Asymmetric and negative return-volatility relationship: the case of the VKOSPI

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Abstract

This study examines the short-term relationship between stock market returns and implied volatility using high frequency data . This is the first study to analyze high frequency data on the VKOPSIa newly introduced volatility index implied by the KOSPI200 options. KOSPI 200 optioins are the most actively traded derivative contracts in the world and trading is dominate by individuals. We find a strong asymmetric and negative return-volatility relationship both at the daily and intraday frequency, which cannot be explained by the standardhypotheses on the asymmetric volatility effect. Our results also show that the relationship is more pronounced in the presence of extremely negative stock market returns.

JEL classification:

Keywords: Asymmetric volatility, Implied volatility, VKOSPI, KOSPI200 options

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1. Introduction

The relationship between stock market returns and volatility has been the subject of a number of studies in the financial economic literature. These studies evidence of a negative and asymmetric relationship. Specifically a negative return is generally associated with a large increase in volatility whereas the same magnitude of positive return is associated with a relatively small decrease in volatility. Traditionally, two representative hypotheses, the *leverage hypothesis* and the *volatility feedback hypothesis*, have explained this phenomenon. According to the leverage hypothesis, if the stock price of a firm declines, the relative proportion of equity (debt) value to the firm value decreases (increases) (See Black (1976) and Christie (1982)), which makes the firm's stock riskier and increases its volatility as a result. The volatility feedback hypothesis states that the negative change in expected return tends to be intensified whereas the positive change in the expected return tends to be dampened and these effects generate the asymmetric volatility phenomenon (See French, Schwert, and Stambaugh (1987), Campbell and Hentschel (1992), and Ghysels, Santa-Clara, and Valkanov (2005)).

Although many studies have reported the asymmetric and negative return-volatility relationship using low frequency (i.e. weekly or monthly) data (See Bekaert and Wu (2000) and Avramov, Chordia, and Goyal (2006)), the two hypotheses may not be appropriate to explain the return-volatility relationship at a higher frequency (i.e. daily or intraday) level in that the leverage and volatility feedback effects are related to the changes in the fundamental factors of firms, and thus may only be reflected in the long run. Another limitation of most previous studies is that they base their research on either historical or realized volatilities, which contain little information on the future state of the market and investor sentiments. With this in mind, adopting the models of Hibbert, Daigler, and Dupoyet (2008), which incorporate the behavioral explanations on the asymmetric volatility phenomenon, this study investigates the short-term dynamic relationship between the stock market return and the implied volatility using the daily and intraday data on the Korean market.

We analyze the short-term relationship using VKOSPI (Volatility Index of the KOSPI200) as our implied volatility measure because of the unique traits of the KOSPI200 index options market. The VKOSPI is a recently published market volatility index and is calculated from the market prices of the KOSPI200 options, which are the most actively traded derivatives in the world. Despite the large trading volume of the KOSPI200 options, there is little academic research on the Korea's implied volatility index and, to our knowledge, not even a single paper investigates the intraday properties of the VKOSPI. Another important trait of the KOSPI200 options market is that domestic individual investors actively trade the options and the options market is very speculative as a result. Considering that the domestic individuals, who are dominant market players in the KOSPI200 options market, but tend to be easily affected by market sentiment and other behavioral biases, and that the options market is very speculative and reflects information shocks very quickly, the volatility index implied by Korean's index options provides an ideal opportunity to examine the short-term asymmetric return-volatility relationship, which might result from the behavioral bias of market participants.

The empirical results of this study show that there exists a strong negative and asymmetric relationship between the stock market return (KOSPI200 return) and the change of the implied volatility index (VKOSPI) at both the daily and intraday levels. This asymmetric volatility phenomenon (detected using high-frequency data) indicates that neither the leverage nor volatility feedback hypothesis adequately explains the results. The results also suggest that negative returns have greater power for explaining the return-volatility relationship than positive returns do and that, among the negative returns, the extremely negative return has a dominant role in explaining the observed asymmetric volatility and the return-volatility relationship. Considering that Avramov et al. (2006) claim that the uninformed individual trading can generate asymmetric and negative return-volatility relationship and that Hibbert et al. (2008) suggest the positive association between the asymmetric volatility and investors' behavioral biases, we might attribute the asymmetric volatility detected by the high-frequency data to the higher participation rates of the domestic individuals and the fast change of market sentiments found in the KOSPI200 options market.

