The short-term mean reversion of stock price and the change in trading volume

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Abstract

This study aims to analyze the effect of change in trading volume on the short-term mean reversion of the stock price in the Korean stock market. Through the variance ratio test, this paper finds that the market shows the mean reversion pattern after 2000, but not before. This study also confirms that the mean reversion property is significantly reduced if the effect of change in trading volume is excluded from the return of a stock with a significant contemporaneous correlation between return and change in trading volume in the post-2000 market. The results appear in both the Korea Composite Stock Price Index and Korea Securities Dealers Automated Quotation. This phenomenon stems from the significance of the return response to change in trading volume *per se* and not the sign of the response. Additionally, the findings imply that the trading volume has a term structure because of the mean reversion of the trading volume and the return also has a partial term structure because of the contemporaneous correlation between return and change in trading volume. This conclusion suggests that considering the short-term impact of change in trading volume enables a more efficient observation of the market and avoidance of asset misallocation.

Keywords Trading volume, Granger causality, Variance ratio, Korean stock market, Contemporaneous correlation, Mean-reversion

Paper type Research paper

1. Introduction

If the market is efficient, stock prices fully reflect all available information and it is impossible to make economic profits by trading based on the information set (Fama, 1970; Malkiel, 1989). Therefore, stock prices follow the martingale process [1] and stock returns are not predictable. However, various studies have been conducted on the mean reversion of stock returns, which suggests that stock returns can be predictable. These findings are inconsistent with the efficient market hypothesis. Poterba and Summers (1988) observe that

the divergence between market and fundamental values will eventually be eliminated by speculative forces, causing the stock price to mean-revert. This correction of “erroneous” market movements leads to the argument that stock returns must be negatively correlated at some frequency. More recently, [Nagel \(2012\)](#) shows that individual stocks have a negative serial correlation at daily and even monthly frequencies. Therefore, a short-term reversal strategy that buys losers and sells winners over the prior days generates profits. The mean-reverting phenomenon is not US-specific. Earlier literature shows that mean-reverting stock index returns exist in the Korean stock market ([Lee, 2002](#); [Bae, 2006](#)).

However, earlier research mainly focuses on the return-generating process and trading volume level. Recent studies investigate another possible channel for the mean-reversion of stock returns: the change in trading volume. [Kang and Chae \(2019b\)](#) find that in addition to the relationship between the trading volume and stock return, the change in trading volume also has a separate contemporaneous correlation with stock returns (hereinafter, CCRV) in the Korean stock market. They also argue that the illiquidity premium hypothesis offers an appropriate explanation for this phenomenon. Specifically, increased liquidity simultaneously causes larger trading volume and higher prices because of lowered illiquidity premiums, thereby leading to a significant and positive CCRV. Furthermore, [Kang and Chae \(2019a\)](#) confirm the presence of mean reversion of the trading volume in the Korean market. These findings imply that trading volume has a term structure and through the CCRV channel, this term structure affects stock price movements.

This study sheds light on the role of trading volume change in stock price mean reversion. If the trading volume mean-reverts and has a significant contemporaneous correlation with stock returns, the return is predictable, conditional on the current trading volume. In other words, the stock return process reflects the mean reversion of the trading volume and implies that the price term structure is related to the trading volume term structure. Therefore, if we extract the return component orthogonal to the volume change effect, the component becomes more comparable to the martingale process. We use the variance ratio (VR) test to empirically investigate how CCRV-orthogonalized returns become closely comparable to the martingale process than the original returns.

Why is it important to examine how trading volume change affects the mean reversion of stock returns? The study on it has important implications for investors’ risk perceptions and asset allocations. If we do not consider the impact of volume change on stock returns, the return volatility may be misestimated according to the term length. Consequently, investors may misallocate their wealth to assets, leading to market inefficiency.

Our sample includes all stocks in the Korea Composite Stock Price Index (KOSPI) and Korea Securities Dealers Automated Quotation (KOSDAQ) from September 1987 to December 2017. First, we verify whether the volume change affects the return contemporaneously in the Korean stock market. Consistent with [Kang and Chae’s \(2019b\)](#) findings, the distribution of CCRV in our sample shows that most stocks have positive and significant CCRV. In total, 74% of stocks have positive CCRV and 11% of stocks have negative CCRV at the 10% significance level. Only 15% of the stocks had insignificant CCRV. This result does not change in the sub-periods and the different exchanges, indicating that the mean-reversion of trading volume affects the stock price mean reversion through the CCRV channel. Based on this implication, we hypothesize that CCRV-orthogonalized returns are more comparable to random walks.

Next, we analyze our hypothesis using the VR test following [Lo and MacKinlay \(1988\)](#) and [Poterba and Summers \(1988\)](#). If we remove the CCRV effects on stock returns, the stock returns are closer to the martingale process, leading to the VR of CCRV-orthogonalized

returns being closer to 1 than the original stock returns. Our empirical results support this prediction. The differences in the average VRs between CCRV-orthogonalized returns and original stock returns are significantly positive and increase as the test horizon becomes longer. For example, the difference in the average VRs of 10-day to 5-day between CCRV-orthogonalized returns and original returns is 0.0017 (t -values: 4.12), but the difference in the average VRs of 100-day to 5-day increases to 0.01 (t -values: 21.91).

For robustness, we conduct a subsample analysis to examine whether the effect changes in the different subsamples. First, we divide the entire sample into two groups as of 2000. As earlier literature notes that the 1997 currency crisis had a severe impact on the Korean economy, stock returns after the crisis behave quite differently from before and the mean reversion phenomenon of stock returns may have changed. Our subsample results also show structural changes in the stock return behavior. In the first half of the sample, all VRs are greater than 1, indicating mean aversion. This result is consistent with Bae (2006), which finds that the KOSPI shows a mean aversion phenomenon. However, in the second half of the sample, we find that stock returns show mean reversion. Bae (2006) suggests that this change contributes to an increase in foreign and institutional investors who pursue long-term investments. In both subsamples, the VRs of CCRV-orthogonalized returns are always greater than those of the original returns, consistent with the main result.

Second, stocks in the KOSPI and KOSDAQ markets have different characteristics such as investor and industry composition. Therefore, it is necessary to conduct VR tests separately in each market. However, the evidence shows no significant difference.

Finally, we also investigate whether both the significance and sign of the CCRV variable affect the results. We find that VR increases when we eliminate the volume effect of CCRV in stocks with both positive and negative CCRV. However, securities with insignificant CCRV do not show a significant change in the VR value, even after the volume effect of the CCRV is eliminated. The result suggests that regardless of its sign, the significance of CCRV plays a role in increasing the short-term variance in stock returns.

Overall, our empirical evidence supports the hypothesis that stock returns are affected by the volume change through the CCRV channel. Therefore, if we eliminate the volume change effect on stock returns, the stock returns become closely comparable to the martingale process. This evidence suggests that the mean reversion of trading volume affects the variance of short-term and long-term returns differently. Thus, we need to consider the volume effect on short-term stock returns to avoid asset misallocation.

The remainder of this paper is organized as follows. Section 2 summarizes previous studies. Section 3 describes the data and methodology. Section 4 presents our empirical results. Section 5 presents the results of robustness tests. Section 6 concludes.

2. Literature review

Our work builds on long-lasting literature on the mean reversion of stock returns. Tversky and Kahneman (1974) argue that a representativeness heuristic inclines people to overreact to new information. Many studies show that investor sentiment causes prices to swing away from the true value in the financial market (De Bondt and Thaler, 1985, 1987; Shefrin and Statman, 1985; De Long *et al.*, 1990; Lehmann, 1990). If market values diverge from fundamental values, speculative forces may eliminate the difference, leading to a negative serial correlation in stock returns (Poterba and Summers, 1988). Fama and French (1988) also describe how long-horizon returns lead to predictability because of slowly decaying price components. They note that the long-term mean reversion of stock returns is consistent with two alternate explanations: overreaction by irrational investors or time-varying equilibrium expected returns in an efficient market.

Some research has challenged the evidence of stock return mean reversion based on the test methodology. [Richardson and Stock \(1989\)](#) show that small-sample bias correction provides evidence for the mean reversion in long-horizon returns of the NYSE index and size decile portfolios. Using US data, [McQueen \(1992\)](#) argues that the general least square (GLS) randomization test does not reject the random walk of returns for horizons of 1 to 10 years. [Jegadeesh \(1991\)](#) also provides evidence against mean reversion by noting that the mean reversion phenomenon is concentrated only in January. A similar result is also observed in the market index of the London Stock Exchange. However, other studies support the mean-reverting phenomenon with more powerful panel methods or new data. [Balvers et al. \(2000\)](#) use a more robust test with annual panel data from 18 countries and find the mean reversion of index returns with a reversion speed of 18 to 20% per year. [Gropp \(2004\)](#) uses a panel method and discovers the mean reversion for the NYSE, AMEX and NASDAQ. More recently, [Mukherji \(2011\)](#) shows that mean reversion persists for small company stocks in one-, four- and five-year returns. [Cecchetti, Lam and Mark \(1990\)](#) described how the desire for consumption smoothing leads to negative autocorrelations without overreaction.

