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Volatility Control Mechanisms: The International Experience and the Evidence from Hong Kong

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Abstract

Trading venues have adopted volatility interruption measures to protect investors from extreme price gyrations and disorderly markets. Among such measures, Volatility Control Mechanisms (VCMs) are implemented among major international security markets. After reviewing the institutional details of VCMs, this study empirically investigates the impact of VCMs to Hong Kong's stock market. Our results show that VCMs are able to curb further price swings. We also find that there is a reduction in the effective bid-ask spreads, and an increase in the depth and trading volume when trading is resumed after the cooling-off period. Furthermore, both difference-in-difference regression (DID) and regression discontinuity design (RDD) analysis show that the improvement in liquidity is statistically significant, especially in terms of the effective bid-ask spreads and depth.

Keywords: Market Microstructure, Price limit, Volatility Control Mechanism, Stock Market
JEL classification: G14, G15, G18, G28

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1. Introduction

Extreme price variations are often indicative of security markets' distress and have been regularly studied by academics and regulators because of their revealing nature of existing market imbalances and for their important implications for market quality and financial stability. Jurisdictions, trading venues and regulators after assessing the consequences of volatility events have or are considering measures to minimize extreme price variations and maintain orderly markets (IOSCO, 2018). According to a 2016 survey of the World Federation of Exchanges (Clapham et al., 2017), 86% of the trading venues adopt some form of volatility interruption measures to ensure investor protection. The most widely-used volatility interruption measures are market-wide circuit breakers (or trading halts) and price limit measures. Among the latter, Volatility Control Mechanisms (VCMs henceforth) are commonly used interruption measures aimed to moderate price variations in situation of market distress, although debates still occur on whether these measures are beneficial to the financial market in curbing price volatility and providing liquidity. A number of theoretical and empirical studies have attempted to investigate the effectiveness of volatility interruption measures, although the majority of them are focused on either trading halts or static price limit measures.

The purpose of this study is to review the institutional details of VCMs introduced in international security markets and focus empirically on the investigation of the impact of VCMs to market volatility and liquidity in Hong Kong's stock market.[2] Using intraday transaction prices and bid-ask quotations constructed from the historical limit-order book data on the Hong Kong Stock Exchange (HKEX), we examine the effectiveness of VCMs on

[2] With a growing incidence of electronic/algorithmic trading and the associated risks, the Hong Kong Stock Exchange launched a VCM in 2016. It was initially applied to only the constituent stocks of the Hang Seng Index and the Hang Seng China Enterprise Index and it was expanded in May 2020 to cover constituent stocks of the Hang Seng Composite Large Cap Index, the Hang Seng Composite Mid Cap Index and the Hang Seng Composite Small Cap Index, albeit with different triggering thresholds.

curbing volatility and providing liquidity during the period from May 2020 to Jan 2021. A total of 17 VCM events occurred during this period and are investigated in this study.

Among the first empirical study conducted on examining VCMs, we show that VCMs in Hong Kong's stock market are able to curb further price swings. When comparing a battery of market quality measures before and after VCM triggers, we find that there is a reduction in the quoted and effective bid-ask spreads, and an increase in the depth and trading volume when trading is resumed after the cooling-off period. Furthermore, based on difference-in-difference regression (DID) and regression discontinuity design (RDD) analysis of the stocks whose trading activities are moderated by VCMs versus comparable stocks that are not affected by VCMs, the improvement in liquidity to the former is statistically significant in terms of the effective bid-ask spreads and depth. Taken together these findings suggest that VCMs generate the intended results in that they prevent the continuation of large price variation while improving various facets of market liquidity.

The rest of the paper is organized as follows. Section 2 provides a survey of the relevant literature while Section 3 reviews the institutional details of VCMs introduced in major stock markets. Section 4 contains the description of the data used in our empirical investigation together with the discussion of summary statistics and our findings. A final Section 5 concludes.

2. Relevant Literature

Volatility interruption measures, such as VCMs, are designed to reduce extreme price variations while preserving orderly trading. A vast academic literature is still debating on the effectiveness of such mechanisms, especially in the aftermath of October 1987's stock market crash. The Brady Commission, which was appointed in the US to investigate the causes of the crash, recommended that there should be price limits on how much a security could rise or fall

during a day, and suggested that circuit breakers could facilitate price discovery and calm down extreme market movements (Brady, 1988).

However, a number of theoretical studies have noted that circuit breakers can exert both positive and negative effects on market quality and price discovery (see, among others, Greenwald and Stein, 1991; Kyle 1988; Lehmann, 1989; and Moser, 1990). On the one hand, Ma et al. (1989) argued that circuit breakers can allow traders to reassess their inventories and trading strategies, and trading halts reduce the risk for liquidity providers, i.e. limit order traders to be picked off by informed traders (as in Copeland and Galai, 1983). Along similar lines, Greenwald and Stein (1991) showed that circuit breakers may support markets in absorbing large volume shocks. On the other hand, others have argued that circuit breakers can distort market liquidity (Lauterbach and Ben-Zion, 1993) and delay the efficient incorporation of information into market prices and therefore defers price discovery (Lehmann, 1989). In fact, when trading prices approach the threshold for triggering the circuit-breaker or the price-limit, this may encourage orders to reach the limit faster, as market participants worries not to be able to trade the security during the trading session. This phenomenon is usually referred to as "gravitational" or "magnet" effect (Subrahmanyam, 1994; Cho et al., 2003; Goldstein and Kavajecz, 2004).

Madhavan (1992) introduced a model for analyzing the effect of volatility interruptions, with an illustration of a rule-based circuit breaker that switches from continuous trading to a call auction in high volatile markets. In that contribution, he showed that continuous trading it not optimal during periods of severe information asymmetries and extremely high volatility. A trading halt would not desirable as well, since this could worsen the prevailing information asymmetries because, once halted, the resuming of the continuous trading process may be difficult. The suggestion in the study is therefore to switch to a call auction to avoid a market failure. Subrahmanyam (1997) investigated strategic informed trading in a regime with rule-

based market closures. Closure rules can be designed to reduce the ex-ante trading costs of liquidity traders but they may cause informed traders to scale back their trading in order to reduce the chance of the closure being triggered. In the study it is shown that this effect can be mitigated by randomizing the halting rule to reduce the degree of predictability of the halt from the perspective of informed traders.

From an empirical perspective, several studies have explored volatility interruption measures, although there are contradicting results on whether these measures are effective in reducing volatility, preserving liquidity, and contributing to price discovery. The differences in the findings are potentially due to the various designs of volatility interruption measures implemented on different markets being analyzed.

Some studies have found a positive role for the volatility interruption measures. For example, Lee and Kim (1995) highlighted a reduction in volatility due to the introduction of price limits in the Korean stock market, Zimmermann (2014) found that the volatility interruptions on the Deutsche Boerse contributed to the price discovery process leading to a reduction in volatility after the call auction, Lu (2016) showed that there are no adverse effects of price limits on stocks cross-listed in Hong Kong and Mainland China on volatility spillovers or price discovery.

Nonetheless, other studies showed no empirical evidence of a reduction in volatility (Phylaktis et al., 1999; Bildik and Gülay, 2006 and Kim et al., 2008) or identified an increase in volatility after volatility interruptions (Chen, 1993; Lee et al., 1994 and Farag, 2014). Corwin and Lipson (2000) corroborated the early findings by showing an increase in volatility following security-specific NYSE trading halts, while Christie et al. (2002) found that bid-ask spreads and volatility increased significantly after Nasdaq trading halts. Some other studies also found circuit breakers to lead to volatility spillovers over time (Kim and Rhee, 1997) and across different stocks, in case of a single-stock circuit breakers (Brugler et al., 2018).

A number of empirical studies have also investigated the role of specific design parameters on the effectiveness of circuit breakers. Berkman and Lee (2002) analyzed the effects of a change in price limits on the Korean Stock Exchange and conclude that tighter limits may have positive effects by reducing volatility and increasing trading volume. Kim (2001) looked at the relation between volatility and different regimes of price limits that were implemented on the Taiwan Stock Exchange and did not find any evidence of reduction in volatility when price limits were more restrictive. Chan et al. (2005) provide evidence related to the Kuala Lumpur Stock Exchange that wider price limits delay the arrival of information and increase order imbalance. Chou et al. (2013) analyzed the duration of the cooling-off period on the Taiwan Stock Exchange, and found that the endogenous limit-hit duration depends on stock-specific risk factors. Finally, Clapham et al. (2017) investigated different designs of circuit breakers implemented on the German and Spanish stock markets, and found that tighter price ranges and shorter durations facilitate the achievement of the volatility interruption measure's goals.

3. VCMs in Action: The International Experience and the Case of Hong Kong

This section reviews the institutional details of the VCMs that have been introduced in various international exchanges and in Hong Kong. To provide a broad understanding of the major parameters governing the triggering and execution of the interruption measures, Figure 1 illustrates how a typical VCM operates during the normal continuous trading session for a given security on an exchange[3]. Although VCMs vary across security markets, most of them follow a similar structure which requires a reference price, upper and lower price limits and a cooling-off period. In dynamic VCMs, the reference price and price limits are

[3] Trading sessions of exchanges usually include auction sessions and continuous trading sessions, the former being the opening, closing and half-time break sessions or under special circumstances, while the latter are the normal trading hours. VCMs are always active during continuous trading sessions, and some exchanges also apply VCMs to auction sessions.

calculated in real time, whereas in static VCMs, the reference price and price limits are calculated only once or a few time times during the trading day. The price limits are usually calculated according to the following equation:

$$\text{Price limits} \begin{cases} \text{Upper limit} = \text{ Reference price } \times (1 + p\%) \\ \text{Lower limit} = \text{ Reference price } \times (1 - p\%) \end{cases} \quad (1)$$

where the reference price in dynamic VCMs can be the last execution price while in static VCMs it can be the opening price. The parameter $p\%$ is the triggering threshold (in percentage) set by the exchange.

During normal trading hours, the execution price is monitored. As soon as the price exceeds or is expected to exceed the dynamic or static price limits (at the orange dots), a cooling-off period will be triggered. Circuit breakers and price limits are two types of measures taken within the cooling-off period, the former suspending trading altogether and using an auction to determine reopening price while the latter still allowing trading but only within the price limits. After the cooling-off period, the price continues to be monitored against the prevailing price limits for both types of measures.

3.1. The International Experience

This subsection reviews the major characteristics of the VCMs implemented for individual securities in the international exchanges including the Australian Securities Exchange (ASX), the Deutsche Boerse (including Xetra and Eurex Deutschland), the Japan Exchange Group (JPX), the Singapore Exchange (SGX), the London Stock Exchange (LSE), the New York Stock Exchange (NYSE) and the Nasdaq. In addition to the descriptions provided below, Table 1 also summarizes the key VCM parameters for these exchanges.