The rest of this study is organized as follows. Section 2 describes the KOSPI200 options market, the VKOSPI, and the sample data. Section 3 explains the regression models and discusses the empirical results. Section 4 concludes this paper.

2. KOSPI200 options and VKOSPI

Since itsintroduction in 1997, the trading volume of KOSPI200 options has sharply increased and is currently the single most actively traded derivative security in the world. Table 1depicts the ten most actively traded index derivatives worldwide.[2] The table reports the names of the contracts, their corresponding exchanges, index multipliers, and trading volumes which are measured by the number of contracts traded and/or cleared in 2010. The trading volume of the KOSPI200 options dominates those of other derivatives. Its high trading volume reflects the great interest of market participants in this market. In addition to its ample liquidity, the KOSPI200 options market has other unique characteristics. First, in contrast to the other financial markets of developed countries, the domestic

[2] Source: Futures Industry Association (www.futuresindustry.org).

individual investors are the major market players in the KOSPI200 options market. Table 2 presents the trading volume (measured by the number of contracts) by three investor types, which are domestic individuals, domestic institutions, and foreigner investors, for the period between January 2003 and December 2010.[3] The table shows that the domestic individuals are the most active options trader group, which presents the stark contrast with the case of options market in the developed countries. Unlike institutional investors who mostly participate in the options market for hedging purpose or broad portfolio management issues, individuals, who mostly seek short-term profits and trade options to enjoy the leverage effect provided by the option contracts, are highly speculative and potentially more easily affected by the behavioral bias and market sentiments. Second, the relatively high concentration of investors in the out-of-the-money (OTM) and deep-OTM options market also implies that the KOSPI200 options market is a very speculative market (See Ahn, Kang, and Ryu (2008)). Third, because of the presence of many professional investors and day traders who try to make short-term profits, the KOSPI200 option prices can reflect market information and investors' expectation very quickly (See Ahn, Kang, and Ryu (2010) and Ryu (2011)).

The VIX is a widely used market indicator to measure expected market volatility, market sentiment, and investors' fear. Recognizing the necessity of a volatility index which can represent and summarize the opinions of investors investing in the Korean financial market, the Korea Exchange (KRX) introduced the volatility index implied by the KOSPI200 option prices and named it VKOSPI. Though the VKOSPI is the product of thorough research and preparation by experts in academic community and financial industry, there is little research investigating the VKOSPI in academia.

The VKOSPI has only been publicly reported by the KRX since April 19, 2009. Nevertheless, using the "fair variance swap" method that is used to construct the VKOSPI and the VIX, one can replicate the VKOSPI before the official publication date.[4] The daily VKOSPI and underlying KOSPI200 index price data in this study covers the period from January 2003 to December 2010. We also obtained the intraday (1-min interval) VKOSPI and the index price data from the KRX from March 3, 2008 to May, 13, 2010. Table 3 presents summary statistics for daily stock index price and return and for daily VKOSPI level and its change. S_t denotes the daily closing price of KOSPI200 index. $\ln R_t$ is the log-return of the KOSPI200 index price and $|\ln R_t|$ denotes its absolute value. $VKOSPI_t$ and $\Delta VKOSPI_t$ represent the level and first-difference of the implied volatility index, respectively.

[3] The trading activities of government and government owned firms are excluded because they account for only a small portion of total trading volume.
[4] The KRX has disclosed the for formula for calculating VKOSPI and reports the the daily VKOSPI value from January 2003.

