Does Price Limit Affect the Autocorrelation of Stock Return Series? A Monte Carlo Experiment

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Abstract—**This paper explores whether the regulation of price limits in financial markets will result in the autocorrelation of stock return series. The results of Monte Carlo Experiment under different error term distribution hypothesis suggest that such price limit mechanism will result in a positive first-order autocorrelation of return series. The results indicates that some statistics in empirical finance literature for testing random walk or market efficiency, for example, the variance ratio of Lo and MacKinlay(1988), may be biased when the stock price is subject to the price limit. This paper also suggests that the further research on the price limit is necessary when more exchanges adopt such regulations in the world.**

Keywords-price limit; autocorrelation; Monte Carlo; stock return

I. INTRODUCTION

Price limits are not only important exchange regulations in financial market that aim to restrict extreme price oscillations, but also are indispensable parts in the research of market microstructure in financial literature. Price limits allow each stock listed on a security exchange to fluctuate on trading day within the pre-specified percentage level above or below the previous day's closing price for that stock.

Through rigidly limiting the price change, the regulations are adopted to discourage investor from irrational speculation and prevent the existence of market panic due to over volatility of security price. Accordingly, such mechanism aims to stabilize the financial market in that investors in market can accurately calculate the maximal loss in next trading day.

Price limits can provide a time-out period for the market to cool off but do not necessarily require trading to halt. Many exchanges in Asian and European countries impose daily price fluctuation limits on individual securities, see table 1.

TABLE 1 THE EXCHANGES AND CORRESPONDING PRICE LIMITS IN PERCENTAGE

Stock markets	limits	Stock markets	Limits
Austria	15%	Malaysia	30%*
Belgium	(5-10%)	Mexico	10%
China mainland	10%	Peru	15%
China Taiwan	7%	Philippine	40%
Egypt	5%	Portugal	15%
Finland	15%	Romania	15%
France	15%	South Africa	(2-6%)
Greece	8%	Switzerland	(10-15%)
India	10%	Spain	15%
Italy	(10-20%)	Thailand	30%
Japan	(10-60%)	Turkey	10%
Korea	15%	Vietnam	3%
Luxemburg	1%		
* Price limit applies only to down-turn price change			

Source: Stock exchange websites and Fact Books

Being an important part of microstructure of market, the effects of price limit in financial markets have already been explored by many researchers. There has already existed a huge literature on price limits(see, for example, Kodres, 1988; Chung, 1991; Chen, 1993; Lee and Kim, 1995; George and Hwang, 1995; Kim and Rhee, 1997; Gan and Li, 2001; Chan, Kim, and Rhee, 2005; Choi and Lee, 2001; Kim and Sweeney, 2001; Cho et al., 2003; Bildik and Gulay, 2004; Kim and Yang, 2004, 2008, among others).

The empirical researches, generally speaking, focus on whether price limit can moderate volatility, delay the price discovery process, counter overreaction, affect informed investors' trading behavior and result in magnet effect in the literature. However, researches on such five problems have not formulated an agreement because different data samples or different countries which are selected in same research will result in the different results.

Rather than studying the effects of price limits, several other interesting studies relate to price limits. Ryoo and Smith (2002) consider that the price limit mechanism prevents stock prices from following a random walk process and causes market inefficiency. Based on a nonlinear stochastic asset-pricing model, Westerhoff (2003) shows that price limit can reduce both volatility and deviation from fundamental. Using the Gibbs sampler, Chou (1997) develops a Bayesians approach to estimate linear regression

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models in which the dependent variable is subject to price limits. Wei and Chiang (2001) derive a GMM estimator for variances in markets with price limits and they argue that the estimator should be used in real application. Wei (2002) firstly proposes and applies a censored-GARCH model for the return process of assets subject to price limits. Overall, such researches on price limit are important not only for academic study but also for the practitioner application.

Several empirical papers in literature imply that the price limit may result in the autocorrelation of return series. However, they do not move forward to study the implication. For example, Kodres(1988)indicates that serial correlation in the currency futures data appears to be induced while studying the unbiasness of future prices under price limit. Chen(1993) calculated the autocorrelation coefficients under different price limit regimes for Taiwan stock market. The result indicates that the autocorrelation coefficients under the limit of 3 percent are significantly larger than those under the limit of 5 percent. Chen(1993) considers that the series correlations of stock returns are inversely related to the range of price limit and there exists delaying effect of price limit.

Whether the price limit can result in autocorrelation of return series is not only a complex theory problem, but an empirical question that can not be studied because there is no appropriate sample data. Since it becomes very difficult, if it is not impossible, to obtain analytic results and sample data, we attack the problem via Monte Carlo simulations. The results will contribute to the market microstructure literatures.