The mean reversion evidence varies across investment horizons and whether the focus is on the index or individual stocks. [Sims \(1980\)](#) argues that systematic short-term variations in fundamental values should be negligible in a competitive market. Therefore, price should follow a martingale process over brief time intervals, even if stock returns include a component that varies predictably over the long horizon. Early studies focus on the long-run mean reversion of stock index returns. Using the VR test, [Poterba and Summers \(1988\)](#) show that the S&P composite stock index has a long-term negative correlation but a short-term positive correlation because of the transitory component in stock returns. [Fama and French \(1988\)](#) also show that size and industry portfolio autocorrelations are weak for daily and weekly holding periods. Temporary components account for 40% of the predictable price variation of three- to five-year returns for small firms and 25% for large firms. However, stock index returns have a positive autocorrelation in the short horizon such as weekly or monthly, especially for small stocks. [Lo and MacKinlay \(1988\)](#) suggest that this result is mainly attributed to small firms and is not entirely explained by time-varying risk premiums and infrequent trading. [Lo and MacKinlay \(1990\)](#) describe further how despite negative autocorrelation in individual stock returns, weekly portfolio returns are strongly positively auto-correlated and result from important cross-autocorrelation. [Nagel \(2012\)](#) shows that individual stocks still have small negative autocorrelations daily, weekly and monthly. A positive high-frequency autocorrelation of the index declines and has even been negative in recent years ([Campbell, 2017](#), p. 162).

There have been few studies of mean reversion in the Korean market. [Lee \(2002\)](#) finds that the KOSPI's daily returns revert to the mean by using a fractionally integrated process. [Bae \(2006\)](#) also shows that the KOSPI and KOSDAQ's monthly returns followed a weak mean-reverting process after the 1997 currency crisis. Our study focuses on short-term reversion in individual stock returns and suggests this phenomenon as a possible factor.

We also extend the literature on the relationship between abnormal trading volumes and stock returns. One pillar of research shows that heterogeneity in investment environments causes abnormal trading volumes. As this heterogeneity is resolved by trading between investors from different backgrounds, the abnormal trading volume decreases and the price becomes stable. Therefore, abnormal trading volume *per se* does not affect future returns. The differences in investment environments arise because of asymmetric information among investors ([Wang, 1994](#); [Llorente et al., 2002](#); [Tetlock, 2010](#)), differences in opinion among traders ([Harris and Raviv, 1993](#); [Kandel and Pearson, 1995](#); [Garfinkel and Sokobin, 2006](#)) and irrational behavior by investors ([Campbell et al., 1993](#); [Odean, 1998](#); [Scheinkman](#)

and Xiong, 2003; Baker and Stein, 2004; Grinblatt and Han, 2005; Statman Thorley and Vorkink, 2006; Choi *et al.*, 2010).

Another pillar suggests that abnormal trading volumes and market frictions affect stock returns. According to the investor recognition hypothesis (Miller, 1977; Mayshar, 1983; Merton, 1987), stocks can be overvalued when a market has short-selling constraints. In particular, Odean and Barber (2009) argue that salient events affecting a stock such as unpredicted news, rapid price changes or unusual trading volumes, increase investors' buying and selling demand. However, increased selling demand is not activated because of short-selling restrictions. Therefore, these events create net buying demand and higher returns on average. Gervais *et al.* (2001) suggest the visibility hypothesis that a sharp increase in trading volumes would attract investors' attention to the stock, resulting in net buying pressure and, thus, in stock price increases. They find evidentiary support for this hypothesis that future returns with high trading volumes are significantly higher than those with low trading volumes. Kaniel *et al.* (2012) also show consistent results for stock markets across 41 countries.

Earlier research on stock returns and trading volumes in the Korean stock market has mainly focused on the causality test between these two variables. As for the stock index, various studies find that index returns are positively correlated with both trading volumes and changes in trading volumes (Chung, 1987; Kho, 1997; Silvapulle and Choi, 1999; Kim and Kim, 1996; Chang, 1997). However, Lim (2016) finds that using the TGARCH model, the change in the KOSPI trading volume is affected by the return but not vice versa.

In a study on the relationship between trading volume and individual stock returns, Lee (2009) shows that using GARCH and regression methods, large and medium-sized stocks in the KOSPI market positively correlate and have a two-way Granger causal relationship with trading volumes. Small stocks, however, do not show a simultaneous relationship but only a Granger causal relationship. Eom (2013) uses the VAR model of the KOSDAQ stock to show that both past individual stock and market returns have a positive relationship with current trading volumes. Using the TGARCH and EGARCH models, Jheon and Park (2014) show a simultaneous correlation between trading volumes and returns in the KOSDAQ market. They also show that the degree of correlation between trading volumes and previous trading volumes depends significantly on the size of the stock. Finally, Lee *et al.* (2015) use the variance decomposition method to represent a more significant impact of the return on trading volume than the opposite.

In a study of the relationship between the change in trading volume and returns, Jinn *et al.* (1994) show that changes in the trading volume positively correlate with the return. Kook and Jung (2001) find that while an increase in past trading volume is likely to reverse the current return sign, the decrease continues the return trend. Kang and Chae (2019b) note that the CCRV of most stocks in the Korean market is significantly positive and the CCRV accounts for 4.22% of the total volatility of stocks. Furthermore, they argue that the liquidity premium hypothesis supports positive CCRV in the Korean market. Our study does not focus on the relationship between trading volume and returns but sheds light on how the trading volume change affects the short-term mean reversion of stock returns through the CCRV channel.

Among the studies on the relationship between abnormal trading volumes and stock returns, certain studies investigate how trading volumes positively affect the mean reversion of stock returns. Campbell *et al.* (1993) argue this relationship theoretically. According to their model, noisy trading causes price movements, but those movements are reverted when absorbed by liquidity providers. Further, the model assumes that such noisy

trading is followed by high trading volume, while informed trading is not. The model implicitly assumes a downward-sloping demand curve and not a perfectly elastic demand curve. This assumption allows the price to be affected by trading volume. Empirically, [Conrad et al. \(1994\)](#), based on a sample of NASDAQ stocks, find that high trading activity increases with reversal profitability. [Avramov et al. \(2006\)](#) show that the weekly or monthly negative autocorrelation of an individual stock, measured by a profit of contrarian strategy, is stronger for firms with high trading volume and high illiquidity. However, our study focuses on the impact of change, instead of the level of trading volume, on the mean-reversion of stock returns through the CCRV channel suggested by [Kang and Chae \(2019b\)](#). Mean-reversion of trading volume can affect the returns when a stock has significant CCRV. Therefore, if we eliminate volume effects from returns, the short-term mean-reversion phenomenon in stock returns can be partially mitigated. This point is an additional aspect that differentiates this study from previous ones. Furthermore, to the best of our knowledge, this study is the first to investigate the relation between trading volume and mean reversion in the Korean stock market.

3. Data and methodology

3.1 Methodology

This study mainly argues that the mean reversion of stock prices is overestimated by responding to the trading volume change. [Kang and Chae \(2019b\)](#) show that daily volatility caused by trading volume change in the Korean stock market, on average, accounts for about 4% of the total daily volatility. However, as [Kang and Chae \(2019b\)](#) have stated, the volatility caused by the volume change will disappear in the long run because the trading volume mean-reverts and the price changes resulting from the change in trading volume will be restored to the original position. Therefore, [Kang and Chae \(2019b\)](#) also argue that it is desirable to consider the effect of the trading volume change on the return when estimating future prices based on current information. A stock return can be decomposed into the induced return by the change in trading volume and fundamental return. [Figure 1](#) shows the concept for this argument. [Figure 1\(a\)](#) represents the fundamental return path of a stock, [Figure 1\(b\)](#) presents the return movements induced by trading volume change and [Figure 1\(c\)](#) is the original return path, which is the sum of [Figures 1\(a\)](#) and [1\(b\)](#).