ASX

The ASX adopts dynamic VCMs called the Anomalous Order Threshold (AOT) and static VCMs called the Extreme Trade Range (ETR) to stocks, corporate options, exchange traded funds (ETFs), managed fund products, etc., but not to warrants and futures. On the one hand, the AOT operates during continuous trading sessions and updates price limits dynamically, rejecting orders outside the price limits but not initiating a cooling-off period. On the other hand, the ETR uses larger price limits than the AOT and offers a cooling-off period of two minutes with suspension of trading if the price limits are exceeded.[4,5]

Deutsche Boerse

The Deutsche Boerse implements different VCMs on the Xetra and the Eurex Deutschland, covering stocks, ETFs, exchange-traded products (ETPs) in the Xetra and simple futures instruments in the Eurex Deutschland. Both dynamic and static VCMs are adopted in the Xetra for auctions and continuous trading sessions, although details on price limits are not publicly disclosed. The Eurex Deutschland does not publish information on reference price, price limits and the cooling-off arrangement.[6,7]

JPX

The JPX adopts two dynamic VCMs for stocks which are referred to as the Special Quote and Sequential Trade Quote. The price limits of the Sequential Trade Quote are twice as high as those of the Special Quote. For the Special Quote, when execution price is expected to exceed the price limits, the VCMs activate a three-minute cooling-off period that only allow trading

[4] https://www2.asx.com.au/markets/market-resources/market-volatility-faqs
[5] See Page 20, https://www.asx.com.au/documents/rules/asx_or_procedures.pdf
[6] https://www.xetra.com/xetra-en/trading/market-quality/reference-market
[7] See Page 36, https://www.eurexchange.com/resource/blob/2448162/e5205fe908b767d40a687aa6658196dd/data/Eurex-Trading-Safeguard-Presentation_02-2021.pdf

within the prices limits, with the limits displayed as a special quote to encourage market participants to balance orders. For the Sequential Trade Quote, the cooling-off period entails a circuit breaker, where trading is suspended, and the post cooling-off price to be determined with an auction.[8] The JPX also implement static and dynamic VCMs on derivatives, covering a list of options and futures. The static implementation is called the Price Limits or Circuit Breaker Rule, with predetermined price limits and a ten-minute cooling-off period that suspend trading. The dynamic implementation is called the Immediately Executable Price Range Rule or Dynamic Circuit Breaker, with reference price and price limits updated in real time. A cooling-off period of at least 30 seconds (15 seconds for index options) is activated when the price limits are exceeded and continues until matching price returns to within the price limits.[9,10]

SGX

The SGX implements dynamic VCMs called the Circuit Breaker to continuous trading sessions for three kinds of securities: (1) stocks and unit trusts that are components of several indices; (2) stocks, stapled securities, real estate investment trusts, business trusts, funds, ETFs and exchange traded notes with a reference price not smaller than 0.5 dollar at the beginning of the trading day; and (3) marginable futures contracts with underlying assets in the first and second categories.[11] The SGX uses ±10% of the reference price as the price limits for all covered securities and permits trading within the price limits during the cooling-off period.[12]

LSE

[8] https://www.jpx.co.jp/english/equities/trading/domestic/04.html
[9] https://www.jpx.co.jp/english/derivatives/rules/price-range/
[10] https://www.jpx.co.jp/english/derivatives/rules/price-limit-cb/index.html
[11] The indices in the first category are Straits Times Index or the MSCI Singapore Free Index.
[12] http://rulebook.sgx.com/rulebook/regulatory-notice-8141-circuit-breaker

The LSE adopts both static and dynamic VCMs to stocks, securitized derivatives, order book for retail bonds and fixed income securities, etc.[13] The LSE publishes very detailed static and dynamic percentage parameters used to calculated price limits. LSE's cooling-off period is initiated not only by execution price exceeding price limits, but also by an imbalance in market orders, e.g., when the sum of market orders on one side is greater than that on the other side. The number of cooling-off periods allowed per trading day is limited and is also disclosed by the LSE.[14]

NYSE and Nasdaq

The NYSE and the Nasdaq implement dynamic VCMs called the Limit Up-Limit Down on the continuous trading of all National Market System (NMS) securities, including domestic and international stocks, fixed income, currency, commodities, and futures, but excluding rights, warrants and options. The NMS securities are divided into Tier 1 and Tier 2, with Tier 1 comprising the S&P 500, Russell 1000 and selected ETPs and Tier 2 comprising all other securities. [15,16] The NYSE and the Nasdaq also apply a static Market-Wide Circuit Breaker (MWCB) to stock, options, and futures markets, potentially activating up to three triggers based on the movement of the S& P 500 Index. For MWCB Levels 1 and 2, trading is suspended for 15 minutes if the S&P 500 falls 7% and 13%, respectively, from the previous trading day's closing price (i.e., the static reference price). For MWCB Level 3, trading will be suspended for the remainder of the trading day if the S&P 500 falls by 20%.[17]

[13] See Trading Service Breakdown sheet of https://docs.londonstockexchange.com/sites/default/files/documents/20210628%20MIT%20%26%20TE%20Parameters%20version%207.9.xls
[14] See page 60 to 63, https://www.lseg.com/sites/default/files/content/documents/MIT201%20-%20Guide%20to%20the%20Trading%20System%20Issue%2012%202.pdf
[15] See Page 1, https://assets.website-files.com/5fd0e55ae5f254cd291b2d35/60663c2660e0056c9c8b6023_LULD%20FINAL.pdf
[16] www.nasdaqtrader.com/content/MarketRegulation/LULD_FAQ.pdf
[17] https://www.nyse.com/publicdocs/nyse/NYSE_MWCB_FAQ.pdf

3.2. VCMs in Hong Kong

The HKEX adopts dynamic VCMs, covering the components of stock market indices and the spot month and next calendar month contracts of various index futures in the derivatives market. The relevant stock indices include the Hang Seng Composite Large Cap Index, the Hang Seng Composite Mid Cap Index and the Hang Seng Composite Small Cap Index. The futures include the Hang Seng Index futures, the Mini-Hang Seng Index futures, the H-Share Index futures and the Mini-H-Share Index futures. The HKEX sets the price limits of the VCMs for the components of the three stock market indices at ±10%, ±15% and ±20%, respectively, and sets the limits for covered futures at ±5% of the reference price. The HKEX does not apply the VCMs to the opening and closing auctions, the first 15 minutes of the morning and afternoon continuous trading sessions and the last 20 minutes of the afternoon continuous trading session. The cooling period lasts for five minutes for both stock and derivatives markets, with trading allowed with the price limits.[18,19]

4. Data and Empirical Results

This section describes the data, presents key summary statistics and the empirical results and discusses our findings.

4.1. Data Description and Summary Statistics

In our empirical investigation, we use the historical limit-order book data recorded by the HKEX. The dataset contains all of the execution prices and trading volumes. In addition, it also provides a series of messages that describe the orders added to, removed from, and executed on the HKEX. The timestamp of the observations is recorded at the closest

[18] https://www.hkex.com.hk/Global/Exchange/FAQ/Securities-Market/Trading/VCM?sc_lang=zh-HK#collapse-2

[19] https://www.hkex.com.hk/Global/Exchange/FAQ/Derivatives-Market/Trading/Volatility-Control-Mechanism-(VCM)?sc_lang=en

nanosecond. We use the sequence of messages to reconstruct the dynamics of the limit-order book, from which we compute the various market quality measures.

Our sample period spans from the beginning of the second phase implementation of the VCMs (i.e., May 2020) to Jan 2021. Although the HKEX launched the VCMs in 2016, which was initially applied to only the constituent stocks of the Hang Seng Index and the Hang Seng China Enterprise Index, there were no VCMs triggered during this first phase of implementation. In the second phase beginning from May 2020, the VCMs were expanded to include constituent stocks of the Hang Seng Composite Large Cap Index, the Hang Seng Composite Mid Cap Index and the Hang Seng Composite Small Cap Index, and 20 VCM events have been recorded so far. Hence, our sample contains all the VCM events triggered on stocks traded on the HKEX. A full history of the VCM events occurred during the period is shown in Table 2.

Out of the 20 VCM events recorded, 18 were triggered due to large stock price appreciations, and two were triggered due to large stock prices depreciations. Most of the VCM events were recorded for small-cap stocks, with four for medium-cap stocks, and only one for a large-cap stock.[20] As there is no meaningful sample size for VCMs triggered by negative price movements, we confine our analysis to the VCM events triggered by price appreciations. In addition, we exclude one stock that exhibited abnormal price movements around the VCM trigger, leading to a final sample comprising 17 VCM events. We think that it is worthwhile exploring the primary patterns exhibited by the stock market during these events to provide a better understanding of the effects of the VCMs.

In order to examine the effects of the VCM events on market quality, the following 10 key market variables capturing liquidity or volatility are constructed for every 5-minute interval

[20] It is worthwhile noting that for some VCM events, the 5-minute returns prior to the VCM trigger are not close to the triggering thresholds. This is because the VCM is triggered not with reference to returns, but when there is a potential trade hitting the threshold price limits.

during the one-hour session before and after the VCM cooling-off period. Quoted Spread is the time-weighted average of the spread between the best bid and ask prices, Quoted Spread10 is the time-weighted average of the spread between the 10^{th} best bid and 10^{th} best ask prices, Depth is the time-weighted of sum of depth size at the best bid and ask prices, Depth10 is the time-weight of sum of depth size between the 10^{th} best bid and 10^{th} best ask prices, Volume is the total trading volume (in shares), Dollar Volume is the total trading dollar volume, Realized Variance is the variance of transaction returns, Effective Spread is the time-weighted average of the spread between the trade price and best bid (or ask) price, Order Imbalance is the difference between buy volume and sell volume, and, last but not least, Depth Imbalance is the difference between depth size at the best bid and best ask prices.

4.2. Empirical Results

A. Univariate Analysis

Figure 2 plots the price movement in the one-hour session before and after the cooling-off period. Panel A is based the midpoint of bid-ask prices, while Panel B is based on trade prices, although both charts display a similar pattern. The time intervals are in terms of the event time, with time 0 being the time the VCMs are triggered. The security returns at a particular time interval are calculated based on the prevailing prices in that time interval relative to the price at time 0, that is the last trade price before the VCMs are triggered.

Across all the 17 VCM events, there is a small price increase even prior to the last 5-minute interval before the triggers. There is then a significant price increase in the last 5-minute interval, with an average return of around 15%. During the cooling-off period, the price decreases by roughly 2%. But once trading is resumed to normal, the price bounces back by around 3%, before it settles around the price level during the cooling-off period. Overall, Figure

2 shows that the cooling-off period delays price movement, although there is evidence of small price overshooting when the trading is resumed to normal.

Figures 3 to 8 plot the behaviour of the 10 market variables in the one-hour session before and after the VCM event. In order to aggregate the observations across the 17 VCM events, which involve stocks of different market capitalizations and having various liquidity or volatility levels, we normalize each variable by dividing the 5-minute raw variable by the average or sum of the variable over 25 five-minute intervals around the VCM event (60-minute before and after the VCMs are triggered as well as the 5-minute cooling-off period), so that all variables are expressed in terms of self-normalized ratios.

Figure 3 plots Quoted Spread and Quoted Spread10 around the VCM triggers. We observe that Quoted Spread gradually increases before the VCMs are triggered, and remains relatively high in the first few 5-minute intervals after the cooling-off period, and finally comes down to the pre-event level after 30 minutes. On the other hand, Quote Sparead10 is at a relatively high level even 30-mintues before the VCMs are triggered, but sharply comes down after the cooling-off period. This suggests that even before the VCMs are triggered, there has already been a widening of bid-ask spreads when the more distant quotations are considered, even though the best bid-ask quotes are very tight. But regardless of whether we measure the liquidity based on Quoted Spread or Quoted Spread10, Figure 2 indicates that market liquidity deteriorates before the VCMs are triggered, but improves and restores to the normal level after the cooling-off period.

