0186
t-stat	-2.9495	-0.9980	-3.3131	-1.1394
$\widehat{\beta}_4$	-0.3068	-2.2394	-0.5867	-2.1641
t-stat	-2.6232	-3.7988	-3.3603	-2.7006
R^2	0.3627	0.2464	0.3308	0.2513
C_t				
$\widehat{\beta}_1$	0.0244	0.2000	0.0517	0.0478
t-stat	2.5597	3.9223	3.3957	1.5019
$\widehat{\beta}_2$	0.3302	-0.2817	0.5029	0.6425
t-stat	2.9266	-1.2209	2.5951	4.5147
$\widehat{\beta}_3$	-0.0102	-0.0114	-0.0140	-0.0154
t-stat	-2.9903	-0.9269	-3.0887	-0.9194
$\widehat{\beta}_4$	-0.2959	-2.0690	-0.6397	-2.0063
t-stat	-2.4801	-3.6559	-3.8338	-2.5073
R^2	0.3425	0.2390	0.2933	0.2558

Table 5: Regression results for equation 10.

tion. Along with trading volume, trade frequency has been found to be significantly related to volatility in various studies. Giot, Laurent and Petitjean (2009) extend this literature by examining the link between trading volume and trade frequency and the components of total realized volatility. This paper presents a novel contribution to our understanding of the volume volatility relationship. It examines the role played by the structure of an open limit order book on volatility. It is found that at the best quotes, it is depth on the ask side of the market that is important. Not surprisingly, greater depth leads to lower volatility on average. It is also found that while order imbalance across the best quotes is not important, imbalance at quotes away from the best quotes is highly significant. This indicates that when market activity is heavily skewed in one direction volatility is on average lower. Overall, a number of variables capturing the state of the order book appear to be relevant for explaining variations in volatility, even in the presence of the traditional trading volume or frequency variables. An interesting future direction for research would be examine the importance of such variables for modeling very high frequency intraday movements in volatility.

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