

Testing Dynamic Relationship between Returns and Trading Volume on the National Stock Exchange

Abstract

This paper investigates the dynamic relationship between stock index returns and trading volume using the linear and non-linear Granger non-causality hypothesis test on the National Stock Exchange (NSE) data. Widely used linear Granger non-causality test is used to investigate the linear relationship while the non-linear Granger causality is investigated using modified Baek and Brock test proposed by Hemstra and Jones (1994) for the daily returns on S&P CNX Nifty and the total trading volume at NSE. Bi-directional linear Granger causality between index returns and volume change is observed for the period when rolling settlement was either not introduced or partially introduced. The period, when rolling settlement is introduced widely, there is no evidence of linear causality in either direction. The shift in linear causal relationship indicates that efficiency at NSE has improved with introduction of rolling settlement mechanism. Nonlinear Granger causality between the returns and volume change is not evident in either direction.

Testing Dynamic Relationship between Returns and Trading Volume on the National Stock Exchange

Abstract:

This paper investigates the dynamic relationship between stock index returns and trading volume using the linear and non-linear Granger non-causality hypothesis test on the National Stock Exchange (NSE) data. Widely used linear Granger non-causality test is used to investigate the linear relationship while the non-linear Granger causality is investigated using modified Baek and Brock test proposed by Hiemstra and Jones (1994) for the daily returns on S&P CNX Nifty and the total trading volume at NSE. Bi-directional linear Granger causality between index returns and volume change is observed for the period when rolling settlement was either not introduced or partially introduced. The period, when rolling settlement is introduced widely, there is no evidence of linear causality in either direction. The shift in linear causal relationship indicates that efficiency at NSE has improved with introduction of rolling settlement mechanism. Nonlinear Granger causality between the returns and volume change is not evident in either direction.

Introduction:

Return on stock prices and trading volume are two prime indicators of trading activity in a stock market. These factors are jointly determined by the same market dynamics and may contain valuable information about a security. While the return on stock prices are widely studied for the purpose of forecasting and analyzing information contained in the historical prices, there is little agreement on interpretation of past trading volume. Blume, Easley, and O'Hara (1994) have highlighted that volume captures the important information contained in the quality of the traders' information signals and may be useful in interpreting information contained in prices. Gallant, Rossi, and Tauchen (1992) show that more can be learned about the stock market through studying the joint dynamics of stock prices and trading volume than by focusing only on the univariate dynamics of stock prices.

Campbell, Grossman, and Wang (1993) and Smirlock, and Starks (1985) indicate that there is some link between stock returns and trading volume, and also that past trading volume may provide valuable information about a security. The empirical work on the stock price-volume relation focuses on the study of causality between stock prices and trading volume. Vector auto regression (VAR) model based Linear Granger causality test was first introduced in a seminal paper by Granger (1969). This test has been widely used for studying causality among macroeconomic factors and to a lesser extent for stock prices and trading volume data. This test has high power in uncovering linear causal relations, but fails to satisfactorily explain the relationship between returns and volume (Hiemstra and Jones, 1994). An emerging body of research has stressed nonlinearities as one of the potential reasons for such poor performance. In their study Hiemstra and Jones (1994) used nonlinear Granger causality test based on nonparametric estimators of temporal relations in time series, which is a modification of the model earlier suggested by Baek and Brock in 1992. The modified Beak and Brock test is a nonparametric test, designed to detect linkages that cannot be uncovered by conventional linear test statistics.

This study investigates whether any causality exists between trading volume and returns in the stock market index. The study is largely inspired by the work of Hiemstra and Jones (1994). We employ both linear and nonlinear causality tests to study daily S&P CNX Nifty returns and percentage change in the National Stock Exchange trading volume for a period (divide into three sub-periods) of more than six and half years.

A causal relation between returns and trading volume can provide understanding if information on the past movements in trading volume improves the short run current and future forecasts of the current and future stock price movements. Though, not as important the effect of information of past movements in stock prices on short run current and future forecasts of the current and future trading volume can also be ascertained. Stock price-volume relation can be used as basis of trading strategy and as evidence for and against the efficiency or otherwise of stock markets.