If we assume that the fundamental return path follows the Wiener process, for $t < T$, the relation between the short-term return volatility $\sigma_f(t)^2$ and the long-term return volatility $\sigma_f(T)^2$ can be expressed as $\sigma_f(t)^2/t = \sigma_f(T)^2/T$. In contrast, the relation between long- and short-term volatility observed in a separate CCRV induced return path, which has negative autocorrelation caused by mean-reversion of trading volume and CCRV, can be expressed as $\sigma_{CCRV}(t)^2/t > \sigma_{CCRV}(T)^2/T$. Therefore, the long-term original return volatility $\sigma(T)^2/T = \sigma_f(T)^2/T + \sigma_{CCRV}(T)^2/T$ is less than $\sigma(t)^2/t = \sigma_f(t)^2/t + \sigma_{CCRV}(t)^2/t$ and $\sigma(T)^2/T < \sigma(t)^2/t$ holds. As short-term volatility is more affected by CCRV-induced components having negative autocorrelation than long-term volatility, a short-term structural mean-reversion in price is observed. To confirm this, we conduct the following process.

First, we extract the effect of change in trading volume from the original return path to compare the mean reversion phenomenon in the original return with that in the CCRV-orthogonalized return. We construct CCRV-orthogonalized time-series returns for each stock by using the following regression specification:

Figure 1.
Return path
decomposition

Notes: (A) Fundamental return path; (b) Induced return path by CCRV;
(c) Original return path

$$r_{i,t} = a_i + \beta_i \Delta V_{i,t} + \varepsilon_{i,t}, \quad (1)$$

where $\Delta V_{i,t}$ is defined as the change in log volume turnover of stock i at time t . We use $\varepsilon_{i,t}$ s as CCRV-orthogonalized stock returns. Significant β_i implies that the return of stock i is affected by the trading volume change.

Next, we compare the mean reversion of original returns with that of CCRV-orthogonalized returns using the VR test following [Lo and MacKinlay \(1988\)](#) and [Poterba and Summers \(1988\)](#) [2]. The test is based on the fact that the stock variance should be proportional to the return horizon if the returns follow a random walk. We examine the variance of returns at different horizons relative to the variance over the base interval. For daily returns, the VR statistics are, therefore:

$$VR_l(k) = \frac{\text{var}(r_t^k)}{k} / \frac{\text{var}(r_t^l)}{l}, \quad (2)$$

where $r_t^\tau = \sum_{i=0}^{\tau-1} r_{t-i}$, t is the test interval and l is the base interval. When conducting the VR test for the CCRV-orthogonalized returns, we substitute r_t with ε_t .

If daily returns do not have serial autocorrelations through time, the $VR_l(k)$ statistics should converge to 1. However, if daily returns are autocorrelative, $VR_l(k)$ varies depending on the sign of autocorrelation and the length of the test interval. If a positive (negative) autocorrelation exists in the daily returns, $VR_l(k)$ is greater (less) than one and increases (decreases) as k increases.

We set the base interval, l , as five days [3] and the test interval, k , to 1, 10, 20, 30, 50 and 100 days to calculate the VR statistics for short-, mid- and long-term test intervals. We compute two VR statistics for each test interval using the original and CCRV-orthogonalized returns and compare these statistics. If both VR values are less than 1, but the VR value from CCRV-orthogonalized returns is greater than that from the original stock returns, the mean reversion phenomenon of stock returns is weakened after excluding the volume effects. We suggest that CCRV-orthogonalized returns are more comparable to random walks.

3.2 Data

Our sample covers all common stocks listed on the KOSPI and KOSDAQ from September 1, 1978 to December 31, 2015. We exclude ETNs, ETFs, REITs, SPACs, KDRs, preferred stocks and common stocks with less than one year of stock returns. We obtain stock information from FnDataGuide.

4. Empirical analysis

4.1 Distribution of contemporaneous correlation between return and change in trading volume

We eventually show that the stock price's mean reversion phenomenon in the CCRV-orthogonalized returns becomes weaker than that in the original returns. However, before conducting this discussion, we first need to verify whether the volume change affects the return contemporaneously. Although Kang and Chae (2019b) show the Korean stock market's result, it is applied to each stock each year. As our analysis is performed without year-by-year classification, it is essential to reaffirm the volume effect on the price for each level. Therefore, we use equation (1) as a regression specification to estimate β_i , which refers to the sensitivity of returns to volume changes. Figure 2 shows the histogram of the t -values of the estimated β_i and Panel A in Table 1 shows the overall distribution of the estimated β_i .

Figure 2 shows that stocks with significantly positive CCRV (located on the right side of t -values 1.645 on the x-axis) are the majority, while stocks with significantly negative CCRV (located on the left side of t -values -1.645 on the x-axis) are the minority. Panel A in Table 1 represents the supporting result that the positive CCRV stocks account for 74% of the total, while the negative CCRV stocks account only for 11%. These findings are consistent with those of Kang and Chae (2019b). This panel also describes the results for the sub-period before and after 2000 and for the KOSPI and KOSDAQ markets after 2000. These sub-sample results are not different from those in the entire sample, except that the proportion of negative CCRV stocks decreases to approximately 7% before 2000. The fact that more than 80% of stocks in our sample have significant CCRV indicates that the returns of most stocks are affected by trading volume changes.

In addition, we analyze the difference in characteristics of the significant and insignificant CCRV stocks. First, we classify each stock's size, Be/Me ratio and return volatility into 10 groups each year, assigning one to the smallest group and 10 to the largest group by sequentially increasing them. Additionally, stocks belonging to KOSPI are assigned 0 and stocks belonging to KOSDAQ are assigned 1 to distinguish the exchanges. Panel B in Table 1 shows the statistics for the group numbers calculated through this process. We then apply the daily Carhart model (Carhart, 1997) to calculate the adjusted- R^2 and alpha of each stock. Panel B also reports the statistics for these results. Significant CCRV stocks have a larger size and less volatility than insignificant CCRV stocks. Further, adjusted- R^2 and alpha of Significant CCRV stocks are also significantly higher. However,

Notes: This figure shows the overall distribution of the significance of CCRV in the Korean stock market. The CCRV signifies the contemporaneous correlation between return and change in trading volume. To estimate the CCRV, we regress the daily return of each stock by the stock's change in daily turnover. We interpret the estimated t-values of the variable as the significance of the CCRV

Figure 2.
CCRV distribution
(histogram)

the difference in size is only 1.24 and considering the dispersion of standard deviation within each group, it may be unreasonable to consider size as a major determinant of the significance of CCRV [4]. This evidence is also applicable for adjusted- R^2 and alpha.

4.2 Contemporaneous correlation between return and change in trading volume effect on mean reversion of stock return

4.2.1 Determination of the base interval for variance ratio test. As we have seen in Section 4.1, our sample confirms that most shares are affected by a change in trading volume. For stocks with significant CCRV, $\beta_i \Delta V_{i,t}$ in equation (1) operates as a determinant factor for the stock return to explain the discrepancy between the original return, $r_{i,t}$ and the CCRV-orthogonalized return, $\varepsilon_{i,t}$. Therefore, in this section, we demonstrate that using the VR test, these stocks have significant mean reversion differences between CCRV-orthogonalized and original returns.

Before we proceed with the VR test, it is necessary to select the base interval in equation (2). As described in Section 3.1, stock returns and variances are measured at frequencies of 1, 5, 10, 20, 30, 50 and 100 days. In measuring variance, we exclude data with fewer than 20 consecutive observations. The left side of Table 2 shows the statistics of the estimated variances and the right side displays the return variance scaled by the interval for comparison between the results of each interval.