The dynamics of Depth and Depth10 around the VCM event are depicted in Figure 4. We find that Depth starts to increase in 15 minutes prior to the VCM triggers, but then comes down in the cooling-period period, and remains stable afterwards. As for Depth10, it reaches the lowest level during the cooling-off period, but then gradually increases after the VCM event.

Therefore, the VCMs have a positive effect on market liquidity, when the measures are based on Depth10 but not Depth.

Figure 5 plots Volume and Dollar Volume around the VCM events. For both volume measures, there is a dramatic increase in trading activity right before the VCMs are triggered. There is no decline of trading volume during the cooling-off period, indicating that the price limits used by the VCMs do not prohibit trading activity. Even after the cooling-off period, the trading activity remains at a relatively high level, and finally declines to the pre-event level around 20 to 25 minutes after the cooling-off period.

Figure 6 plots Realized Variance around the VCM events. We observe a dramatic increase in volatility before the VCMs are triggered, as Realized Variance increases 5 times (from 1.0 to 5.0) within 5 minutes right before the VCMs are triggered. We observe that Realized Variance gradually comes down afterwards, getting back to the level of 1.0 after 20 minutes in the post-event period.

The pattern of Effective Spread around the VCM events is shown in Figure 7. Similar to Quoted Spread, we find that Effective Spread gradually increases before the cooling-off period, but then declines afterwards. As effective spread measures the cost of immediate liquidity, this shows that the VCMs are effective in restoring immediate liquidity to the normal level.

The dynamics of Order Imbalance and Depth Imbalance around the VCM triggers are presented in Figure 8. There is a significant increase of Order Imbalance before the VCMs are triggered. This is anticipated as these VCM events are set off by large positive returns due to an excess of buy volume over sell volume. On the other hand, while there are fluctuations of Depth Imbalance around the VCM events, there is not an apparent trend.

To examine the differences in the above variables before and after the VCM events, we perform the Wilcoxon sign rank test to test for their statistical significance. The Wilcoxon sign

rank test is a non-parametric test that does not require normality assumption, and is therefore suitable for our test given a small sample of 17 VCM events is unlikely to conform to a normal distribution. The results are reported in Table 3, with Panel A based on observations 60 minutes before versus after the VCMs are triggered, and Panel B based on observations 30 minutes before and after the VCMs are triggered.

Panel A shows that relative to the pre-event period, Quoted Spread10 and Depth10 are significantly lower in the post-event period at 1% level, and Effective Spread is significantly lower at the 10% level. This confirms that there is a significant improvement in market liquidity after the cooling-off period. Furthermore, the level of trading activity is also significantly higher in the post-event period, with both the logarithm of Volume and the logarithm of Dollar Volume are significantly higher at the 1% level. Meanwhile, Order Imbalance is significantly lower in the post-event period. However, we cannot reject the equality of Realized Variance before and after the cooling-off period. The results based on the alternative specification reported in Panel B are generally similar.

B. Difference-in-difference regression analysis

The evidence so far is based on comparing the market variables before and after the VCM events. A natural concern is whether the change in these variables is driven by the VCM triggers, or it will occur anyhow even without the VCMs being triggered. For example, it may be even without the VCM events, while market liquidity deteriorates amidst large price movements, it will revert to a normal level once stock price stabilizes. This is not easy an easy question to answer. According to the design of VCMs, for a stock having its price hitting the price limits (VCM stocks henceforth), its trading should enter a cooling-off period. If trading of a stock remains normal, its price must not have hit the limits (non-VCM stocks henceforth). Therefore, it is not possible to find non-VCM stocks that have price movements entirely similar

to those of VCM stocks. Despite this issue, we still attempt to construct a control sample of non-VCM stocks that have very large 5-minute price movements, but inherently not large enough to have VCMs triggered.

To construct the control sample, each VCM stock is matched with 4 stocks from a similar market cap or lower cap category, that also have the highest 5-minute returns in any time interval within the same trading day the VCM event occurred. We then estimate the following difference-in-difference (DID) regression equation:

$$Var_{i,post} = \beta_0 + \beta_1 \times VCM_i + \beta_2 \times Var_{i,pre} + \beta_3 \times VCM_i \times Var_{i,pre} + \epsilon_i \qquad (2)$$

where VCM_i equals 1 if stock *i* is a VCM stock and 0 if a control stock, $Var_{i,pre}$ and $Var_{i,post}$ is one of the 10 market variables measured during the trading session before and after, respectively, the cooling-off period for VCM stocks, or before and after, respectively, the large 5-minute price movement for non-VCM stocks. The coefficient β_2 captures the time-series relationship of the variable across the pre- to the post-event period, while the coefficient β_3 captures the change of time-series relationship due to the VCM triggers. The coefficient β_1 is the variable of interest, as it measures the impact of VCMs on market volatility and liquidity with the time-series relationship statistically held constant.

Table 4 presents the DID regression estimates, with Panel A based on observations 60 minutes before and after the cooling-off period, and Panel B based on 30 minutes before and after. For both specifications, the coefficient β_1 is insignificant for most of the market volatility and liquidity variables. The only exception is the estimates associated with Quoted Spread and Effective Spread, which are significantly negative. This suggests that relative to the control sample, there is a significant improvement of market liquidity in VCM stocks. Again, we should point out the limitation of this analysis. Even we try to match VCM stocks with non-

VCM stocks of comparable market capitalization and 5-minute price movements, the fact that non-VCM stocks did not experience the VCM trigger means that they are not strictly comparable to VCM stocks. Presumably, since non-VCM stocks have price movements of slightly smaller magnitudes than VCM stocks (so that their VCMs were not triggered), they do not form not a perfect sample of controls.

We have also included some control variables in the DID regressions, to accommodate the potential explanatory power of stock characteristics for market liquidity and volatility. These control variables include return volatility measured by the daily return volatility in the previous month, price at the end of previous month, firm size measured by market capitalization at the end of previous month, past return in the previous month, and book-to-market ratio in the previous month.

Results are presented in Panel C and Panel D of Table 4, for observations 60 minutes and 30 minutes before and after the cooling-off period, respectively. As we observe, the results are similar to those presented in Panel A and Panel B, whereby the coefficient estimates associated with Quoted Spread and Effective Spread are significantly negative.

C. Regression discontinuity design (RDD) analysis

We have also used the regression discontinuity design (RDD) to assess the effect of VCM on market liquidity and volatility. RDD is a quasi-experimental design that focuses on observations around a threshold, or cut-off point, to determine the causal effects of a treatment. After a variable crosses the threshold, the treatment occurs. RDD compares observations lying closely on either side of the threshold: those that receive the treatment, and those that do not. The RDD approach assumes thus that subjects near the threshold are likely to be very similar and therefore, comparable.

In reference to Lee and Lemieux [2010], we introduce the following model to control for the effects of discontinuity on market liquidity and volatility:

$$Var_{i,post} = \beta_0 + \beta_1 \times VCM_i + \beta_2 \times Var_{i,pre} + f\ (Distance) + Control + \epsilon_i \quad (3)$$

where *Distance* is the difference between the pre-VCM 5-minute return and the VCM threshold, and *Contro*l is the set of control variables including return volatility, price, firm size, past return, and book-to-market ratio. The VCM threshold for the treatment stocks (i.e., VCM stocks) will be 10%, 15% and 20%, for large cap stocks, medium cap stocks, and small cap stocks, respectively. The VCM threshold for the control stocks is based on the threshold for the VCM stocks that are matched against.

According to the design of VCMs, for a stock having its price hitting the price limits (i.e., VCM threshold), its trading should enter a cooling-off period. Therefore, the 5-minute return is always lower than VCM threshold, so that *Distance* for VCM stocks is always slightly negative. As for the control stocks, for them not to experience the VCM trigger, their 5-minute returns are usually smaller so that they do not hit the VCM threshold. However, as some of the control stocks are of lower market cap category than the VCM stocks that they are matched against, they will have a higher VCM threshold and therefore relatively higher 5-minute returns. As a result, *Distance* for control stocks are usually negative, but can be positive sometimes. Results for RDD are presented in Table 5, based on observations 60 minutes (Panel A) and 30 minutes (Panel B) before and after the cooling-off period, respectively. We have estimated using both first order polynomial of *Distance* (i.e., *Distance* only) and second order polynomial of distance (i.e., *Distance* and *Squared Distance*). As the results are similar, we only present those based on first order polynomial. Results from the RDD analysis are slightly different from those of DID regression analysis. We find that the coefficient estimates associated with

Effective Spread remain significantly negative although the coefficient estimates associated with Quoted Spread are significantly positive. In addition, we find that the coefficient estimates associated with Log(Depth10), Log(Volume) and Log(Dollar Volume) are all significantly positive. Overall, the results from RDD analysis show that VCM will improve trading activity and liquidity after the cooling-off period.

4.2. Discussion

The results of our empirical investigation suggest that market liquidity generally improves after VCMs are triggered in Hong Kong's stock market. In addition, our regression analysis also shows that the improvement in liquidity is statistically significant, especially in terms of the reduction of bid-ask spreads. We also observe that VCMs are able to curb further price swings when trading is resumed after the cooling-off period, suggesting that VCMs in Hong Kong lead the intended results, as they prevent the continuation of large price variations while improving various facets of market liquidity.

Two important caveats are in order: First, we do not claim that VCMs are the only effective market interruption measures. In fact, it is clear from the international experience that the institutional details of existing VCMs not only differ across exchanges but also vary across different types of security traded within the same trading venue. Hence, we can reasonably conjecture that there is no single VCM implementation that fits all circumstances and the specifications of VCMs should be tailored to reflect the specificities of individual financial markets and instruments with an aim to maintain orderly trading and ensure investor protection.[21]

[21] For example, different levels of the threshold used to trigger VCMs are considered by different exchanges and trading venues.

Second, our research is among the first to empirically examine the effect of VCMs on market quality. However, our experiment is limited by our sample size, that for this study is inherently small, and by the fact that the control sample we constructed is far from perfect. Therefore, we caution against placing too much emphasis on the statistical significance derived from our statistical analysis. When larger sample becomes available, further research is needed to draw a more definitive conclusion on the effects of VCMs.

5. Concluding Remarks

To minimize extreme price variations and maintain orderly markets, most trading venues use among available tools some form of volatility interruption measures to protect investors. While VCMs are common interruption measures aimed to moderate price variations in situation of market distress, it is still debated whether these measures are beneficial to the financial market in terms of curbing price gyrations while maintaining ample market liquidity. Our empirical investigation based on Hong Kong's stock market data shows that VCMs indeed are able to curb further price swings. We also find there is a reduction in the effective bid-ask spreads, together with an increase in the depth and trading volume after VCMs are triggered. Furthermore, our difference-in-difference regression and regression discontinuity design analysis show that the improvement in market liquidity for stocks moderated by VCMs is statistically significant, in particular in terms of the effective spreads and depth.