3. Models and Empirical Results

3.1. Daily Results

FollowingHibbert et al. (2008), we ran the following five regression models to investigate the daily and intraday return-volatility relationship.[5]

M1:

$$\Delta V_t=\alpha+\beta_0 R_t+\beta_{-1}R_{t-1}+\beta_{-2}R_{t-2}+\beta_{-3}R_{t-3}+\beta_1 R_{t+1}+\beta_2 R_{t+2}+\beta_{v,-1}\Delta V_{t-1}+\beta_{v,-2}\Delta V_{t-2}+\beta_{v,-3}\Delta V_{t-3}+\beta_{rv}\Delta RV_t+\beta_0^{abs}|R_t|+\varepsilon_t$$

M2: $\Delta V_t=\alpha+\beta_0 R_t+\beta_{-1}R_{t-1}+\beta_{-2}R_{t-2}+\beta_{-3}R_{t-3}+\beta_{v,-1}\Delta V_{t-1}+\beta_{v,-2}\Delta V_{t-2}+\beta_{v,-3}\Delta V_{t-3}+\beta_{rv}\Delta RV_t+\varepsilon_t$

M3: $\Delta V_t=\alpha+\beta_0 R_t+\beta_{-1}R_{t-1}+\beta_{-2}R_{t-2}+\beta_1 R_{t+1}+\beta_2 R_{t+2}+\beta_0^{abs}|R_t|+\varepsilon_t$

M4: $\Delta V_t=\alpha+\beta_0 R_t+\varepsilon_t$

M5: $\Delta V_t=\alpha+\beta_0 R_t+\beta_{22}R_t^2+\varepsilon_t$

Where, V_t is the level of the VKOSPI at time t; ΔV_t ($=V_t-V_{t-1}$) denotes the change in the VKOSPI from time t-1 to time t; R_t is the log-return of the KOSPI 200 index at time t; RV_t denotes the realized volatility at time t, (which is calculated from the 5-minute intraday data on index prices); ε_t is an error term; and β is the regression coefficient to be estimated.

Model M1 is the most complicated model and contains all lead and lag return terms (R_{t-1}, R_{t-2}, R_{t-3}, R_{t+1}, R_{t+2}) capturing the intertemporal return-volatility relationship, absolute contemporaneous return ($|R_t|$) capturing the asymmetric effect of current return to volatility, lagged implied volatility index changes (ΔV_{t-1}, ΔV_{t-2}, ΔV_{t-3}), and the realized volatility changes (ΔRV_t). Models M2, M3, and M4 are versions of the model M1. Model M4 is the simplest model of which explanatory variable is only contemporaneous return. M5 is also a simple model. In model M5, volatility is measured by squared returns. Based on the adjusted-R^2 values, we can measure the explanatory power of each model. By comparing the size and significance of the β coefficients in each regression model, we are

[5] However, we allow more general structure for the M1 model by incorporating the two lead returns (R_{t+1} and R_{t+2}) and the absolute value of contemporaneous stock return ($|R_{t+1}|$). We do not consider the ATM implied volatility because the VKOSPI is known to perform better than the Black-Scholes implied volatility derived from the ATM or OTM option prices and the BS-implied volatilities generally contain many biases.

able to determine which factor has more power in explaining the change of volatility.

Table 4 shows the estimation results for the five regression models using daily data. Though the differences of adjusted-R^2 values across the models are not large, the table indicates that the M1 model exhibits greater explanatory power than all the other simple models. On the other hand, the more complicated model M2 (which contains both lagged implied volatilities and the realized volatility as explanatory variables) has a even lower adjusted-R^2 value than the two simpler models M3 and M5. This indicates that past implied volatility and current realized volatility do not play a critical role in explaining the current change of the implied volatility index for daily data.[6]

The significant negative coefficient of the current return (R_t) for all models suggests that there is a contemporaneous negative relationship between the returns and implied volatility changes. Further, the absolute value of its coefficient is much larger than those coefficients of lagged and lead returns (R_{t-1}, R_{t-2}, R_{t-3}, R_{t+1}, R_{t+2}), which indicates that the contemporaneous return is the most important determinant of the change of the VKOSPI. The coefficient of the contemporaneous absolute return, $|R_t|$ in both M1 and M3, is both significant and positive. The different magnitudes and signs between the two coefficients of returns R_t and $|R_t|$ indicate an asymmetric volatility response to positive and negative returns at the daily level.