Panel A shows the entire sample result. The average variances scaled by each interval peak at 0.00205 for the test interval of one day and gradually decreases to 0.00158 as the test

Panel A. CCRV distribution					Short-term mean reversion of stock price <div>199</div>			
Sample	$t > 1.645$	$ t < 1.645$	$t < -1.645$	Total				
Whole sample	1,838	386	275	2,499				
(1987~2015)	(73.55%)	(15.45%)	(11.00%)					
1987~1999	765	183	82	1,030				
	(74.27%)	(17.77%)	(7.96%)					
2000~2015	1,717	355	286	2,358				
	(72.82%)	(15.06%)	(12.13%)					
KOSPI(2000~)	683	137	109	929				
	(73.52%)	(14.75%)	(11.73%)					
KOSDAQ(2000~)	1,034	219	177	1,430				
	(72.31%)	(15.31%)	(12.38%)					
Panel B. Characteristics according to the significance of CCRV								
Variables	Significant CCRV			Insignificant CCRV			Difference	
	N.OBS	Mean	SD	N.OBS	Mean	SD	Mean	t -value
Size	29,544	5.642	2.838	3,302	4.405	2.838	1.24	23.69
Be/me	29,544	5.326	2.897	3,302	5.327	2.897	0.00	-0.02
Std(rt)	29,544	5.484	2.831	3,302	5.732	2.831	-0.25	-4.32
Exchange	2,289	0.516	0.500	409	0.521	0.500	0.00	-0.18
Adj. R^2 (Carhart4)	2,289	16.41%	8.99%	409	11.62%	8.99%	4.79%	7.73
Alpha (Carhart4)	2,289	0.00%	0.13%	409	-0.05%	0.13%	0.05%	3.93
<p>Notes: Panel A shows the distribution of CCRV in the Korean stock market from 1987 to 2015. CCRV indicates the contemporaneous correlation between return and change in trading volume. To estimate CCRV, we regress the daily return of each stock by the stock's change in daily turnover. We estimate the t-values of the coefficients on the change in trading volume. CCRV estimation is also adopted for the sub-period samples before 2000 and after 2000 and for KOSPI and KOSDAQ. Based on the level of t-values as the classification standard, each cell reports the number of observations above the parentheses and the proportion within the parentheses. Panel B reports the characteristic distribution of CCRV according to the size, be/me ratio, return standard deviation, exchange, adjusted R^2 and risk-adjusted return. For size, be/me and return standard deviation, we classified stocks into 10 groups for each year. The lowest groups are assigned values of one and the highest groups are assigned values of 10 in an increasing sequence. For stock exchanges, a stock that belongs to KOSPI is assigned zero value and a stock that belongs to KOSDAQ is assigned values of one. The values reported for size, be/me, standard deviation and exchange are for those number of groups. For adjusted R^2 and risk-adjusted return, the values are estimated based on the daily Carhart (1997) four-factor model under the Dimson (1979) regression methodology with one-day lead-lag variables</p>								

Table 1.
CCRV distribution

Table 1.
CCRV distribution

interval increases to 100 days. Panel B represents the result of significant CCRV stocks. The average return variance/interval is 0.00207 for the one-day interval, similar to that in Panel A, but peaks at 0.00224 for the five-day interval. Then, it gradually declines to 0.00169 for the 100-day return. This difference is caused by approximately 400 stocks with insignificant CCRV, excluded from the sample in Panel B. This result is consistent with the prediction in Figure 1 that greater variance will be observed in stocks significantly affected by trading volume changes. Return variance/interval of stocks with significant CCRV is maximized at the five-day test interval because, as demonstrated by Kang and Chae (2019a), the abnormal trading volume is halved in two to three days; thus, most of the variance enhanced by the trading volume change disappears in five days. Based on these results, we determined five days as the base interval, l , in equation (2).

Additionally, Panel C provides the result for CCRV-orthogonalized return. Comparing the results in Panel B and Panel C, we confirm that CCRV-orthogonalization decreases the return variance. This result may be expected because the Panel B and Panel C samples are composed

Interval	n	Return variance		Return variance/interval	
		Average	Std.err	Average	Std.err
<i>Panel A. Whole sample</i>					
1	2,473	0.00205	0.00005	0.00205	0.00005
5	2,452	0.00942	0.00014	0.00188	0.00003
10	2,434	0.01853	0.00029	0.00185	0.00003
20	2,388	0.03692	0.00059	0.00185	0.00003
30	2,350	0.05422	0.00093	0.00181	0.00003
50	2,223	0.08794	0.00155	0.00176	0.00003
100	1,830	0.15779	0.00267	0.00158	0.00003
<i>Panel B. Significant CCRV stocks</i>					
1	2,102	0.00207	0.00006	0.00207	0.00006
5	2,090	0.01120	0.00030	0.00224	0.00006
10	2,085	0.02091	0.00050	0.00209	0.00005
20	2,045	0.03880	0.00082	0.00194	0.00004
30	1,999	0.05736	0.00122	0.00191	0.00004
50	1,841	0.09011	0.00167	0.00180	0.00003
100	1,429	0.16861	0.00336	0.00169	0.00003
<i>Panel C. CCRV-orthogonalized return within significant CCRV stocks</i>					
1	2,102	0.00200	0.00005	0.00200	0.00005
5	2,090	0.01083	0.00027	0.00217	0.00005
10	2,085	0.02045	0.00047	0.00204	0.00005
20	2,045	0.03827	0.00081	0.00191	0.00004
30	1,999	0.05655	0.00121	0.00189	0.00004
50	1,841	0.08903	0.00167	0.00178	0.00003
100	1,429	0.16716	0.00336	0.00167	0.00003

Table 2.
Statistics for return
variance

Notes: This table shows the estimated return variance on the left and the return variance scaled by the interval for comparison between each interval on the right. Panel A reports the full sample result. Panel B shows the result for the significant CCRV stock sample. Panel C shows the results for CCRV-orthogonalized return. Std.err stands for the standard error

of significant CCRV stocks. However, it contains more information. As shown in the return variance/interval column, the proportion of decrement for each interval is different. The proportion decreases gradually as the interval increases. This evidence implies that the CCRV effect is relatively stronger on short-term prices.

These results have important implications for option pricing. One of the most important requirements for option pricing and hedging is the volatility estimation of the forward price. Options are often traded through the over-the-counter (OTC) market for hedging the existing portfolios, stock grants and product development for customers. For options that are not traded in such a market, implied volatility cannot be used for volatility estimation, and therefore, it relies heavily on historical volatility. As shown in Panel C of [Table 2](#), if the long-term forward price volatility is estimated based on the short-term historical return, the long-term volatility of significant CCRV stock can be over-estimated. In this case, because of the convexity of the options price, a small error in volatility estimation may cause a large error in the options price [\[5\]](#). In addition, volatility misestimation also affects Greeks, causes errors in the hedging ratio, increases book management costs and may also affect risk management. As described above, misestimation of volatility has important implications in dealing with derivatives. Therefore, the forward prices' volatility from historical returns must be estimated carefully.

4.2.2 Variance ratio test. In this section, we compare the mean reversion in original stock returns with that in CCRV-orthogonalized returns. Table 3 presents the results of the VR test for each test interval. First, column (a) shows that the average of VR (1) in the whole sample is 1.0669, which is significantly greater than 1. This result suggests that the variance of the five-day return is less than five times that of the unit-day return because of a negative autocorrelation between one-day returns within five days.

On the other hand, VR (10) to VR (100) are significantly smaller than 1 and monotonically decrease as the test interval increases. This evidence indicates a negative autocorrelation between the unit-day returns, even for longer than 10 days. The evidence suggests that, overall, the mean reversion of stock returns exists across all test intervals.

Unlike the results for the whole sample, the original returns of significant CCRV stocks have different results for VR (1). The mean of VR (1) is 0.9548, which is significantly less than 1. This evidence shows that positive autocorrelations exist between one-day returns within a base interval of five days. On the other hand, for the test intervals of more than 10 days, all VR values are significantly less than 1 and monotonically decrease as the test interval increases, consistent with results for the whole sample. The original return of significant CCRV stocks shows momentum for a short period of fewer than five days and reversal for a more extended period.

CCRV-orthogonalized returns show similar results in most cases to the original returns of stocks with significant CCRV. All test values of VR (1) through VR (100) are significantly less than 1. In other words, even CCRV-orthogonalized returns present momentum for shorter periods of less than five days and reversal for longer periods.