Overall, the evidence we gather shows that VCMs in Hong Kong's stock market work well as intended. VCMs are able to prevent extreme price gyrations and improve various facets of market liquidity. In order to better ensure investor protection, it is worth noting that, based on international experience, the implementation of VCMs should consider the specificities of individual financial markets and instruments.

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Figure 1: VCM - how it works

This Figure illustrates how a VCM can be triggered. The dynamic price limits (grey solid lines) are usually expressed as percentages (i.e., ±a%) of the time-varying reference price. The static price limits (grey dotted lines) are usually expressed as percentages (i.e., ±b%) of the fixed reference price. The execution price is monitored during normal trading hours and a cooling-off period will be set off once the price exceeds or is expected to exceed the dynamic or static price limits (at the orange dots). Circuit breaker and price limit are two kinds of cooling-off measures, with the former halting trading and using an auction to determine reopening price while the latter allowing trading only within the price limits. After the cooling-off period, the execution price will continue to be monitored against the prevailing price limits.

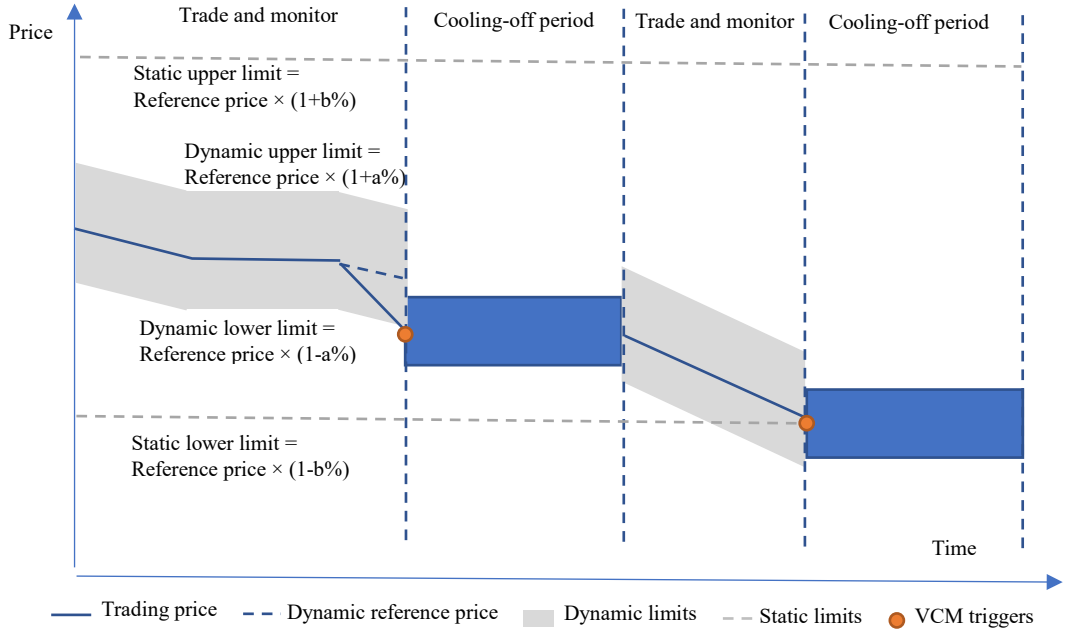

Table 1: VCMs for individual securities of selected exchanges

This table shows the key features of VCMs implemented on securities traded in international and Hong Kong exchanges. Dynamic (static) class indicates that the reference price and price limits are calculated in real-time (once or several times within a trading day). For the cooling-off arrangement, circuit breaker suspends trading and use an auction to determine reopening price while price limit allows trading only within the price limits.

Exchange	Class	Reference price(s)	Price limits	Cooling-off duration	Cooling-off arrangement
Australia (ASX)	Dynamic	Given by ASX, update every minute	0-15 cents or 10%, reject orders out of price limits	-	-
	Static	Last opening or last auction	10-50 cents or 20-50%, depends on reference price	2 minutes	Circuit breaker
Germany (Xetra)	Dynamic	Last execution	Depends on security	At least 2 minutes	Circuit breaker
	Static	Last auction in a regular auction			
Japan (JPX stocks)	Dynamic	Last execution	5-1 million yen, depends on reference price	3 minutes	Price limit
	Dynamic		Twice of the limits above	1 minutes	Circuit breaker
Japan (JPX derivatives)	Dynamic	Last auction or mid-price of the last best offer and best bid	Depends on security	At least 15 secs	Price limit
	Static	Last closing		10 minutes	Circuit breaker
Singapore (SGX)	Dynamic	Last execution 5 minutes ago	10%	5 minutes	Price limit
UK (LSE)	Dynamic	Last execution or closing	2-25%, depends on security liquidity	5 minutes	Circuit breaker
	Static	Last auction	3-25%, depends on security liquidity		
US (NYSE and Nasdaq)	Dynamic	Average of last 5 minutes execution	Tier 1: 5%, 20%, or 75% Tier 2: 10%	5 minutes	Circuit breaker
Hong Kong (HKEX)	Dynamic	Last execution 5 minutes ago	Stocks: Large (10%), Mid (15%), Small (20%) Futures: 5%	5 minutes	Price limit

Table 2: VCM trigger history

This table shows the list of 20 Volatility Control Mechanism (VCM) events from May 2020 – Jan 2021. The study excludes two stocks (stock code = 1681 and 6186) that are preceded by negative price movement in the previous 5-minutes, and one stock (stock code = 120) due to outliner price movement. The final sample has 17 events.

Stock Code	Company Name	VCM Trigger date	VCM Trigger time	5-min return before VCM trigger	Market cap (in million) (as of 2020/06/30)	Market Cap Category	Industry Sector	Trigger Price	In the Final Sample?
120	Cosmopolitan International Holdings Ltd.	2020/5/13	10:09:52	14.74%	7,719	S	Properties & construction	1.25	No
136	Hengten Networks Group Ltd.	2020/5/20	11:19:52	12.48%	10,744	M	Information technology	0.174	Yes
1681	Consun Pharmaceutical Group Ltd.	2020/5/22	10:28:43	0.00%	2,704	S	Healthcare	3.74	No
1131	Agritrade Resources Limited	2020/6/2	14:42:24	19.45%	529	S	Energy	0.09	Yes
2051	51 Credit Card Inc.	2020/6/22	11:46:41	16.73%	596	S	Financials	0.55	Yes
493	Gome Retail Holdings Ltd.	2020/6/24	13:19:15	15.16%	27,809	M	Consumer discretionary	1.55	Yes
6186	China Feihe Ltd.	2020/7/8	10:21:51	-9.13%	138,645	L	Consumer staples	15.48	No
136	Hengten Networks Group Ltd.	2020/8/4	11:11:10	13.49%	10,744	M	Information technology	0.28	Yes
687	Tysan Holdings Ltd.	2020/8/13	13:54:14	18.73%	1,397	S	Properties & construction	0.81	Yes
120	Cosmopolitan International Holdings Ltd.	2020/8/24	9:46:50	16.52%	7,719	S	Properties & construction	1.68	Yes
687	Tysan Holdings Ltd.	2020/8/26	11:33:18	18.24%	1,397	S	Properties & construction	0.62	Yes
2051	51 Credit Card Inc.	2020/9/1	13:49:47	16.19%	596	S	Financials	0.68	Yes
687	Tysan Holdings Ltd.	2020/9/3	9:51:01	18.88%	1,397	S	Properties & construction	0.57	Yes
1141	Cmbc Capital Holdings Ltd.	2020/9/7	9:47:24	16.67%	7,816	S	Financials	0.19	Yes
1269	China First Capital Group Ltd.	2020/11/6	13:29:39	16.86%	1,357	S	Consumer discretionary	0.143	Yes
410	Soho China Limited	2020/11/13	13:18:52	13.85%	14,143	M	Properties & construction	2.74	Yes
2858	Yixin Group Ltd.	2020/12/4	10:01:34	14.40%	12,112	M	Financials	2.49	Yes
1269	China First Capital Group Ltd.	2020/12/8	10:31:55	19.15%	1,357	S	Consumer discretionary -	0.128	Yes
302	Cmge Technology Group Ltd.	2020/12/22	13:48:32	18.57%	8,319	S	Information technology -	3.57	Yes
2727	Shanghai Electric Group Company Ltd.	2021/1/8	11:12:58	19.04%	6,540	S	Industrials - industrial engineering	2.99	Yes

Figure 2: Price movement around VCM cooling-off period

The two figures below show the pattern of price movement of 17 VCM stocks one-hour before and after VCM cooling-off period. The left panel is based on bid-ask quotations, and the right panel is based on trade prices.

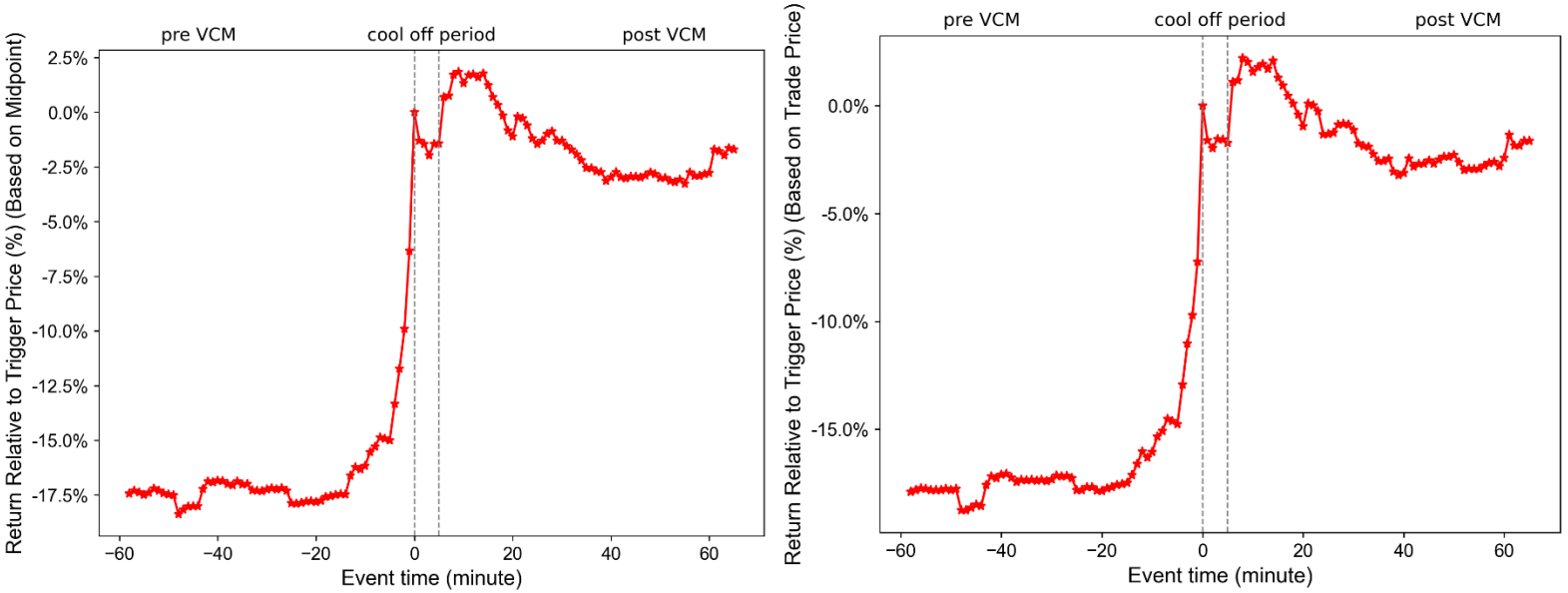

Figure 3: Quoted spread around VCM cooling-off period

The two figures below show the pattern of quoted bid-ask spread of 17 VCM stocks one-hour before and after the VCM cooling-off period. The left figure shows the average of Quoted Spread Ratio, which is defined as the ratio of Quoted Spread (the time-weighted average of the spread between the best bid and ask prices) of each five-minute interval over the average Quoted Spread of 25 intervals. The right figure shows the average of Quoted Spread10 Ratio, which is defined as the ratio of Quoted Spread10 (the time-weighted average of the spread between the 10th best bid and 10th best ask prices) of each five-minute interval over the average Quoted Spread 10 of 25 intervals.