In models M1 and M2, the insignificant coefficients of the lagged returns, R_{t-1} and R_{t-3}, and the positive coefficient of the lagged return, R_{t-2}, provide evidence against the leverage hypothesis. This follows because the positive (negative) return shock should have a significantly negative (positive) effect on the change of future volatility under the leverage hypothesis.

3.2. Intraday Results

Table 5 presents the estimation results for the five regression models using the intraday KOSPI200 index return and the intraday VKOSPI data.[7] As the frequency increases (i.e. from 30-min to 1-min), the fitness of each model measured by the adjusted-R^2 generally increases. Unlike the daily estimation results, the explanatory power of the more complicated models, M1 and M2, are far greater than those of the simpler models,M3, M4, and M5. Specifically, the adjusted-R^2 values of the M3, M4, and M5 models are all below 16%, while the values of the M1 and M2 models exceed 90% for all intraday intervals. The coefficients of lagged returns and lagged VKOSPI are also highly significant in M1 and

[6] The coefficient of the realized volatility is not significant in the model M2.
[7] For the intraday analysis, the realized variance term is omitted.

M2. These intraday results show stark contrasts with the daily results and imply that using the information on the intraday serial correlation of the implied volatility index enhances the model performance.

The larger and negative coefficient of R_t and the smaller positive coefficient of $|R_t|$, which are significant in all models and in all intraday intervals, indicate that there exists a strong asymmetric and negative return-volatility relationship even at the high frequency intraday level. However, the the leverage and volatility feedback hypotheses, are not applicable to the intraday results because they are only adequate to explain the long term return-volatility relationship. It is not reasonable that a firm's leverage significantly changes within a day. Meanwhile, the risk premium assumed in the volatility feedback hypothesis also tends to change within the long-term business cycle rather than within the intraday interval.

Given the common perception that the index options traders who trade based on the future expected volatility determin the level of the VKOSPI, the behavioral explanation suggested by Hibbert et al. (2008) or the trading-based explanation by Avramov et al. (2006) might be more appropriate in explaining the asymmetric and negative return-volatility relationship clearly observed in high frequency data. Avramov et al. (2006) claim that trades by individual investors can generate the asymmetric volatility phenomenon and Hibbert et al. (2008) insist that the investor's psychological bias is a major factor causing the asymmetric and negative return-volatility relationship. As noted in the previous section, it is known that there are many uninformed, individual investors in the KOSPI200 options market who trade on noise, trade frequently and collectively account for the huge trading volume of KOSPI200 options. Therefore, we might attribute the strong asymmetric and negative relationship between the KOSPI200 return and the VKOSPI, which is detected by the high frequency data, to the active participation of individual investors who are more easily affected by behavioral bias compared to their institutional counterparts, and to the investors' frequent intraday trading in the KOSPI200 options market.

3.3. Positive and Negative Returns

In order to further investigate the asymmetric impacts of returns on volatilities, we separate our analysis by using only positive or negative returns. Table 6 reports the estimation results separately for positive returns (*Panel A*) and negative returns (*Panel B*).[8] The adjusted-R^2 values indicate that model fitness is significantly higher in the presence of negative returns than positive returns. In all models,

[8] Thus, the $|R_t|$ term is excluded for this analysis on positive and negative returns.

compared to the cases of positive returns, the adjusted-R^2 values is more than doubled for the negative returns. The absolute size of the R_t coefficient of each model is about twice the size and more significant in the negative return case than in the positive return case. The lead and lagged returns give a similar interpretation. The lagged implied volatility indices (V_{t-1}, V_{t-2}, V_{t-3}) also have more significant explanatory powers for negative returns. The evidence shows a clear asymmetric volatility relationship. Further, the positive and/or insignificant coefficient estimates of the lagged returns (R_{t-1}, R_{t-2}, R_{t-3}) suggest evidence against the leverage effect hypothesis.