Despite similar VR values between the original return and CCRV-orthogonalized returns, we should pay attention to the change in VR values. The last column (d) indicates that the VRs of the CCRV-orthogonalized return in all test intervals except VR (1) is significantly greater than those of the original return. If we consider the average half-lives of abnormal trading volumes in the Korean stock market, five days may be insufficient for the trading

VR(interval)	Significant CCRV sample									
	(a) Whole sample			(b) Original return			(c) CCRV-Orthogonalized return		(d) Difference: (c) – (b)	
	<i>n</i>	Average	Std.err	<i>n</i>	Average	Std.err	Average	Std.err	Average	<i>t</i> -value
VR(1)	2,452	1.0669	0.0146	2,090	0.9548	0.0063	0.9542	0.0049	–0.0006	–0.22
VR(10)	2,434	0.9614	0.0026	2,085	0.9626	0.0030	0.9642	0.0030	0.0017	4.12
VR(20)	2,388	0.9625	0.0041	2,045	0.9500	0.0045	0.9535	0.0045	0.0035	7.23
VR(30)	2,350	0.9354	0.0052	1,999	0.9376	0.0054	0.9425	0.0054	0.0049	11.14
VR(50)	2,223	0.9373	0.0061	1,841	0.9252	0.0061	0.9320	0.0062	0.0068	16.94
VR(100)	1,830	0.8788	0.0076	1,429	0.9116	0.0084	0.9216	0.0084	0.0100	21.91

Notes: This table shows the variance ratios for Korean daily data between 1987 and 2015. Calculations are based on the daily return for each stock. The variance-ratio statistics is defined as $VR(k) = (5/k) * var(R^k) / var(R^1)$, where R^k denotes returns over a k -day measurement interval. Average indicates the average of variance ratios for each stock within the given group. Std.err stands for the standard error. n is the number of observations. This table contains the whole sample result, the results for the original return of significant CCRV stocks and the results for CCRV-orthogonalized return of significant CCRV stocks. The CCRV-orthogonalized return signifies the regression residual of the daily return on change in daily turnover. This table also reports the difference between the variance ratios of CCRV-orthogonalized return and original return

Table 3.
Variance ratios for
Korean daily data,
1987–2015

volume shock to disappear. As a result, the abnormal volume-induced returns do not disappear in five days. This hypothesis is consistent with the evidence that there is no difference in VR (1) between the original and CCRV-orthogonalized returns. Meanwhile, VR (10) to VR (100) in column (d) indicate that mean reversion of CCRV-orthogonalized returns is weaker for the test intervals of more than 10 days. These findings suggest that the market can be more efficient if we eliminate the short-term price impact of trading volume changes [6].

In addition to the above analysis, we conduct VR tests for each sub-period by dividing the entire sample period since 2000 into two. Bae (2006) demonstrates that the KOSPI shows momentum before the financial crisis but changes to mean reversion subsequently. The KOSDAQ index also presents mean reversion after the financial crisis. A sub-period analysis is necessary to investigate whether these results persist, even in short-term returns of individual stocks, not the index. Moreover, with a sub-period analysis, we examine how volatility in the original and CCRV-orthogonalized returns of stocks with signature CCRV varies over time.

Panel A of Table 4 shows the sub-period result from 1987 to 1999, which is quite different from Table 3. All values of VR (10) to VR (100) are significantly greater than 1 for both the entire sample and significant CCRV stocks. This result implies that stock prices do not show a short-term mean-reversion pattern [7]. Meanwhile, Panel B of Table 4 shows the sub-period result after 2000, similar to Table 3. Among them, in the results of the whole sample, the values of VR (10) to VR (100) are less than 1, which is consistent with Bae (2006), who argues that stock prices revert to the mean after the 1997 currency crisis. Likewise, in both

Significant CCRV sample										
(c) CCRV-										
orthogonalized										
(d) Difference:										
(c) – (b)										
(a) Whole sample										
(b) Original return										
VR(interval)	n	Average	Std.err	n	Average	Std.err	Average	Std.err	Average	t-value
Panel A. Sub-period sample 1987~1999										
VR(1)	1,029	0.8734	0.0174	846	0.8424	0.0052	0.8433	0.0053	0.0010	1.82
VR(10)	1,026	1.0240	0.0051	842	1.0072	0.0049	1.0102	0.0049	0.0031	5.18
VR(20)	968	1.0673	0.0091	796	1.0575	0.0090	1.0626	0.0090	0.0051	9.05
VR(30)	914	1.0061	0.0126	746	1.0534	0.0122	1.0608	0.0122	0.0073	12.51
VR(50)	820	1.1096	0.0154	633	1.0445	0.0128	1.0556	0.0129	0.0111	15.36
VR(100)	626	1.0082	0.0157	581	1.0320	0.0162	1.0478	0.0163	0.0158	17.37
Panel B. Sub-period sample 2000~2015										
VR(1)	2,311	1.1146	0.0159	1,980	0.9923	0.0082	0.9878	0.0058	-0.0045	-1.26
VR(10)	2,293	0.9429	0.0027	1,975	0.9349	0.0034	0.9368	0.0033	0.0019	3.65
VR(20)	2,230	0.9314	0.0038	1,921	0.9118	0.0047	0.9166	0.0046	0.0048	7.63
VR(30)	2,178	0.9017	0.0047	1,854	0.9139	0.0054	0.9197	0.0054	0.0058	10.53
VR(50)	2,025	0.8757	0.0056	1,663	0.8743	0.0061	0.8809	0.0061	0.0066	13.84
VR(100)	1,614	0.8125	0.0067	1,254	0.8155	0.0083	0.8252	0.0084	0.0097	19.89

Notes: This table shows the variance ratios for Korean daily data in the sub-periods. Panel A reports the result in the sub-period 1987~1999 and Panel B reports the result in the sub-period of 2000~2015. Calculations are based on the daily return for each stock. The variance-ratio statistics is defined as $VR(k) = (5/k) \cdot var(R^k) / var(R^1)$, where R^k denotes returns over a k -day measurement interval. Average indicates the average of variance ratios for each stock within the given group. Std.err stands for the standard error. n is the number of observations. This table contains the whole sample result, the results for the original return of significant CCRV stocks and the results for CCRV-orthogonalized return of significant CCRV stocks. The CCRV-orthogonalized return signifies the regression residual of the daily return on change in daily turnover. This table also reports the difference between the variance ratios of CCRV-orthogonalized return and original return

Table 4.
Variance ratios for
Korean daily data,
1987–1999 and
2000–2015

the original and CCRV-orthogonalized return of significant CCRV stocks, short-term mean-reversion patterns are observed at intervals greater than 10.

The last columns (d) of Panels A and B in Table 4 show that the difference in VR values is significantly positive for the test interval of greater than 10 days, consistent with the results in Table 3. However, this should be interpreted carefully. The methodology of this study, which examines the short-term effects of trading volumes on returns, cannot be applied because we do not observe the short-term mean reversion phenomenon of stock returns before 2000. Therefore, the previous argument that the stock market becomes more efficient when we eliminate short-term impact in stock returns because of trading volume changes should apply only to the market after 2000.

Next, we divide the whole sample into KOSPI and KOSDAQ samples and proceed with the above analysis. The KOSPI and KOSDAQ markets may show different market efficiencies because of different investors and industry compositions (Lee *et al.*, 2006; Park *et al.*, 2007). Such differences in market efficiency may cause differences in the mean reversion patterns between the two markets. We conduct the analysis only on the post-2000 sample where the mean reversion phenomenon of the stock price exists. Table 5 describes the results.

First, results between the KOSPI and KOSDAQ markets do not contrast significantly for the whole sample. In both markets, VR (1) is significantly greater than 1. VR (10) to VR (100) are significantly less than 1 and monotonically decrease as the test interval increases. This

VR(interval)	(a) Whole sample			(b) Original return			Significant CCRV sample (c) CCRV-orthogonalized return		(d) Difference: (c) – (b)	
	<i>n</i>	Average	Std.err	<i>n</i>	Average	Std.err	Average	Std.err	Average	<i>t</i> -value
<i>Panel A. KOSPI after 2000</i>										
VR(1)	923	1.1300	0.0232	788	1.0194	0.0143	1.0122	0.0105	−0.0071	−1.28
VR(10)	918	0.9305	0.0041	788	0.9145	0.0053	0.9161	0.0052	0.0017	2.31
VR(20)	893	0.9224	0.0058	768	0.8963	0.0069	0.9019	0.0068	0.0056	5.73
VR(30)	873	0.8881	0.0068	741	0.9133	0.0080	0.9196	0.0079	0.0062	6.49
VR(50)	826	0.8558	0.0082	688	0.8591	0.0091	0.8645	0.0092	0.0055	7.50
VR(100)	695	0.8110	0.0095	581	0.7862	0.0112	0.7939	0.0112	0.0077	12.01
<i>Panel B. KOSDAQ after 2000</i>										
VR(1)	1,389	1.1041	0.0215	1,192	0.9745	0.0097	0.9718	0.0066	−0.0027	−0.59
VR(10)	1,375	0.9512	0.0035	1,187	0.9485	0.0044	0.9505	0.0043	0.0020	2.88
VR(20)	1,337	0.9374	0.0051	1,153	0.9222	0.0062	0.9265	0.0061	0.0044	5.27
VR(30)	1,305	0.9109	0.0065	1,113	0.9144	0.0073	0.9199	0.0072	0.0055	8.38
VR(50)	1,199	0.8894	0.0075	975	0.8851	0.0081	0.8925	0.0082	0.0074	11.77
VR(100)	919	0.8137	0.0093	673	0.8407	0.0120	0.8522	0.0121	0.0115	16.00

Notes: This table shows the variance ratios for Korean daily data from KOSPI and KOSDAQ after 2000. Panel A reports the result of the KOSPI-listed stocks from 2000 to 2015 and panel B reports the result of KOSDAQ-listed stocks from 2000 to 2015. Calculations are based on the daily return for each stock. The variance-ratio statistics is defined as $VR(k) = (5/k) \cdot \text{var}(R^k) / \text{var}(R^1)$, where R^k denotes returns over a k -day measurement interval. Average indicates the average of variance ratios for each stock within the given group. Std.err stands for the standard error. n is the number of observations. This table contains the whole sample result, the results for the original return of significant CCRV stocks and the results for CCRV-orthogonalized return of significant CCRV stocks. The CCRV-orthogonalized return signifies the regression residual of the daily return on change in daily turnover. This table also reports the difference between the variance ratios of CCRV-orthogonalized return and original return

Table 5.
Variance ratios for
Korean daily data:
KOSPI and KOSDAQ
after 2000

evidence shows a short-term mean reversion in the KOSPI and KOSDAQ markets after 2000.