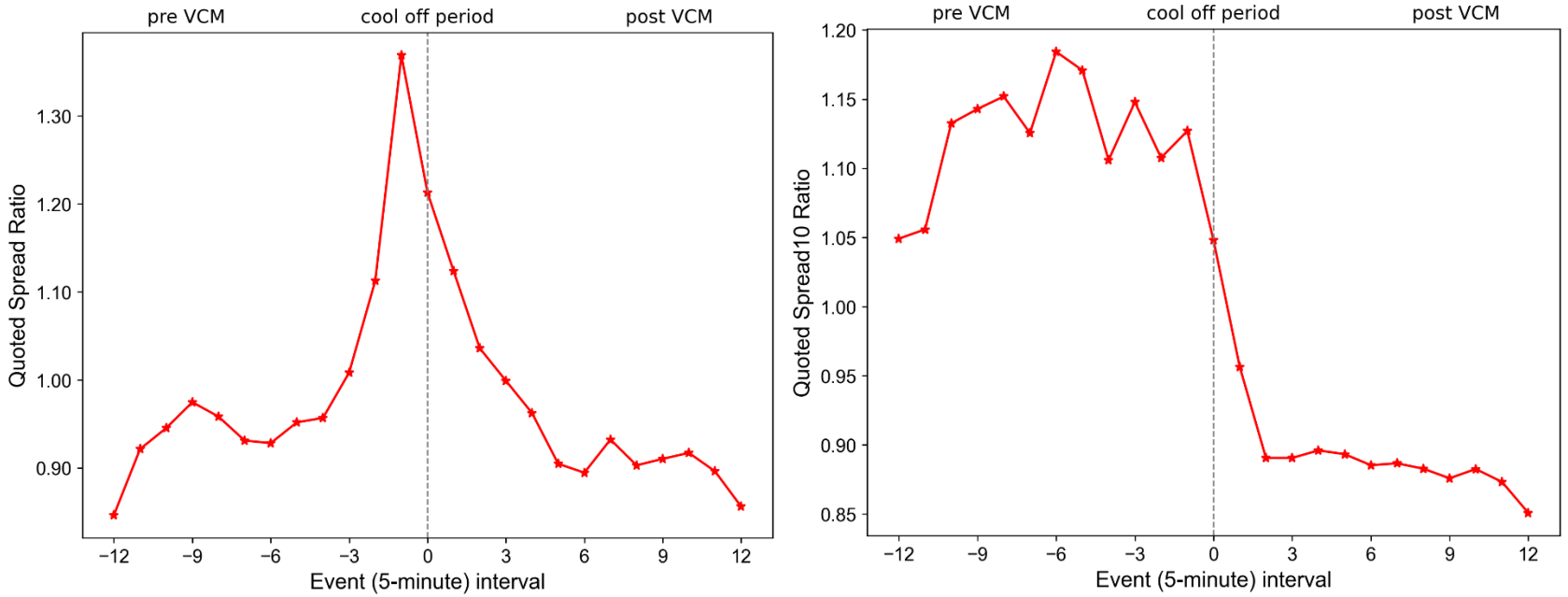

Figure 4: Depth around VCM cooling-off period

The two figures below show the pattern of depth (size at the best bid and ask prices) of 17 VCM stocks one-hour before and after VCM cooling-off period. The left figure shows the average of Depth Ratio, which is defined as the ratio of Depth (the time-weighted of sum of depth size at the best bid and ask prices) of each five-minute interval over the average Depth of 25 intervals. The right figure shows the average of Depth10 Ratio, which is defined as the ratio of Depth10 (the time-weight of sum of depth size between the 10th best bid and 10th best ask prices) of each five-minute interval over the average Depth10 of 25 intervals.

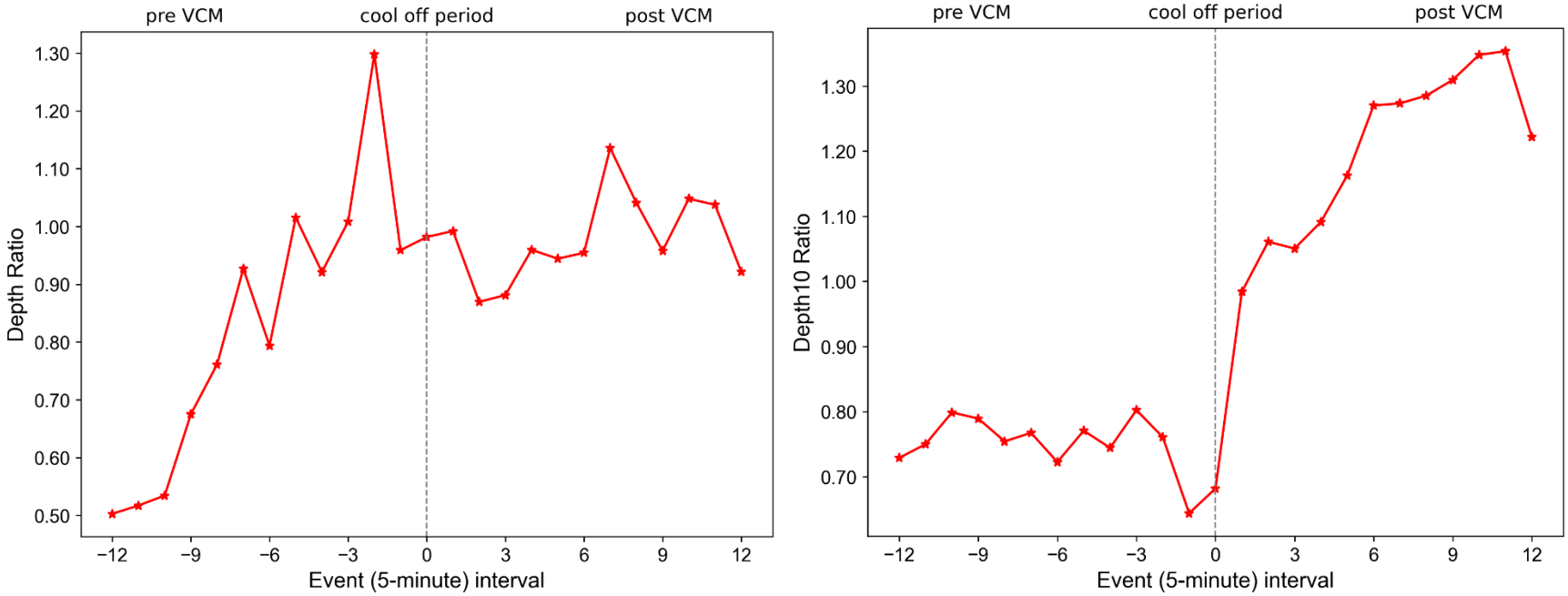

Figure 5: Trading volume around VCM cooling-off period

The two figures below show the pattern of trading volume of 17 VCM stocks one-hour before and after VCM cooling-off period. The left figure shows the proportion of volume (trading volume in shares) of each five-minute interval, which is defined as the ratio of trading volume in the 5-minute interval to the total of trading volume over 25 intervals. The right figure shows the proportion of dollar volume, which is defined as the ratio of dollar volume in the 5-minute interval to the total of dollar volume over 25 intervals.

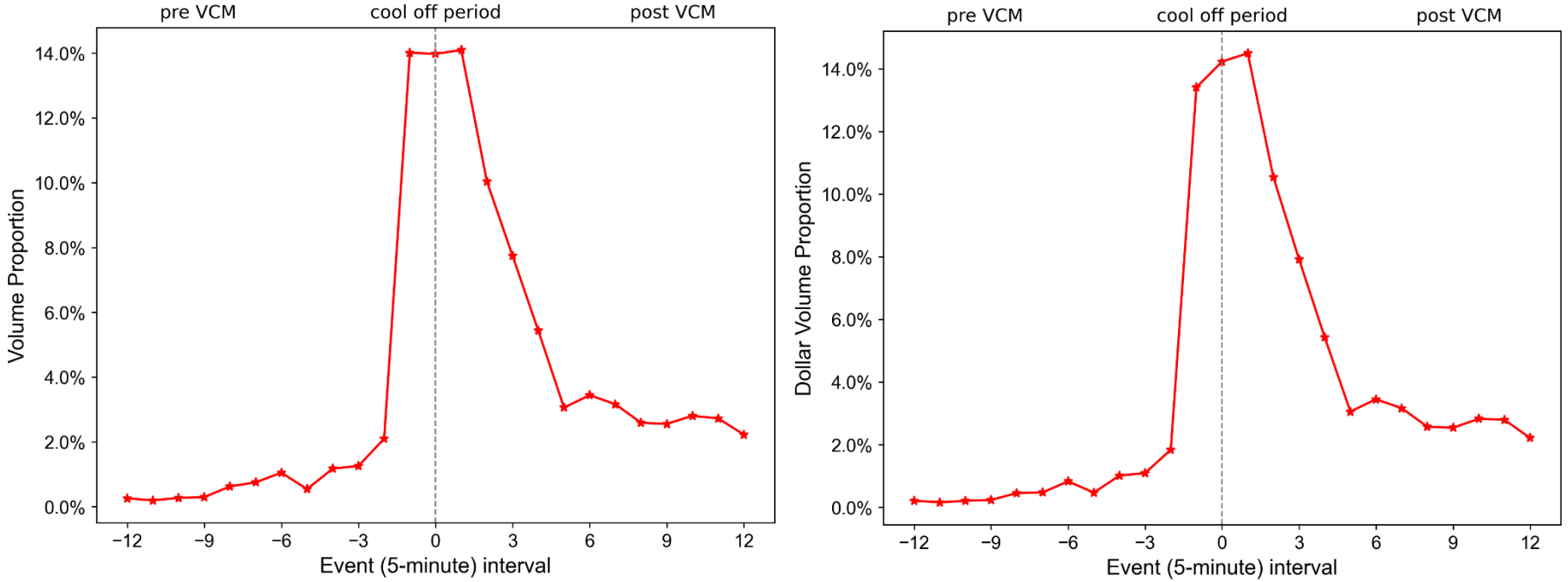

Figure 6: Realized variance around VCM cooling-off period

The figure below shows the pattern of realized variance of 17 VCM stocks one-hour before and after VCM cooling-off period, with the Realized Variance Ratio, which is defined as the ratio of Realized Variance (sum of the square of each 15-second return) of each five-minute interval over the average Realized Variance of 25 intervals.