To investigate the effect of the negative return in more detail, we sort returns based on the absolute size of positive and negative returns, respectively. Table 7 shows the estimation result of the M1 model, which has the best model fitness, for five return quintiles of positive returns (*Panel A*) and negative returns (*Panel B*). In each Panel, the first (fifth) quintile indicates the largest (smallest) return magnitude category. For example, in case of positive returns, the first return quintile has the most extremely positive values whereas the first return quintile has the extremely negative values in the case of negative returns. While we can't find a significant difference of model fitness across return quintiles in case of positive returns, the adjusted-R^2 value of the model is remarkably high at the first quintile of negative returns. In addition, the negative coefficients of R_t for the first quintile in *Panel B* not only has far greater absolute value but also is the only significant R_t coefficient. In general, the evidence in Table 7 shows that the asymmetric and negative return-volatility relationship is considerably dependent on the *extreme returns*. One possible explanation for this observed dependency is the high participation and heavy speculative trading volume of individual investors in the KOSPI200 options market, who are very sensitive to bad news.

4. Conclusion

We examine the return-volatility relationship by analyzing high frequency data on the KOSPI200 index and the VKOSPI implied by the market prices of the KOSPI200 options. The strong and significant asymmetric and negative short-term relationship suggests that neither the leverage or volatility feedback hypotheses satisfactorily explain observed behavior in the Korean market. Rather, one possible explanation for this result is the frequent trading and active participation of individual investors who collectively dominate the Korean market. This is consistent with the conjectures by Avramov et al. (2006) and Hibbert et al. (2008). Our results also show that the asymmetric and negative relationship is more pronounced in the presence of extremely negative stock market returns. Again, if individual investors are more sensitive to bad news than institutional investors, then the greater speculative trading by individuals might explain this phenomenon in the KOSPI200 options market. This is the first study that examines the intraday properties of the VKOSPI and should serve as the starting point for further research on this index. The behavior of volatility indexes, in general, and the VSKOPI, in particular is a matter of great interest to practitioners, academics, and policymakers alike. It is also important for derivative exchanges as they prepare to launch volatility -related derivatives such as VKOSPI futures.

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Table 1. Global top 10 index derivatives contracts at 2010

Rank	Contract	Index Multiplier	Trading Volume
1	KOSPI 200 options, KRX	KRW 100,000	3,525,898,562
2	E-mini S&P 500 index futures, CME	USD 50	555,328,670
3	SPDR S&P 500 ETF options, multiple exchanges	NA	456,863,881
4	S&P CNX Nifty index options, NSE (India)	INR 100	529,773,463
5	Euro Stoxx 50 futures, Eurex	EUR 10	372,229,766
6	Euro Stoxx 50 index options, Eurex	EUR 10	284,707,318
7	RTS index futures, RTS	USD 2	224,696,733
8	S&P 500 index options, CBOE	USD 100	175,291,508
9	S&P CNX Nifty index futures, NSE (India)	INR 100	156,351,505
10	Nikkei 225 Mini futures, OSE	JPY 100	125,113,769

Table 2. Trading volume by investor type

Investor Group	# of contracts	Percentage (%)
Domestic individuals	17,912,571,221	40.3
Domestic institutions	17,052,873,390	38.4
Foreigners	9,497,528,152	21.4
Total	44,462,972,763	100.0

Table 3. Summary statistics for the daily data

	S	lnR*100	|lnR|*100	VIX	dVIX
Mean	171.035	0.060	1.109	25.647	-0.008
Std	54.561	1.559	1.097	9.783	1.750
Max	282.030	11.540	11.540	89.300	23.000
Min	65.640	-10.903	0.000	14.150	-13.920
Skewness	-0.075	-0.410	2.602	2.418	2.426
Kurtosis	1.931	8.278	15.843	11.266	37.250