However, we observe discrepant results from the original return in the significant CCRV stock sample. In both markets, VR (10) to VR (100) are smaller than 1 and decrease as the test interval increases. However, while VR (1) in the KOSPI market is not significantly different from 1 (mean: 1.0194, standard error: 0.0143), VR (1) in the KOSDAQ market is significantly smaller than 1 (mean = 0.9745, standard error = 0.0097). The results suggest that while short-term momentum is observed in the KOSDAQ market even for less than five days, this is not the case in the KOSPI market. These results are similar to the results of the CCRV-orthogonalized returns.

In addition, the results in the different columns show that the VR (10) to VR (100) of CCRV-orthogonalized returns are significantly greater than those of original returns in both the KOSPI and KOSDAQ markets. Therefore, our argument that the market can be observed more efficiently when the CCRV effect is eliminated does not depend on the market.

4.3 Sign of contemporaneous correlation between return and change in trading volume and mean reversion of stock return

In the previous sections, we examine our hypothesis that CCRV affects stock mean reversion and, eventually, market efficiency. However, as we have seen in Table 1, CCRV is categorized into three groups based on its significance and sign: a significantly positive CCRV, a significantly negative CCRV and an insignificant CCRV. Thus, the overall response of the return to trading volume changes will be different for each group, as shown in Figure 3.

The price moves in the same direction as the volume change in the significantly positive CCRV stocks and moves in the opposite direction in the significantly negative CCRV stocks.

Notes: This figure illustrates the return response to change in trading volume according to each stock's CCRV sign. Given the same stimulus to trading volume change, the stock price moves in the same direction as the change in volume in the significantly positive CCRV group and moves in the opposite direction in the significantly negative CCRV group. In the insignificant CCRV group, the stock price will be uncorrelated with the volume change

Figure 3.
Return response to
the change in trading
volume

In the insignificant CCRV stocks, the price is uncorrelated with the volume change. As the mean reversion of trading volume is related to price movements only in stocks with significant CCRV, the VR of the CCRV-orthogonalized return is significantly larger than that of the original return in both the significantly positive and significantly negative CCRV stock samples but do not show significant differences in the insignificant CCRV stock sample. To demonstrate this argument empirically, we divide the post-2000 sample into three groups based on the sign of CCRV and investigate the mean reversion phenomenon in each subsample [8].

Table 6 presents the results for each subsample. First, in the positive and negative CCRV groups, the VR difference between the original and CCRV-orthogonalized returns is significantly positive in all test intervals of greater than 10 days. However, the difference in the insignificant CCRV group is small (0.0001) and the t -values are also not significant. This evidence is consistent with our expectation that the impact of CCRV on return mean reversion depends on the significance of CCRV, not on the sign.

On the other hand, in the positive CCRV group, VR (1) is significantly less than 1, at 0.9376, indicating short-term momentum in returns within five days, while in the negative CCRV group, VR (1) is 1.0714, indicating short-term mean reversion. However, this difference may result from each stock's characteristics rather than the CCRV's sign because

CCRV	VR(interval)	n	(a) Original return		(b) CCRV-orthogonalized return		(c) Difference: (b) – (a)	
			Average	Std.err	Average	Std.err	Average	t -value
Positive	VR(1)	1,822	0.9376	0.0037	0.9430	0.0039	0.0054	11.69
	VR(10)	1,818	0.9675	0.0025	0.9687	0.0025	0.0012	4.19
	VR(20)	1,786	0.9630	0.0039	0.9659	0.0039	0.0029	9.11
	VR(30)	1,748	0.9475	0.0048	0.9517	0.0049	0.0042	11.79
	VR(50)	1,626	0.9405	0.0058	0.9471	0.0058	0.0066	16.47
	VR(100)	1,273	0.9312	0.0085	0.9414	0.0085	0.0102	21.12
Negative	VR(1)	268	1.0714	0.0414	1.0302	0.0269	–0.0412	–2.07
	VR(10)	267	0.9287	0.0165	0.9337	0.0158	0.0051	2.01
	VR(20)	259	0.8603	0.0226	0.8675	0.0222	0.0072	2.35
	VR(30)	251	0.8689	0.0265	0.8788	0.0263	0.0099	3.99
	VR(50)	215	0.8099	0.0281	0.8177	0.0278	0.0078	5.01
	VR(100)	156	0.7511	0.0309	0.7595	0.0305	0.0084	6
Insignificant	VR(1)	355	0.9271	0.0111	0.9271	0.0111	–0.0001	–0.18
	VR(10)	344	1.0017	0.0090	1.0018	0.0090	0.0001	0.65
	VR(20)	316	1.0168	0.0165	1.0168	0.0165	0.0000	0.19
	VR(30)	294	0.9999	0.0205	1.0000	0.0205	0.0001	0.55
	VR(50)	228	0.9561	0.0240	0.9561	0.0240	0.0001	0.35
	VR(100)	145	0.9013	0.0282	0.9014	0.0282	0.0001	0.39

Notes: This table shows the variance ratios for Korean daily data according to the CCRV sign after 2000. Calculations are based on the daily return for each stock. The variance-ratio statistics is defined as $VR(k) = (5/k) \cdot \text{var}(R^k) / \text{var}(R^1)$, where R^k denotes returns over a k -day measurement interval. Average indicates the average of variance ratios for each stock within the given group. Std.err stands for the standard error. n is the number of observations. This table contains the results for the original return of significant CCRV stocks and the results for CCRV-orthogonalized return of significant CCRV stocks. The CCRV-orthogonalized return signifies the regression residual of the daily return on change in daily turnover. This table also reports the difference between the variance ratios of CCRV-orthogonalized return and original return

Table 6.
Variance ratios for
Korean daily data
according to the
CCRV sign

CCRV is the mechanical response of returns to volume changes. According to Kang and Chae (2019b), the sign of CCRV depends on stock characteristics such as size and liquidity. This evidence suggests that the difference in VR (1) between stocks with positive and negative CCRV is caused by latent stock characteristics rather than the sign of CCRV *per se* [9].

Table 7 shows the subsample results of applying the analysis of Table 6 to the KOSPI and KOSDAQ markets. In most cases, the results do not differ between markets and are similar to those in Table 6. VR (10) to VR (100) in both the positive and negative CCRV groups are significantly larger than before when the CCRV effect is removed from stock returns, but there is no significant change in the insignificant CCRV group. Although the differences of VR (30) and VR (50) in the insignificant CCRV group in the KOSDAQ market are significant ($t = 1.69$ for VR(30) and $t = 2.65$ for VR(50)), the difference is 0.0005, which is not economically meaningful. Based on the empirical results, we can conclude that the significance of CCRV *per se*, rather than its sign, induces the impact of trading volume change on return and, thus, we can observe the market more efficiently by considering the CCRV.

Moreover, column (a) of Panel A in Table 7 shows that the VR (1) for the KOSPI market is 0.9893 in the positive CCRV group and 1.2105 in the negative CCRV group. As shown in Table 5, the VR (1) of the KOSPI is 1.0194, which is not significant and is larger than 1. Now, we can confirm that the result is because of differences in the VR (1) between the two different CCRV groups. These results are similar to VR (1) for the KOSDAQ market. In Table 5, the VR (1) for the KOSDAQ market is 0.9745, but in Table 7, it is 0.9476 in the positive CCRV group and 1.1336 in the negative CCRV group. In addition, VR (1) increases significantly in the positive CCRV group when the volume effect is removed from stock returns and decreases significantly to close to 1 in the negative CCRV group. This evidence also suggests that removing the volume effect from stock returns enables a more efficient observation of the market [10].