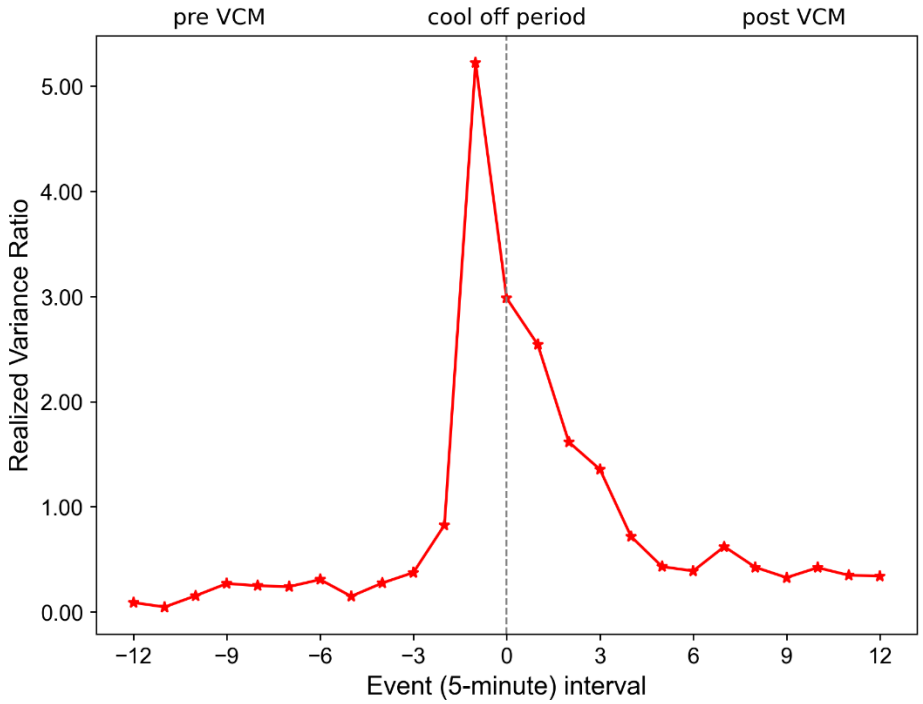

Figure 7: Effective spread around VCM cooling-off period

The figure below shows the pattern of effective bid-ask spread of 17 VCM stocks before and after VCM cooling-off period. The Effective Spread Ratio is defined as the ratio of dollar-volume-weighted Effective Spread (the time-weighted average of the spread between the trade price and the best bid (or ask) price) of each five-minute interval over the average Effective Spread of 25 intervals.

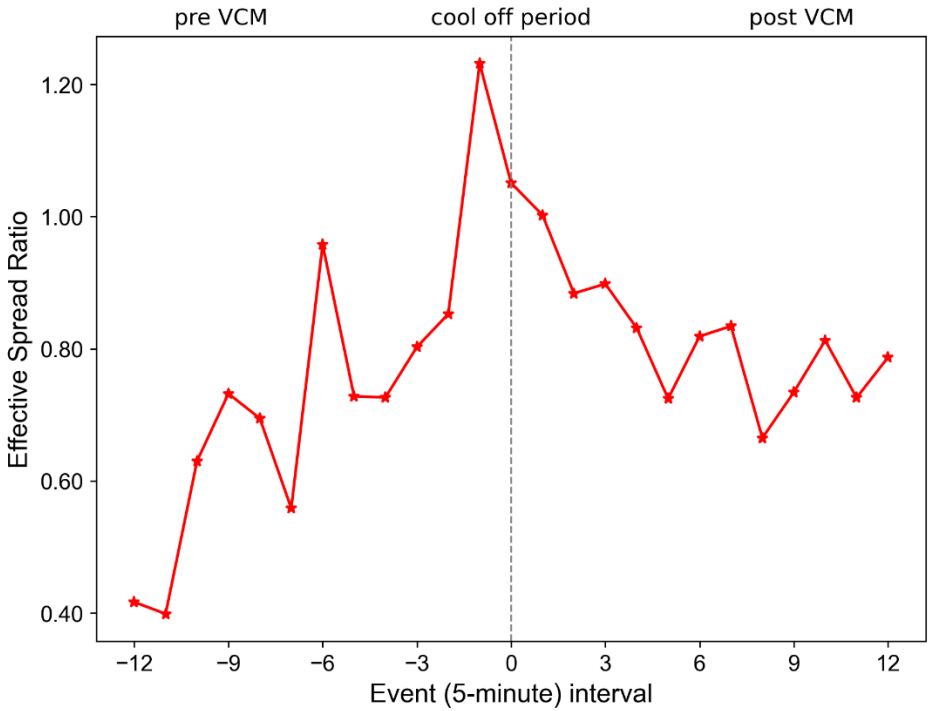

Figure 8: Order imbalance and depth imbalance around VCM cooling-off period

The two figures below show the pattern of order imbalance and depth imbalance of 17 VCM stocks one-hour before and after VCM cooling-off period. The left panel shows the average of Order Imbalance Ratio, which is defined as Order Imbalance (the difference between buy volume and sell volume) divided by the total trading volume of each five-minute interval. The right panel shows the average of Depth Imbalance Ratio, which is defined as Depth Imbalance (the difference between depth size at the best bid and best ask prices) divided by the total depth of each five-minute interval.

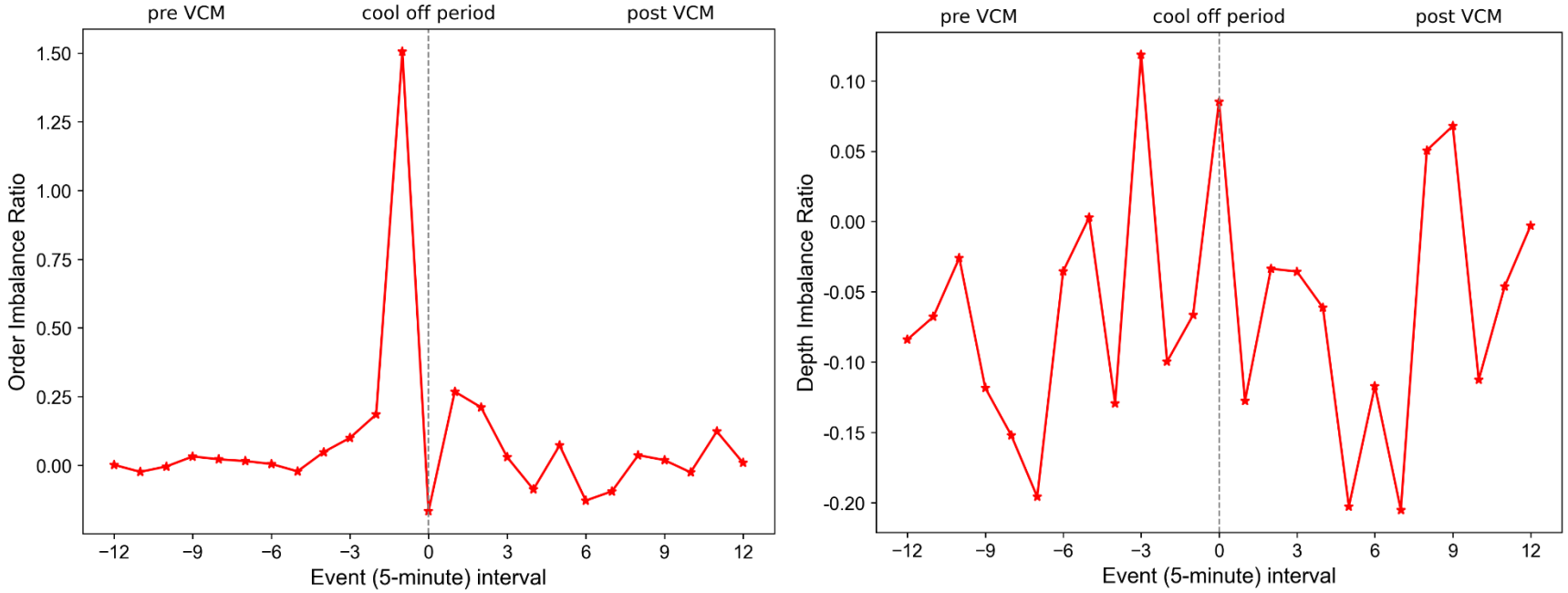

Table 3: Comparison of liquidity and volatility variables before and after VCM events

For each VCM stock, we calculate each market variable capturing either liquidity and volatility 60 minutes (or 30 minutes) before and after VCM cooling-off period. Quoted Spread is the time-weighted average of quoted bid-ask spread; Quoted Spread10 is the time-weighted average of spread between the 10th best bid and 10th best ask prices; Log(Depth) is the log of Depth (the time-weighted average of sum of bid depth and ask depth); Log(Depth10) is the log of Depth10 (time-weighted average of sum of depth size between the 10th best bid and 10th best ask prices); Log(Volume) is the log of Volume (total trading volume in shares); Log(Dollar Volume) is the log of Dollar Volume (total trading dollar volume); Realized Variance is the sum of the square of each 15-second return; Effective Spread is the dollar-weighted average of the time-weighted average of the spread between the trade price and the best bid (or ask) price; Order Imbalance Ratio is the Order Imbalance (the difference between buy volume and sell volume) divided by the total trading volume; Depth Imbalance Ratio is defined as defined as Depth Imbalance (the difference between depth size at the best bid and best ask prices) divided by the total depth. Each variable is winsorized at 2% level. Panel A shows the result based on 60 minutes before /after cooling-off period while panel B shows the result based on 30 minutes before/after VCM cooling-off period. The Wilcoxon sign rank test is conducted for testing whether the pre- and post-VCM variables are equal, and statistics that are significant at 10% (5%) level are denoted by * (**).