Table 4. Daily estimation results for the five regression models

	Const.	R_t	R_{t-1}	R_{t-2}	R_{t-3}	R_{t+1}	R_{t+2}	ΔV_{t-1}	ΔV_{t-2}	ΔV_{t-3}	$\Delta 5min_t$	$\lvert R_t \rvert$	R_t^2	Adj-R^2
M1	-0.366	-74.716	-2.071	14.464	0.531	11.424	4.994	-0.140	0.015	-0.108	-1.474	34.904		0.487
	(-6.79)	(-31.48)	(-0.67)	(4.67)	(0.17)	(4.91)	(2.14)	(-5.50)	(0.60)	(-4.23)	(-2.03)	(10.05)		
M2	0.037	-76.542	-4.029	10.558	-4.141			-0.119	0.004	-0.124	0.426			0.440
	(0.96)	(-30.94)	(-1.26)	(3.31)	(-1.30)			(-4.50)	(0.15)	(-4.68)	(0.58)			
M3	-0.334	-76.520	8.608	10.584		10.935	3.882					31.914		0.466
	(-6.25)	(-32.26)	(3.61)	(4.47)		(4.64)	(1.65)					(9.47)		
M4	0.040	-79.202												0.418
	(1.03)	(-32.20)												
M5	-0.093	-76.045											517.655	0.454
	(-2.31)	(-31.67)											(9.93)	

Table 5. Intraday estimation results for the five regression models

Panel A. 30-min data

	Const.	R_t	R_{t-1}	R_{t-2}	R_{t-3}	R_{t+1}	R_{t+2}	ΔV_{t-1}	ΔV_{t-2}	ΔV_{t-3}	$\|R_t\|$	R_t^2	Adj-R^2
M1	-0.104	-63.742	33.323	7.137	23.115	-0.295	4.393	0.734	0.085	0.166	11.851		0.927
	(-7.76)	(-19.28)	(9.80)	(2.20)	(9.10)	(-0.09)	(1.91)	(43.41)	(4.34)	(10.92)	(10.44)		
M2	-0.003	-59.288	33.678	6.780	21.760			0.745	0.082	0.162			0.925
	(-0.35)	(-25.66)	(9.74)	(2.06)	(8.46)			(43.40)	(4.14)	(10.50)			
M3	-0.545	-65.215	-21.653	-3.697		-0.675	29.862				28.478		0.148
	(-12.14)	(-5.76)	(-1.94)	(-0.44)		(-0.06)	(3.80)				(7.36)		
M4	-0.307	-58.612											0.123
	(-9.67)	(-21.58)											
M5	-0.383	-55.999										570.513	0.134
	(-11.39)	(-20.52)										(6.58)	

Panel B. 15-min data

	Const.	R_t	R_{t-1}	R_{t-2}	R_{t-3}	R_{t+1}	R_{t+2}	ΔV_{t-1}	ΔV_{t-2}	ΔV_{t-3}	$\|R_t\|$	R_t^2	Adj-R^2
M1	-0.061	-45.260	9.470	22.851	12.877	1.635	-2.008	0.808	0.131	0.045	6.422		0.947
	(-9.47)	(-21.30)	(4.28)	(10.57)	(7.81)	(0.77)	(-1.32)	(84.18)	(11.01)	(4.82)	(11.68)		
M2	-0.008	-46.603	10.514	23.362	11.887			0.818	0.130	0.038			0.947
	(-1.73)	(-30.05)	(4.73)	(10.73)	(7.17)			(84.93)	(10.87)	(4.11)			
M3	-0.518	-46.060	-22.768	-12.363		4.311	14.937				26.497		0.148
	(-20.46)	(-5.39)	(-2.61)	(-1.92)		(0.51)	(2.44)				(12.08)		
M4	-0.303	-60.696											0.132
	(-16.63)	(-38.79)											
M5	-0.354	-58.654										390.994	0.138
	(-18.61)	(-37.24)										(8.97)	

Panel C. 5-min data

	Const.	R_t	R_{t-1}	R_{t-2}	R_{t-3}	R_{t+1}	R_{t+2}	ΔV_{t-1}	ΔV_{t-2}	ΔV_{t-3}	$\lvert R_t \rvert$	R_t^2	Adj-R^2
M1	-0.028	-20.939	-13.787	6.686	23.710	0.448	2.570	0.748	0.132	0.109	2.662		0.968
	(-10.67)	(-14.80)	(-9.83)	(4.85)	(23.46)	(0.31)	(2.48)	(145.24)	(20.83)	(21.77)	(11.82)		
M2	-0.006	-18.334	-13.710	6.790	23.829			0.752	0.132	0.107			0.968
	(-3.37)	(-18.08)	(-9.75)	(4.91)	(23.53)			(145.76)	(20.77)	(21.39)			
M3	-0.499	-17.725	-25.170	-33.202		-0.264	13.897				26.089		0.153
	(-38.11)	(-2.44)	(-3.51)	(-6.39)		(-0.04)	(2.62)				(22.75)		
M4	-0.291	-62.391											0.136
	(-30.56)	(-75.25)											
M5	-0.342	-60.225										400.591	0.144
	(-34.59)	(-72.21)										(18.11)	