II. MONTE CARLO EXPERIMENT

A. *Price Generation Process*

The efficient markets hypothesis (EMH) in finance suggests that market prices fully reflect all available information. Accordingly, the equity price should follow a random walk and can not be predicted ahead. The random walk model is fundamental to modern financial economics and the random walk hypothesis (RWH) is used to test the market efficiency in empirical financial research. A great deal of research has been devoted to developing various random walk tests since the late 1980s (see, for example, French and Roll, 1986; Fama and French, 1988; Lo and MacKinlay, 1988, among others).

We assume that the real stock price is generated by the following random walk model,

$$P_t = P_{t-1} + \mu + \varepsilon_t \tag{1}$$

Here, Pt is the real price of stock on the t-th day, μ is the drift term and the disturbance εt is serially uncorrelated with mean zero, but could be heteroscedastic.

Under price limit, the daily price will be limited into an interval which can not exceed the previous closing price plus a certain percentage of the previous closing price and can not drop below the previous closing price minus a certain percentage of the previous closing price. Hence, the observed price at time t, O_t, must satisfy the limitation condition:

$$O_{t-1}(1-L_d) \leqq O_t \leqq O_{t-1}(1+L_u) \tag{2}$$

L_u and L_d are daily up and down limits respectively. For instance, in China stock, the daily limit is 10% of the closing price of the previous trading day for both up and down limit moves since Dec 16th, 1996. In other words, if the true stock price Pt falls outside the interval, one observes a limit price. Therefore, the observed stock price should satisfy the following equations:

If $P_t \geqq O_{t-1}(1+L_u)$ then,

$$O_t = O_{t-1}(1+L_u) \tag{3}$$

If $O_{t-1}(1-L_d) < P_t < O_{t-1}(1+L_u)$ then,

$$O_t = P_t \tag{4}$$

If $P_t \leqq O_{t-1}(1-L_d)$ then,

$$O_t = O_{t-1}(1-L_d) \tag{5}$$

Thereby, equation(1) is the real price generation process which assumes that the stock price does follow a random walk. Equation(3)-(5) are generation processes of observed stock price under different situations.

B. *Monte Carlo experiment*

In order to test whether there exists autocorrelation when a random walk series is truncated by the price limit mechanism, we use Monte Carlo simulation to generate 1000 real stock price series by equation(1) under different distribution hypothesis, and get the observed price series according to the equations(3)-(5). We use t statistic to test whether the mean value of the first-order autocorrelation coefficient calculated from the observed price series is not equal to zero in statistic. To investigate the effect of the price limit on the autocorrelation coefficient, we perform simulation experiments under the hypothesis that the disturbance εt in (1) is not only homoscedasticity serially uncorrelated but also heteroscedastic serially uncorrelated. In homoscedasticity situation, we consider the Gaussian distribution and student t distribution. In heteroscedastic situation, we consider the two common heteroscedasticity process, which are GARCH(1,1)(Bollerslev, 1986) process and EGARCH(1,1)(Nelson, 1991).

Let the disturbance εt satisfy the relation εt = σtηt, where εt is i.i.d. N(0; 1) and σt satisfies the following 1st-order general autoregressive conditional heteroscedasticity (GARCH(1,1)) process,

$$\sigma_t^2 = \gamma + \alpha\sigma_{t-1}^2 + \beta r_{t-1}^2, \tag{6}$$

where parameters α, β and γ are chosen to yield the desired levels of σε . rt-1 is the return based on observed price.

The EGARCH process satisfies the following equation,

$$\ln(\sigma_t^2) = \omega + \alpha(|z_{t-1}|-E(|z_{t-1}|)) + \gamma z_{t-1} + \beta\ln(\sigma_{t-1}^2), \quad (7)$$

where z_t is standardization return and also is i.i.d. N(0,1). ω, α, β and γ are model parameters.

C. *Simulation results*

Table 1 reports the results of the simulation experiment conducted under the Gaussian i.i.d. We report the mean value of the first-order autocorrelation coefficient and the t statistic value in two situations, which one is under price limit and the other is no price limit. In table 1, we also report the times of hitting up and down in 100 trading days, respectively.

TABLE 2 THE MEAN VALUE OF THE FIRST-ORDER AUTOCORRELATION COEFFICIENT UNDER THE GAUSSIAN I.I.D. DISTRIBUTION

Hitting up in 100 days	Hitting down in 100 days	No price limit	Under price limit
2.8	1.7	-0.002(-0.069)	0.034(1.007)
5.6	3.9	-0.000(-0.014)	0.076 (2.296) **
8.6	6.6	-0.001(-0.020)	0.121 (3.927) ***
11.6	9.3	-0.002(-0.006)	0.168 (5.393) ***
14.4	12	-0.001(-0.034)	0.210 (7.262) ***

***, **, * signify that the coefficients of variables are significantly different from zero at the 1%, 5%, and 10%, respectively (one-tailed).