Panel A: 60 minutes before (pre) and after (post) VCM, mean and median

	Quoted Spread (in %)	Quoted Spread10 (in %)	Log(Depth)	Log (Depth10)	Log (Volume)	Log(Dollar Volume)	Realized Variance	Effective Spread (in %)	Order Imbalance Ratio (in %)	Depth Imbalance Ration (in %)
Pre mean	1.2991	28.7980	13.5326	15.8197	16.6492	16.0606	0.0119	0.8775	53.2385	-7.5437
Pre median	1.0012	18.8626	13.0918	15.4280	16.9972	15.7430	0.0069	0.7279	53.3668	-8.6335
Post mean	1.1550	18.4234	13.6018	16.3625	17.7921	17.3223	0.0181	0.7637	-1.3896	-6.6036
Post median	0.9542	15.6300	13.0354	16.0678	17.8187	17.5431	0.0102	0.6290	3.4528	-4.6961
p-value (pre=post)	0.1454	0.0046**	0.6441	0.0000**	0.0001**	0.0001**	0.1594	0.0714*	0.0000**	0.8900

Table 3 (cont'd)

Panel B: 30 minutes before (pre) and after (post) VCM, mean and median

	Quoted Spread (in %)	Quoted Spread10 (in %)	Log (Depth)	Log (Depth10)	Log (Volume)	Log (Dollar Volume)	Realized Variance	Effective Spread (in %)	Order Imbalance Ratio (in %)	Depth Imbalance Ration (in %)
Pre mean	1.3280	28.6834	13.6024	15.8275	16.5654	15.9841	0.0105	0.8992	55.04339	-4.5942
Pre median	1.0012	18.8626	13.2190	15.3484	16.8798	15.6305	0.0066	0.7279	55.29563	-8.6335
Post mean	1.1987	18.7918	13.5551	16.2691	17.4083	16.9433	0.0141	0.7781	-0.8209	-10.8830
Post median	1.0262	15.6618	13.0372	15.9206	17.2618	17.1682	0.0060	0.6404	2.6095	-13.0756
p-value (pre=post)	0.3318	0.0065**	0.6874	0.0031**	0.0065**	0.0031**	0.5540	0.1488	0.0003**	0.5540

Table 4: Difference-in-difference (DID) Regression Analysis

This table shows the DID regression result for different market variables capturing liquidity or volatility of VCM stocks and control stocks. To construct the control sample, each VCM stock is matched with 4 stocks from a similar market cap or lower cap category, that has the highest 5-minute returns in any time interval of the same day as the VCM event. The DID regression equation is specified as follows.

$$Var_{i,post} = \beta_0 + \beta_1 \times VCM_i + \beta_2 \times Var_{i,pre} + \beta_3 \times VCM_i \times Var_{i,pre} + \epsilon_i$$

where VCM_i equals 1 if stock *i* is a VCM stock and 0 if a control stock, $Var_{i,pre}$ and $Var_{i,post}$ are one of the market variables in the trading session before and after, respectively, the cooling-off period (for VCM stocks), or before and after, respectively, the large 5-minute price movement though not reaching triggering threshold (non-VCM stocks). Quoted Spread is the time-weighted average of quoted bid-ask spread; Quoted Spread10 is the time-weighted average of spread between the 10th best bid and 10th best ask prices; Log(Depth) is the log of Depth (the time-weighted average of sum of bid depth and ask depth); Log(Depth10) is the log of Depth10 (time-weighted average of sum of depth size between the 10th best bid and 10th best ask prices); Log(Volume) is the log of Volume (total trading volume in shares); Log(Dollar Volume) is the log of Dollar Volume (total trading dollar volume); Realized Variance is the sum of the square of each 15-second return; Effective Spread is the dollar-weighted average of the time-weighted average of the spread between the trade price and the best bid (or ask) price; Order Imbalance Ratio is the Order Imbalance (the difference between buy volume and sell volume) divided by the total trading volume; Depth Imbalance Ratio is defined as defined as Depth Imbalance (the difference between depth size at the best bid and best ask prices) divided by the total depth. Each variable is winsorized at 2% level and each regression is clustered at daily level. Panel A shows the results based on 60 minutes before/after cooling-off period while panel B shows the results based on 30 minutes before/after cooling-off period. *, ** and *** represent statistical significance level at 10%, 5% and 1% levels, respectively. Panels C and e-off period, while including additional explanatory variables, including return volatility, price, firm size, past return, and book-to-market ratio.

Table 4 (cont'd)

Panel A: DID regression result based on 60 minutes before/after the cooling-off period

	Quoted Spread (in %)	Quoted Spread10 (in %)	Log (Depth)	Log (Depth10)	Log (Volume)	Log(Dollar Volume)	Realized Variance	Effective Spread (in %)	Order Imbalance Ratio (in %)	Depth Imbalance Ratio (in %)
VCM dummy	-0.348*	1.374	1.321	0.420	1.471	-0.883	0.001	-0.600***	-18.781	-4.960
	(-1.86)	(0.32)	(0.70)	(0.24)	(0.41)	(-0.26)	(0.22)	(-4.92)	(-0.62)	(-0.60)
VCM dummy × Pre VCM variable	0.241	-0.129	-0.080	-0.003	-0.008	0.139	0.685***	0.708***	0.192	0.129
	(1.53)	(-0.79)	(-0.57)	(-0.02)	(-0.04)	(0.67)	(3.93)	(5.01)	(0.40)	(0.51)
Pre VCM variable	0.464***	0.349**	0.855***	0.905***	0.812***	0.764***	0.274*	0.062	0.359**	-0.088
	(11.38)	(2.85)	(10.00)	(15.88)	(9.95)	(9.23)	(1.77)	(1.17)	(2.26)	(-0.78)
Constant	0.582***	10.713***	1.815	1.673*	2.948**	3.723***	0.006**	0.682***	-12.096	-1.427
	(7.93)	(3.39)	(1.74)	(1.99)	(2.36)	(2.93)	(2.47)	(11.65)	(-1.71)	(-0.59)
N	82	82	82	82	82	82	82	82	82	82
R^2	0.534	0.363	0.835	0.906	0.837	0.793	0.530	0.468	0.303	0.145

Table 4 (cont'd)

Panel B: DID regression result based on 30 minutes before/after the cooling-off period

	Quoted Spread (%)	Quoted spread10 (%)	Log (Depth)	Log (Depth10)	Log (Volume)	Log(Dollar volume)	Realized variance	Effective spread (%)	Order imbalance ratio (%)	Depth imbalance ratio (%)
VCM dummy	-0.406*	1.842	1.111	0.705	0.712	-0.352	-0.000	-0.628***	-32.855	-6.647
	(-2.10)	(0.42)	(0.66)	(0.40)	(0.18)	(-0.11)	(-0.10)	(-4.55)	(-0.91)	(-0.73)
VCM dummy × Pre VCM variable	0.262	-0.139	-0.065	-0.023	0.035	0.102	0.836*	0.732***	0.369	0.148
	(1.38)	(-0.79)	(-0.54)	(-0.20)	(0.15)	(0.50)	(2.12)	(4.56)	(0.67)	(0.64)
Pre VCM variable	0.445***	0.359***	0.860***	0.914***	0.859***	0.875***	0.149**	0.044	0.497**	-0.076
	(7.13)	(3.02)	(12.82)	(20.20)	(13.50)	(11.43)	(2.81)	(0.89)	(2.61)	(-0.57)
Constant	0.658***	10.634***	1.659*	1.460**	1.898*	1.704	0.004***	0.702***	-16.185	-3.591
	(6.11)	(3.52)	(2.03)	(2.18)	(1.94)	(1.46)	(3.69)	(13.17)	(-1.74)	(-1.21)
N	82	82	82	82	82	82	82	82	82	82
R^2	0.534	0.363	0.835	0.906	0.837	0.793	0.530	0.468	0.303	0.145

Table 4 (cont'd)

Panel C: DID regression result based on 60 minutes before/after the cooling-off period, with control variables included

	Quoted Spread (in %)	Quoted Spread10 (in %)	Log (Depth)	Log (Depth10)	Log (Volume)	Log (Dollar Volume)	Realized Variance	Effective Spread (in %)	Order Imbalance Ratio (in %)	Depth Imbalance Ratio (in %)
VCM dummy	-0.354*	0.039	-1.687	0.220	2.297	-1.369	0.007	-0.413***	-17.797	-4.907
	(-1.77)	(0.01)	(-1.17)	(0.11)	(0.76)	(-0.41)	(1.22)	(-2.94)	(-0.58)	(-0.41)
VCM*dummy x Pre VCM variable	0.326**	-0.072	0.152	0.011	-0.046	0.183	0.668***	0.563***	0.324	0.093
	(2.20)	(-0.46)	(1.40)	(0.09)	(-0.26)	(0.88)	(4.22)	(3.49)	(0.69)	(0.32)
Pre VCM variable	0.419***	0.269*	0.619***	0.838***	0.780***	0.771***	0.224	0.091	0.324**	-0.103
	(7.46)	(2.11)	(6.46)	(9.54)	(12.35)	(13.09)	(1.43)	(1.54)	(2.16)	(-0.80)
Past Volatility	-0.007	2.539	0.284**	0.108	0.464**	0.418**	0.005***	0.002	1.250	14.080**
	(-0.09)	(1.54)	(2.12)	(0.87)	(2.56)	(2.15)	(3.25)	(0.02)	(0.36)	(2.26)
Price	0.062	-1.508**	-0.285***	-0.019	-0.027	0.044	-0.001	-0.013	8.350**	-4.525*
	(1.06)	(-2.26)	(-3.48)	(-0.22)	(-0.32)	(0.54)	(-1.19)	(-0.61)	(2.17)	(-1.94)
Firm Size	-0.101*	-0.604	0.126	0.040	-0.100	-0.163	-0.003***	-0.073**	-5.620	-1.699
	(-2.12)	(-0.84)	(1.24)	(0.64)	(-0.68)	(-1.18)	(-2.99)	(-2.66)	(-1.13)	(-0.41)
Past return	0.051	0.402	0.564**	0.388***	0.226	0.184	0.000	-0.011	9.942	14.038
	(0.52)	(0.18)	(2.50)	(3.31)	(0.71)	(0.55)	(0.01)	(-0.10)	(1.15)	(1.23)
Book-to-market	-0.002	0.017	0.004	0.007	-0.011	-0.012	-0.000	-0.011**	-0.565*	0.475**
	(-0.65)	(0.29)	(0.85)	(1.43)	(-1.34)	(-1.29)	(-1.68)	(-2.46)	(-2.08)	(2.71)
Constant	1.292***	17.033**	3.932***	2.293	3.781***	4.365***	0.027**	1.214***	17.663	2.221
	(3.19)	(2.19)	(4.23)	(1.54)	(3.48)	(5.30)	(2.88)	(5.85)	(0.51)	(0.08)
N	73	73	73	73	73	73	73	73	73	73
R^2	0.600	0.513	0.870	0.903	0.876	0.837	0.720	0.568	0.406	0.307

Table 4 (cont'd)

Panel D: DID regression result based on 30 minutes before/after the cooling-off period, with control variables included