Panel D. 1-min data

	Const.	R_t	R_{t-1}	R_{t-2}	R_{t-3}	R_{t+1}	R_{t+2}	ΔV_{t-1}	ΔV_{t-2}	ΔV_{t-3}	$\lvert R_t \rvert$	R_t^2	Adj-R^2
M1	-0.006	32.308	-18.454	-14.709	14.721	-14.311	-0.248	0.878	0.048	0.069	0.497		0.989
	(-9.80)	(31.40)	(-17.95)	(-14.48)	(22.67)	(-13.97)	(-0.38)	(385.59)	(16.02)	(30.39)	(8.69)		
M2	-0.002	14.859	-15.665	-14.022	14.111			0.878	0.048	0.069			0.989
	(-5.26)	(22.70)	(-15.34)	(-13.79)	(21.73)			(385.31)	(15.90)	(30.39)			
M3	-0.482	22.277	12.913	-87.092		-19.664	10.165				25.352		0.150
	(-86.01)	(2.48)	(1.45)	(-15.30)		(-2.20)	(1.77)				(51.13)		
M4	-0.285	-62.602											0.136
	(-69.32)	(-173.29)											
M5	-0.334	-60.555										398.195	0.144
	(-78.57)	(-166.87)										(41.92)	

Table 6. Estimation results for positive (Panel A) and negative (Panel B) returns

Panel A. Positive contemporaneous returns

	Const.	R_t	R_{t-1}	R_{t-2}	R_{t-3}	R_{t+1}	R_{t+2}	ΔV_{t-1}	ΔV_{t-2}	ΔV_{t-3}	$\Delta 5min_t$	R_t^2	Adj-R^2
M1	-0.109	-53.817	-0.468	2.729	2.165	1.685	-0.352	-0.062	-0.095	-0.095			0.207
	(-1.60)	(-11.53)	(-0.13)	(0.74)	(0.59)	(0.52)	(-0.11)	(-1.99)	(-3.14)	(-2.98)			
M2	-0.110	-53.652	-0.490	2.915	2.162			-0.062	-0.095	-0.095	-0.185		0.208
	(-1.62)	(-11.56)	(-0.14)	(0.79)	(0.60)			(-2.02)	(-3.15)	(-2.97)	(-0.21)		
M3	-0.092	-56.129	4.243	8.320		0.593	-1.751						0.183
	(-1.39)	(-12.37)	(1.55)	(2.95)		(0.18)	(-0.58)						
M4	-0.059	-58.638											0.176
	(-0.90)	(-13.14)											
M5	-0.033	-62.785										80.307	0.175
	(-0.42)	(-7.75)										(0.61)	

Panel B. Negative contemporaneous returns

	Const.	R_t	R_{t-1}	R_{t-2}	R_{t-3}	R_{t+1}	R_{t+2}	ΔV_{t-1}	ΔV_{t-2}	ΔV_{t-3}	$\Delta 5min_t$	R_t^2	Adj-R^2
M1	-0.655	-123.842	2.024	32.899	-0.473	15.197	3.251	-0.192	0.195	-0.151			0.548
	(-7.80)	(-23.68)	(0.38)	(6.43)	(-0.09)	(4.51)	(0.90)	(-4.53)	(4.32)	(-3.67)			
M2	-0.674	-126.039	3.254	35.162	-1.507			-0.183	0.250	-0.164	-2.644		0.534
	(-7.93)	(-23.85)	(0.60)	(6.80)	(-0.28)			(-4.27)	(5.69)	(-4.00)	(-2.27)		
M3	-0.622	-119.943	14.028	16.202		18.757	8.756						0.504
	(-7.30)	(-24.45)	(3.34)	(4.03)		(5.47)	(2.42)						
M4	-0.566	-117.113											0.459
	(-6.45)	(-23.27)											
M5	-0.275	-73.769										752.514	0.479
	(-2.64)	(-7.42)										(5.03)	