5. Robustness test

5.1 Controlling the effects of the previous trading volume level

Previous studies focus on the relationship between trading volume level and return and the effect of the current trading volume on the following return. In the context of those studies, Kang and Chae (2019b) argue that the CCRV is a phenomenon that acts in addition to the existing relationship between the trading volume level and returns.

Following Kang and Chae (2019b), we assume that the effect of CCRV on stock price mean-reversion is an additional phenomenon overlapping the relation between trading volume level and return. Therefore, the results of this study must hold when the effect of trading volume level on stock return is removed. To confirm this, we must control the lead-lag effect observed in the time series of trading volumes and returns. In this regard, Lee (2002), Lee (2009) and Lee *et al.* (2015) verify the Granger causality for the Korean stock market, but the results of daily data at the individual stock level are yet to be reported. Therefore, we check whether the Granger causality appears in the daily trading volume and return in the Korean market as a prerequisite for the main analysis. Panel A in Table 8 below shows the results of a Granger causality test for the Korean market from 2001 to 2015 by using the five lagged daily returns and trading volumes from $t-1$ to $t-5$.

As shown in Panel A of Table 8, in the Korean stock market, 84.36% of the stocks' returns Granger-cause the trading volumes, 48.87% of the stocks' trading volumes Granger-cause the returns and 44.81% of the stocks shows a bidirectional Granger causality.

Further, a VR test is conducted to verify if VR appears closer to one in the CCRV-orthogonalized return when the influence of previous trading volumes and returns on the

									Short-term mean reversion of stock price
CCRV	VR(interval)	(a) Original return			(b) CCRV- orthogonalized return		(c) Difference: (b) – (a)		
		<i>n</i>	Average	Std.err	Average	Std.err	Average	<i>t</i> -value	
<i>Panel A. KOSPI after 2000</i>									207
Positive	VR(1)	681	0.9893	0.0083	0.9917	0.0080	0.0024	2.91	
	VR(10)	681	0.9245	0.0041	0.9249	0.0041	0.0004	0.87	
	VR(20)	670	0.9200	0.0059	0.9227	0.0059	0.0027	5.14	
	VR(30)	658	0.9383	0.0072	0.9429	0.0072	0.0046	6.31	
	VR(50)	623	0.8831	0.0085	0.8883	0.0087	0.0052	7.49	
Negative	VR(100)	535	0.8012	0.0111	0.8089	0.0113	0.0076	11.98	
	VR(1)	107	1.2105	0.0889	1.1431	0.0568	−0.0674	−1.68	
	VR(10)	107	0.8507	0.0288	0.8604	0.0273	0.0098	2.24	
	VR(20)	98	0.7344	0.0319	0.7594	0.0306	0.0250	3.92	
	VR(30)	83	0.7157	0.0361	0.7344	0.0353	0.0188	3.06	
Insignificant	VR(50)	65	0.6286	0.0425	0.6365	0.0416	0.0079	2.03	
	VR(100)	46	0.6116	0.0497	0.6198	0.0488	0.0081	2.52	
	VR(1)	133	1.0371	0.0157	1.0361	0.0158	−0.0010	−2.03	
	VR(10)	129	0.9401	0.0133	0.9400	0.0132	−0.0001	−0.38	
	VR(20)	113	0.9226	0.0204	0.9225	0.0204	−0.0001	−0.24	
	VR(30)	105	0.9705	0.0285	0.9703	0.0285	−0.0002	−0.92	
	VR(50)	85	0.8733	0.0302	0.8730	0.0303	−0.0003	−1.09	
VR(100)	56	0.8183	0.0418	0.8183	0.0418	0.0000	0.02		
<i>Panel B. KOSDAQ after 2000</i>									
Positive	VR(1)	1020	0.9476	0.0042	0.9563	0.0045	0.0086	11.61	
	VR(10)	1016	0.9588	0.0036	0.9597	0.0036	0.0009	2.19	
	VR(20)	987	0.9489	0.0053	0.9522	0.0053	0.0033	6.74	
	VR(30)	956	0.9386	0.0065	0.9431	0.0066	0.0045	8.4	
	VR(50)	862	0.9138	0.0080	0.9211	0.0081	0.0073	12.07	
Negative	VR(100)	600	0.8659	0.0124	0.8775	0.0126	0.0116	15.63	
	VR(1)	172	1.1336	0.0616	1.0637	0.0367	−0.0698	−2.25	
	VR(10)	171	0.8876	0.0214	0.8962	0.0205	0.0087	2.06	
	VR(20)	166	0.7634	0.0265	0.7738	0.0258	0.0104	2.11	
	VR(30)	157	0.7669	0.0303	0.7784	0.0299	0.0116	3.51	
Insignificant	VR(50)	113	0.6665	0.0270	0.6741	0.0262	0.0075	2.72	
	VR(100)	73	0.6338	0.0339	0.6438	0.0333	0.0101	4.02	
	VR(1)	192	0.9292	0.0150	0.9293	0.0151	0.0001	0.26	
	VR(10)	184	0.9928	0.0118	0.9931	0.0118	0.0004	1.54	
	VR(20)	162	1.0198	0.0219	1.0202	0.0220	0.0004	1.09	
	VR(30)	144	0.9992	0.0306	0.9997	0.0306	0.0005	1.69	
	VR(50)	105	0.9123	0.0416	0.9129	0.0416	0.0006	2.65	
VR(100)	57	0.8124	0.0459	0.8127	0.0459	0.0002	0.91		

Notes: This table shows the variance ratios for Korean daily data of KOSPI and KOSDAQ according to the CCRV sign after 2000. Panel A reports the result for KOSPI and Panel B reports the result for KOSDAQ. Calculations are based on the daily return for each stock. The variance-ratio statistics is defined as $VR(k) = (5/k) \cdot \text{var}(R^k) / \text{var}(R^1)$, where R^k denotes returns over a k -day measurement interval. Average indicates the average of variance ratios for each stock within the given group. Std.err stands for the standard error. n is the number of observations. This table contains the results for the original return of significant CCRV stocks and the results for CCRV-orthogonalized return of significant CCRV stocks. The CCRV-orthogonalized return signifies the regression residual of the daily return on change in daily turnover. This table also reports the difference between the variance ratios of CCRV-orthogonalized return and original return

Table 7.
Variance ratios for
Korean daily data for
KOSPI and KOSDAQ
according to the
CCRV sign

Table 8.
Analysis controlling
granger causality in
return and trading
volume

Panel A. Granger causality test: 2000~2015							
Causal direction		$p < 0.05$			$p < 0.01$		
Return $\implies$ trading volume		84.36%			78.52%		
Trading volume $\Leftarrow$ return		48.87%			37.78%		
Trading volume $\Longleftrightarrow$ return		44.81%			35.22%		
Panel B. Control for the return-trading volume granger causality							
VR(interval)	(a) Return-volume granger causal effect controlled			(b) CCRV-effect additionally removed		(c) Difference: (b) – (a)	
	n	Average	Std.err	Average	Std.err	Average	t -value
VR(1)	1,957	1.0415	0.0083	1.0365	0.0055	–0.0050	–1.32
VR(10)	1,957	0.9711	0.0034	0.9756	0.0033	0.0045	7.06
VR(20)	1,922	0.9599	0.0048	0.9665	0.0047	0.0066	12.02
VR(30)	1,883	0.9641	0.0055	0.9724	0.0054	0.0083	13.7
VR(50)	1,770	0.9538	0.0062	0.9630	0.0062	0.0093	16.92
VR(100)	1,428	0.9613	0.0082	0.9731	0.0083	0.0119	20.68
Notes: This table shows the analysis controlling granger causality in return and trading volume for the Korean stock market during 2000–2015. Panel A shows the result of the daily granger causality test between return and trading volume. We use five lagged variables from $t-1$ to $t-5$ in this analysis. Panel B reports the variance ratios for Korean daily data. The variance-ratio statistics is defined as $VR(k) = (5/k) * var(R^k)/var(R^5)$, where R^k denotes returns over a k -day measurement interval. Average indicates the average of variance ratios for each stock within the given group. Std.err stands for the standard error. n is the number of observations. This table contains the results for the return-volume granger-causal effect controlled of significant CCRV stocks and the results for CCRV-effect additionally removed return of significant CCRV stocks by CCRV-orthogonalization. This table also reports the difference between the variance ratios of return-volume granger-causal effect-controlled return and CCRV-effect additionally-removed return							

current return is removed. The test is conducted on the variance observed in the two-type residuals of the following two-stage regression equations. The following regression [equation \(3a\)](#) controls the five lagged returns and trading volumes applied to the Granger causality test. In addition, in the regression [equation \(3b\)](#), the residual of the regression [equation \(3a\)](#), $\epsilon_{1,i,t}$, is the dependent variable and the change in trading volume is the explanatory variable:

$$r_{i,t} = \alpha_{1,i} + \sum_{j=1}^m \gamma_{ij} r_{t-j} + \sum_{j=1}^m \beta_{ij} TV_{t-j} + \epsilon_{1,i,t}, \tag{3a}$$

$$\epsilon_{i,t} = \alpha_{2,i} + \beta_i' \Delta TV_t + \epsilon_{2,i,t}, \tag{3b}$$