	Quoted Spread (in %)	Quoted Spread10 (in %)	Log (Depth)	Log (Depth10)	Log (Volume)	Log(Dollar Volume)	Realized Variance	Effective Spread (in %)	Order Imbalance Ratio (in %)	Depth Imbalance Ratio (in %)
VCM dummy	-0.405*	0.466	-0.164	1.166	2.480	-1.049	0.004	-0.516**	-23.239	2.270
	(-1.87)	(0.10)	(-0.10)	(0.61)	(0.73)	(-0.33)	(0.63)	(-2.92)	(-0.57)	(0.21)
VCM*dummy x Pre VCM variable	0.333*	-0.082	0.034	-0.052	-0.059	0.164	0.839**	0.657***	0.370	0.350
	(1.91)	(-0.49)	(0.29)	(-0.42)	(-0.29)	(0.82)	(2.34)	(3.12)	(0.63)	(1.32)
Pre VCM variable	0.388***	0.282**	0.712***	0.893***	0.880***	0.906***	0.073	0.082	0.417***	-0.238
	(6.81)	(2.21)	(8.69)	(14.65)	(13.17)	(13.94)	(0.87)	(1.30)	(2.98)	(-1.58)
Past Volatility	-0.049	2.303	0.288*	0.083	0.391*	0.380	0.003**	0.024	10.056**	13.396**
	(-0.57)	(1.61)	(2.08)	(0.76)	(1.77)	(1.52)	(2.13)	(0.30)	(2.42)	(2.34)
Price	0.037	-1.296*	-0.177*	0.022	0.090	0.119	-0.000	-0.006	9.791***	-4.970
	(0.97)	(-2.00)	(-2.04)	(0.26)	(1.11)	(1.54)	(-0.69)	(-0.29)	(3.00)	(-1.40)
Firm Size	-0.116**	-0.648	0.060	0.007	-0.191	-0.281**	-0.003**	-0.063*	-5.811	-4.093
	(-2.17)	(-0.85)	(0.59)	(0.13)	(-1.47)	(-2.35)	(-2.44)	(-2.06)	(-0.92)	(-1.60)
Past return	0.124	0.694	0.503*	0.356**	0.146	0.086	0.001	0.052	9.881	21.746
	(1.23)	(0.33)	(2.06)	(2.47)	(0.45)	(0.25)	(0.28)	(0.59)	(1.13)	(1.55)
Book-to-market	-0.007**	0.008	0.006	0.009*	-0.007	-0.008	-0.000	-0.012**	0.134	0.254
	(-2.41)	(0.15)	(1.02)	(1.75)	(-0.62)	(-0.69)	(-1.32)	(-2.28)	(0.42)	(1.08)
Constant	1.575***	17.181**	3.029**	1.600	2.475**	2.743**	0.022**	1.122***	6.012	13.251
	(3.73)	(2.19)	(2.86)	(1.27)	(2.33)	(2.71)	(2.67)	(5.05)	(0.14)	(0.70)
N	73	73	73	73	73	73	73	73	73	73
R^2	0.569	0.487	0.856	0.906	0.891	0.862	0.671	0.553	0.412	0.260

Table 5: Regression Discontinuity Design (RDD) Regression Analysis

This table shows the regression discontinuity design (RDD) result for different market variables capturing liquidity or volatility of VCM stocks and control stocks. To construct the control sample, each VCM stock is matched with 4 stocks from a similar market cap or lower cap category, that has the highest 5-minute returns in any time interval of the same day as the VCM event. The RDD analysis is specified as follows:

$$Var_{i,post} = \beta_0 + \beta_1 \times VCM_i + \beta_2 \times Var_{i,pre} + f\ (Distance) + Control + \epsilon_i$$

where VCM_i equals 1 if stock *i* is a VCM stock and 0 if a control stock, $Var_{i,pre}$ and $Var_{i,post}$ are one of the market variables in the trading session before and after, respectively, the cooling-off period (for VCM stocks), or before and after, respectively, the large 5-minute price movement though not reaching triggering threshold (non-VCM stocks), *Distance* is the difference between the pre-VCM 5-minute return and the VCM threshold, and *Contro*l is the set of control variables, including return volatility, price, firm size, past return, and book-to-market ratio. The VCM threshold for the treatment stocks (i.e. VCM stocks) will be 10%, 15% and 20%, for large cap stocks, medium cap stocks, and small cap stocks, and the VCM threshold for the control stocks is based on the threshold for the VCM stocks being matched against. Quoted Spread is the time-weighted average of quoted bid-ask spread; Quoted Spread10 is the time-weighted average of spread between the 10^{th} best bid and 10^{th} best ask prices; Log(Depth) is the log of Depth (the time-weighted average of sum of bid depth and ask depth); Log(Depth10) is the log of Depth10 (time-weighted average of sum of depth size between the 10^{th} best bid and 10^{th} best ask prices); Log(Volume) is the log of Volume (total trading volume in shares); Log(Dollar Volume) is the log of Dollar Volume (total trading dollar volume); Realized Variance is the sum of the square of each 15-second return; Effective Spread is the dollar-weighted average of the time-weighted average of the spread between the trade price and the best bid (or ask) price; Order Imbalance Ratio is the Order Imbalance (the difference between buy volume and sell volume) divided by the total trading volume; Depth Imbalance Ratio is defined as defined as Depth Imbalance (the difference between depth size at the best bid and best ask prices) divided by the total depth. Each variable is winsorized at 2% level and each regression is clustered at daily level. Panel A shows the results based on 60 minutes before/after cooling-off period while panel B shows the results based on 30 minutes before/after cooling-off period. *, ** and *** represent statistical significance level at 10%, 5% and 1% levels, respectively. Panels C and D shows the results based on 60 minutes and 30 minutes before/after cooling-off period, while including additional explanatory variables, including return volatility, price, firm size, past return, and book-to-market ratio.

Table 5 (cont'd)

Panel A: RDD result based on 60 minutes before/after the cooling-off period, with control variables included

	Quoted Spread (in %)	Quoted Spread10 (in %)	Log (Depth)	Log (Depth10)	Log (Volume)	Log(Dollar Volume)	Realized Variance	Effective Spread (in %)	Order Imbalance Ratio (in %)	Depth Imbalance Ratio (in %)
VCM dummy	0.716***	5.907	-0.062	0.545*	1.591***	1.654***	0.007	-0.292**	-4.549	-5.216
	(3.32)	(1.04)	(-0.17)	(2.11)	(3.80)	(3.17)	(0.75)	(-2.39)	(-0.26)	(-0.31)
Pre VCM variable	0.470***	0.214	0.665***	0.842***	0.764***	0.788***	0.176	0.112**	0.342**	-0.082
	(6.89)	(1.65)	(7.02)	(9.78)	(11.20)	(10.80)	(0.92)	(2.21)	(2.26)	(-0.72)
Distance	-2.250**	-36.86***	-0.397	-0.238	2.781	3.691	0.040	-0.188	125.464*	23.921
	(-2.92)	(-4.36)	(-0.19)	(-0.17)	(1.13)	(1.33)	(1.10)	(-0.25)	(1.77)	(0.23)
Distance*VCM dummy	-16.83***	-189.49	14.316	-4.799	10.528	17.604	-0.201	-20.238***	190.269	106.225
	(-2.94)	(-1.09)	(1.28)	(-0.50)	(0.58)	(0.85)	(-0.61)	(-5.60)	(0.35)	(0.16)
Past Volatility	0.028	3.322*	0.294**	0.114	0.419*	0.354	0.004**	0.026	-0.049	13.794**
	(0.38)	(1.98)	(2.32)	(0.94)	(2.06)	(1.62)	(2.30)	(0.32)	(-0.01)	(2.45)
Price	0.035	-1.782**	-0.263**	-0.017	-0.019	0.082	-0.001	-0.022	8.932**	-4.291
	(0.54)	(-2.87)	(-2.90)	(-0.19)	(-0.24)	(1.24)	(-1.14)	(-1.01)	(2.41)	(-1.66)
Firm Size	-0.097*	-0.620	0.088	0.046	-0.093	-0.104	-0.003**	-0.071*	-4.515	-1.517
	(-1.77)	(-0.74)	(0.70)	(0.62)	(-0.60)	(-0.69)	(-2.55)	(-1.85)	(-0.91)	(-0.36)
Past return	0.070	1.487	0.590**	0.395**	0.166	0.119	-0.002	-0.034	8.085	13.435
	(0.68)	(0.59)	(2.47)	(2.65)	(0.52)	(0.35)	(-1.41)	(-0.38)	(0.93)	(1.13)
Book-to-market	-0.001	0.007	0.005	0.007	-0.011	-0.010	-0.000	-0.013***	-0.547*	0.495**
	(-0.45)	(0.12)	(0.92)	(1.54)	(-1.27)	(-0.87)	(-1.41)	(-3.23)	(-1.89)	(2.65)
Constant	1.128**	17.391*	3.587***	2.179	4.212***	3.959***	0.026**	1.157***	18.410	3.044
	(2.51)	(2.07)	(3.93)	(1.50)	(3.98)	(3.20)	(2.76)	(4.29)	(0.51)	(0.11)
N	73	73	73	73	73	73	73	73	73	73
R^2	0.632	0.563	0.870	0.904	0.880	0.843	0.652	0.607	0.430	0.307

Table 5 (cont'd)

Panel B: RDD result based on 30 minutes before/after the cooling-off period, with control variables included

	Quoted Spread (in %)	Quoted Spread10 (in %)	Log (Depth)	Log (Depth10)	Log(Volume)	Log(Dollar Volume)	Realized Variance	Effective Spread (in %)	Order Imbalance Ratio (in %)	Depth Imbalance Ratio (in %)
VCM dummy	0.760**	7.507	0.234	0.631*	1.813***	1.829***	0.007	-0.321**	-5.943	7.347
	(2.34)	(1.17)	(0.59)	(1.88)	(4.47)	(3.81)	(0.98)	(-2.78)	(-0.36)	(0.53)
Pre VCM variable	0.448***	0.213	0.687***	0.853***	0.856***	0.913***	0.016	0.109*	0.430***	-0.129
	(6.71)	(1.51)	(7.30)	(11.62)	(11.29)	(11.18)	(0.26)	(2.11)	(3.38)	(-0.81)
Distance	-2.685***	-38.71***	-3.674**	-1.874	1.770	2.355	0.030	-0.234	166.484***	-98.463
	(-3.08)	(-4.74)	(-2.19)	(-1.18)	(0.78)	(0.92)	(1.35)	(-0.37)	(3.61)	(-0.98)
Distance*VCM dummy	-18.461*	-233.830	10.927	-5.041	18.380	20.721	-0.136	-21.853***	348.611	121.927
	(-2.10)	(-1.22)	(0.88)	(-0.46)	(0.95)	(0.98)	(-0.45)	(-4.87)	(0.62)	(0.16)
Past Volatility	-0.008	3.148**	0.351**	0.118	0.361	0.334	0.002	0.050	8.126*	15.094**
	(-0.09)	(2.13)	(2.40)	(1.03)	(1.57)	(1.28)	(1.37)	(0.53)	(1.99)	(2.53)
Price	0.008	-1.640**	-0.220**	-0.018	0.085	0.147**	-0.000	-0.018	10.591***	-5.352
	(0.19)	(-2.70)	(-2.26)	(-0.21)	(1.07)	(2.15)	(-0.87)	(-0.86)	(3.32)	(-1.65)
Firm Size	-0.113*	-0.609	0.019	0.010	-0.207	-0.243*	-0.002**	-0.064	-4.582	-4.719*
	(-1.87)	(-0.67)	(0.16)	(0.15)	(-1.51)	(-1.91)	(-2.53)	(-1.51)	(-0.74)	(-1.84)
Past return	0.153	1.911	0.597**	0.402**	0.106	0.048	-0.002	0.020	7.406	21.455
	(1.48)	(0.84)	(2.33)	(2.27)	(0.32)	(0.13)	(-0.98)	(0.22)	(0.87)	(1.47)
Book-to-market	-0.007*	-0.003	0.006	0.008*	-0.007	-0.006	-0.000	-0.014***	0.159	0.224
	(-2.00)	(-0.05)	(0.88)	(1.77)	(-0.65)	(-0.48)	(-1.27)	(-3.24)	(0.51)	(0.90)
Constant	1.394**	17.458*	3.539***	2.154	3.119**	2.533*	0.023***	1.078***	9.331	12.020
	(2.89)	(1.94)	(3.61)	(1.62)	(2.87)	(1.84)	(3.16)	(3.54)	(0.22)	(0.53)
N	73	73	73	73	73	73	73	73	73	73
R^2	0.617	0.549	0.867	0.909	0.894	0.865	0.567	0.583	0.452	0.257