Table 7. Estimation Results for positive and negative return quintiles

Panel A. Positive return quintiles

	Const.	R_t	R_{t-1}	R_{t-2}	R_{t-3}	R_{t+1}	R_{t+2}	ΔV_{t-1}	ΔV_{t-2}	ΔV_{t-3}	$\Delta 5min_t$	Adj-R^2
1st	-0.092	-53.508	-14.354	12.542	-7.871	18.400	7.893	-0.142	-0.094	-0.083	-0.947	0.124
	(-0.21)	(-3.34)	(-1.28)	(1.09)	(-0.66)	(1.63)	(0.78)	(-1.59)	(-1.29)	(-0.91)	(-0.37)	
2nd	0.688	-114.725	-2.649	14.116	15.339	-0.951	-7.364	-0.219	0.112	-0.001	1.073	0.178
	(1.02)	(-2.21)	(-0.31)	(1.60)	(1.70)	(-0.14)	(-1.29)	(-3.61)	(1.32)	(-0.01)	(0.56)	
3rd	-0.455	-20.736	-1.512	-1.940	10.670	2.221	6.912	-0.121	-0.052	-0.172	4.682	0.160
	(-0.78)	(-0.28)	(-0.19)	(-0.31)	(1.75)	(0.41)	(1.24)	(-1.43)	(-0.55)	(-3.42)	(2.59)	
4th	0.166	-98.640	22.905	6.810	-4.335	-7.478	2.298	0.229	0.041	-0.033	1.273	0.089
	(0.57)	(-1.59)	(3.75)	(1.07)	(-0.76)	(-1.53)	(0.48)	(3.26)	(0.57)	(-0.51)	(0.77)	
5th	-0.078	-86.820	1.039	10.186	9.501	-8.752	1.812	0.017	-0.059	-0.034	-1.409	0.108
	(-0.76)	(-1.39)	(0.24)	(1.63)	(1.86)	(-2.05)	(0.37)	(0.28)	(-0.96)	(-0.56)	(-1.02)	

Panel B. Negative return quintiles

	Const.	R_t	R_{t-1}	R_{t-2}	R_{t-3}	R_{t+1}	R_{t+2}	ΔV_{t-1}	ΔV_{t-2}	ΔV_{t-3}	$\Delta 5min_t$	Adj-R^2
1st	-2.624	-188.823	-15.358	67.627	21.743	21.166	-3.855	-0.286	0.434	0.088	-5.828	0.519
	(-4.39)	(-10.13)	(-0.77)	(4.22)	(1.11)	(2.03)	(-0.34)	(-2.33)	(3.22)	(0.71)	(-1.69)	
2nd	0.344	-34.413	7.110	-0.835	-2.488	-0.026	7.437	0.056	-0.002	-0.136	0.990	0.011
	(0.71)	(-1.07)	(0.84)	(-0.11)	(-0.35)	(-0.01)	(1.51)	(0.67)	(-0.03)	(-1.78)	(0.54)	
3rd	0.099	-26.255	0.424	35.317	4.125	5.602	-0.321	-0.184	0.311	-0.310	1.202	0.476
	(0.21)	(-0.47)	(0.06)	(4.60)	(0.49)	(0.98)	(-0.05)	(-2.35)	(3.62)	(-4.78)	(0.67)	
4th	0.102	-0.598	-22.663	22.080	-2.657	3.915	-8.601	-0.570	0.097	-0.130	2.959	0.424
	(0.31)	(-0.01)	(-2.93)	(2.64)	(-0.34)	(0.71)	(-1.67)	(-8.03)	(0.96)	(-1.53)	(1.78)	

5th	-0.121	-89.714	7.700	22.418	0.376	9.294	-3.856	-0.018	0.125	0.076	1.803	0.125
	(-0.92)	(-1.08)	(1.36)	(3.52)	(0.06)	(2.07)	(-0.83)	(-0.26)	(1.92)	(0.97)	(1.13)	