From table 2, we can find that there exists significant positive first-order autocorrelation coefficient in return series when the hitting up days and hitting down days are greater than 5.6 and 3.9, respectively. In our experiment, although we can get the value of first-order autocorrelation coefficient from real return series, the t test statistic indicates that there is no significant first-order autocorrelation coefficient.

From Table 3 to table 5, we report the experiment results under the other three disturbance hypothesis. Table 3 is the result under the t distribution of disturbance ε_t. Table 4 is the result of the heteroscedasticity GARCH(1,1) and the table 5 reports the results under EGARCH(1,1) process.

TABLE 3 THE MEAN VALUE OF THE FIRST-ORDER AUTOCORRELATION COEFFICIENT UNDER THE STUDENT I.I.D. DISTRIBUTION

Hitting up in 100 days	Hitting down in 100 days	No price limit	Under price limit
1.8	1.2	-0.001(-0.040)	0.038(1.187)
4.3	3.0	-0.001(-0.050)	0.078 (2.327) **
7.1	5.4	-0.000(-0.032)	0.125(4.107) ***
10.1	8.1	0.000(-0.009)	0.171 (5.729) ***
13	10.8	-0.000(-0.008)	0.211 (7.152) ***

***, **, * signify that the coefficients of variables are significantly different from zero at the 1%, 5%, and 10%, respectively (one-tailed).

TABLE 4 THE MEAN VALUE OF THE FIRST-ORDER AUTOCORRELATION COEFFICIENT UNDER THE GARCH(1,1) DISTRIBUTION

Hitting up in 100 days	Hitting down in 100 days	No price limit	Under price limit
4	2.7	0.000(0.004)	0.062 (1.720) *
6.3	4.5	0.003(-0.009)	0.092(2.436) **
8.5	6.5	0.001(0.051)	0.131 (3.604) ***
10.6	8.3	-0.000(-0.022)	0.159 (4.459) ***
12.1	9.8	-0.001(-0.038)	0.184 (5.157) ***

***, **, * signify that the coefficients of variables are significantly different from zero at the 1%, 5%, and 10%, respectively (one-tailed).

TABLE 5 THE MEAN VALUE OF THE FIRST-ORDER AUTOCORRELATION COEFFICIENT UNDER THE EGARCH(1,1) PROCESS

Hitting up in 100 days	Hitting down in 100 days	No price limit	Under price limit
2.1	2.0	-0.002(-0.068)	0.013 (1.978) **
4.2	2.9	-0.000(-0.089)	0.019 (3.293) ***
6.1	4.1	-0.000(-0.079)	0.024 (3.399) ***
8.3	5.1	-0.000(-1.033)	0.030 (4.129) ***
10.4	8.2	-0.001(-1.017)	0.037 (5.288) ***

***, **, * signify that the coefficients of variables are significantly different from zero at the 1%, 5%, and 10%, respectively (one-tailed).

In summary, our results show that the price limit will lead to autocorrelation regardless the random walk series generated by equation(1) is homoscedasticity or heteroscedasticity. In our simulation experiment, we respectively consider the homoscedasticity situation such as Gaussian, student distribution of the disturbance ε_t and the heteroscedasticity situation like GARCH(1,1), EGARCH(1,1). Consequently, We anticipate that our results hold, at least qualitatively, for a general class of random walk series.

III. DISCUSSION

Many random walk tests are linear combinations of consistent estimators of autocorrelations. Richardson and Smith (1994) have shown that this class captures many test statistics studied in the recent finance and macroeconomics literature. For example, the test considered in Fama and French (1988) is based on the statistic:

$$Z(q)=\frac{(1/n)\sum_{i=1}^{n}[\sum_{l=1}^{q}(\log p_{i+l}-\log p_{i+l-1}-\hat{\mu})\sum_{l=1}^{q}(\log p_{i+l-q}-\log p_{i+l-q-1}-\hat{\mu})]}{(1/n)\sum_{i=1}^{n}(\sum_{l=1}^{q}(\log p_{i+l}-\log p_{i+l-1}-\hat{\mu}))^2}$$

which can be rewritten asymptotically in terms of consistent autocorrelation estimators as

$$Z(q)\approx\sum_{i=1}^{2q-1}\min(i,2q-i)\hat{\rho}(i)/q$$

Variance ratio proposed by Lo and MacKinlay(1988) is a main statistic to test market efficiency in finance literature. The q-step variance ratio VR(q) is also a linear combination of consistent estimators of autocorrelations. It can be rewritten as

$$VR(q)-1\approx\sum_{j=1}^{q-1}\frac{2(q-j)}{q}\hat{\rho}(j)$$

Therefore, our experiment indicates that statistics in literature for testing random walk or market efficiency may be biased when the stock price is subject to the price limit, the further research on the price limit is needed.

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