Panel B in [Table 8](#) shows the VR test results for the two residuals $\epsilon_{1,i,t}$ and $\epsilon_{2,i,t}$ calculated in the above process. As shown in column (a), in $\epsilon_{1,i,t}$, where the previous return and trading volume level are controlled, VR(1) is 1.0415 and in VR(10)~VR(100), it is significantly smaller than 1. This evidence shows the mean-reversion pattern that appears. The result of $\epsilon_{2,i,t}$ is similar, wherein VR(1) is 1.0365 and VR(10) ~ VR(100) shows a mean-reversion pattern that is significantly smaller than 1, between 0.9630 and 0.9756. In addition, the difference between the two residuals in VR(10) to VR(100) is 0.0045 to 0.0119, which increases as the period increases and all t -values appear at statistically significant levels. The difference is similar to the difference observed in the Korean market from 2000 to 2015 in panel B of [Table 4](#), which is 0.0019 to 0.0097. Therefore, even when the Granger causality between the return and the trading volume level in the Korean market is controlled, the VR of the CCRV-orthogonalized return appears closer to one. Further, this result supports our

main argument that the mean reversion of stock prices is overestimated by responding to the trading volume change.

Short-term
mean
reversion of
stock price

5.2 Testing for efficiency by using the approximate entropy

We use the approximate entropy methodology (hereinafter, *ApEn*) proposed by Pincus (1991) to supplement the results from the previous test.

ApEn is a measure that quantifies and represents the complexity, unpredictability and irregularity observed in time series and is similar to the verification contents of the market efficiency hypothesis of Fama (1970). Pincus and Kalman (2004), Kim *et al.* (2005), Oh *et al.* (2007), Bhaduri (2014) and Pele *et al.* (2017) tests the market efficiency by applying this methodology to the asset market. The method of calculating *ApEn* is as follows:

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$$ApEn(S_N, m, r) = \frac{\sum_{i=1}^{N-m+1} \ln[C_m^i(r)]}{(N-m+1)} - \frac{\sum_{i=1}^{N-m} \ln[C_{m+1}^i(r)]}{(N-m)}$$

$$C_m^i(r) = \frac{B_i}{(N-m+1)}, \quad C_{m+1}^i(r) = \frac{B_i}{(N-m)}$$

$$B_i = \theta(r - d[x(u), x(j)])$$

$$d[x(u), x(j)] = \max_{k=1,2,\dots,m} (|S_{i+k-1} - S_{j+k-1}|), \quad (4)$$

where S_N is an instantaneous time-series, m is a pattern length based on embedding dimension, r is similarity based on the threshold, d is the maximum distance between $x(i)$ elements and $x(j)$ elements and B_i is Heaviside function having 1 if $d < r$ and 0 if $d \geq r$. We set m as two and r as 0.2 times the standard deviation of returns following the definition and assumption of Kim *et al.* (2005).

As shown in the above equation (4), the value of *ApEn* decreases as similar patterns appear in the time series and its value increases as predictions become difficult. Thus, higher values imply higher efficiency.

We compare the *ApEn* value in each stock's original return with that in the CCRV-orthogonalized return. The results are reported in Table 9. The average value of *ApEn* is 1.5802 in the original return and 1.5883 in the CCRV-orthogonalized return. The average difference between the two values measured in each stock appears to be 0.0081 and the corresponding t -values are 12.65. The significant increase in the *ApEn* value observed in

Sample	Original return	CCRV-orthogonalized return	Difference
Whole sample: 2000~2015	1.5802 (0.0063)	1.5883 (0.0063)	0.0081 (0.00064)
Significant CCRV: 2000~2015	1.6173 (0.0057)	1.6264 (0.0057)	0.0091 (0.00075)
Insignificant CCRV: 2000~2015	1.3783 (0.0245)	1.3783 (0.0245)	0.0000 (0.00066)

Notes: This table reports the estimated approximate entropy for original return and CCRV-orthogonalized return in the Korean stock market from 2000 to 2015. Values in parentheses are standard errors

Table 9.
Test for efficiency by
approximate entropy
methodology

the CCRV-orthogonalized return indicates the increased randomness in the time series of the CCRV-orthogonalized return. Therefore, the results of the *ApEn* analysis are consistent with the VR test. This evidence shows that the market can be observed more efficiently if the trading volume change is considered.

6. Conclusion

This study analyzed the short-term mean reversion of stock return in the Korean market from 1987 to 2015. Mainly focusing on the effect of the change in trading volume on stock returns, we compare the mean reversion patterns in the CCRV-orthogonalized return with that in the original return using the VR test.

The empirical analysis confirms the existence of short-term mean reversion of stock price in the Korean market after 2000, but not before 2000. In addition, for stocks whose price has been affected by changes in trading volume since 2000, the VR increases from the original and is closer to 1 if the trading volume effect is excluded. These results appear in the significant CCRV stocks in both KOSPI and KOSDAQ, regardless of the sign of CCRV.

Based on the above results, we confirm that the partial term structure of the stock return is related to the term structure of the trading volume and CCRV and the stock return's term structure also partially affects the short-term mean reversion of price. This term structure of stock prices amplifies the volatility in short-term returns over volatility in long-term returns. However, such a trading volume effect is predictable and extractable by the consideration of the CCRV channel. Consequently, we conclude that the market is observed more efficiently if we remove the effect of trading volume change on the stock price. Moreover, by considering the CCRV effect, we can avoid the misestimation of the forward price volatility that may cause mispricing and hedging errors when dealing with OTC market's options, which usually depend on the historical data when estimating volatility.

On the subject of mean reversion of a stock price, it would be a good research topic to compare the long-term and short-term mean reversions for each stock and examine the factors that affect each phenomenon. Moreover, revealing the determinants of the mean reversion of stock prices can be a promising future work. Given our finding that the mean reversion pattern appears differently because of the sign of CCRV, other factors may play an important role in the mean reversion of a stock price. If we can reveal the causal relationship between these hidden determinants and the mean reversion, we can have a deeper understanding of market efficiency and we can better understand the characteristics of the market. Finally, the discussion on CCRV, the main variable of this study, is still in progress and more research is needed. Therefore, we hope that this study enriches the existing discussion and serves as a useful ingredient for future research.

Notes

1. More precisely, the stock price is not a martingale in the dividend discount model because

$$E_t[P_{t+1}] = (1 + R)P_t - E_t[D_{t+1}].$$

However, we can obtain a martingale process if we substitute P_t with V_t , which is the dividend-adjusted total value:

$$V_t = \frac{N_t P_t}{(1+R)^t} \text{ and } N_{t+1} = N_t \left(1 + \frac{D_{t+1}}{P_{t+1}}\right)$$

2. For the testing of mean reversion of the stock price, the methodologies of [Fama and French \(1988\)](#), [Jegadeesh \(1991\)](#) and [Poterba and Summers \(1988\)](#) are usually applied. We

choose the last one because building the pseudo return path is only possible by this methodology.

3. According to [Kang and Chae \(2019a\)](#), the half-life, which is the time necessary for half of the deviated amount of trading volume to decay, is about two to three days. Thus, we suppose that five days is enough time for trading volume shock to almost disappear.
4. Refer to the difference in CCRV distribution according to size and liquidity level in Table 10 of [Kang and Chae \(2019b\)](#).
5. This tendency is more extreme in out-of-the-money (OTM). For example, when the volatility is 30% for a one-year 120% OTM call option, a 1% change in volatility has a 6% effect on the option price; in a 150% OTM call option, it has an 18% effect or higher.
6. If the market is efficient, the VR value will be 1.
7. For the pre-2000 data, even when we adjust the base interval to 10 or 20 days instead of 5 days, we do not find the short-term mean reversion patterns.
8. As for CCRV, more research is still needed on its cause and we expect this analysis to be useful for discussion.
9. Alternately, it is possible that the difference in mean reversion in the one-to-five-day interval will be one of the determinants of the sign of the CCRV.
10. This result is also observed in [Table 6](#). In [Tables 3, 4 and 5](#), without the CCRV sign classification, the result is not observed.

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