The plan of the paper is as follows. Section 1 enumerates the earlier empirical studies on dynamic relationship between stock returns and volume. In Section 2 we specify the models used in this study. Section 3 details on the data and provides results on the nature of data series. Section 4 gives the main results of the linear and non-linear

Granger non-causality hypothesis. Section 5 provides summary and conclusions of the study.

1.0. Literature Review:

Earlier studies on stock return-volume relationship like Copeland (1976) and Jennings, Stark and Felligham (1981) mainly focus on the relationship between volume and absolute returns. Recent empirical studies such as Gallant, Rossi and Tauchen (1992) and Hiemstra and Jones (1994) focus on the dynamic relationship between volume and returns. Gallant, Rossi and Tauchen (1992) examine dependencies between S&P 500 stock index returns and trading volume on the New York Stock Exchange (NYSE). They find evidence for returns leading volume using nonlinear impulse response functions. Heimstra and Jones (1994) study the dynamic relationship between Dow Jones Industrial Average index returns and aggregate trading volume using nonlinear causality tests. As a new finding to the literature, they report bilateral nonlinear causality (feedback) between returns and trading volume.

In their paper, Blume, Easley and O'Hara (1994) study the informational content of volume. Rather than describing the correlation between volume and price, they set out to show how volume could affect market behavior. Their model suggests that volume provides information on the precision and dispersion of information signals, which price alone does not. Due to lack of information contained in prices, traders cannot obtain the full information signal from price and could use volume as an additional statistic to observe that signal. Market participants, therefore, condition their expectations about price movements on volume as well as price.

1.1. The Stock Price Volume Relationship:

A causal relationship is expected between stock prices and trading volume due to various reasons put forward by Karpoff (1987). First, the sequential information arrival models of Copeland (1976) and Jennings *et al.* (1981) suggested a positive causal relation between stock price and trading volume in either direction. Second, Lakonishok and

Smidt (1989) showed that current volume can be related to past stock price changes due to tax- and non-tax-related trading motives. The dynamic relation is negative for tax-related trading motives and positive for certain non-tax-related trading motives. Third, in the mixture of distributions model of Epps and Epps (1976), trading volume is used to measure disagreement as traders revise their reservation prices based on the arrival of new information into the market. Their model suggested a positive casual relation running from trading volume to absolute stock returns. Finally, the information content of trading volume is important for understanding the validity of technical analysis, which assigns a special to trading volume (Blume et al. 1994).

Examining the relation between returns and volume, a positive contemporaneous correlation was found by Rogalski (1978) using monthly stock and warrant data and by Epps (1977) using transactions data. To explain such results, Epps (1977) proposed a theoretical framework consistent with his findings. His framework implied the ratio of volume to returns should be greater for price increases than for price decreases, which was supported by empirical evidence in Smirlock and Starks (1985). Smirlock and Starks (1985) have investigated the lagged relation between price changes and volume employing individual stock transactions data. They have documented a strong positive lagged relation between absolute price changes and volume. In addition, Hiemstra and Jones (1994) found a new result through the use of nonlinear Granger causality. They found a significant positive relation going in both directions between stock returns and trading volume.

It is now widely accepted that nonlinearity is present in models representing economic and financial time series. The richer types of asset behavior such as large stock price swings and abrupt changes in stock market volatility can only be properly modeled with nonlinear structures (Silvapulle and Choi, 1999).

2. 0. Model Specification:

In this section we briefly explain linear Granger causality test and outline the modified Baek and Brock test as proposed by Hiemstra and Jones (1994) for testing nonlinear Granger causal relations that cannot be detected by the traditional linear causality test.

2.1. Testing for Linear Granger Causality:

The study proceeds to test for Granger causality relations between volume and returns. Granger causality testing investigates whether the past of one time series improves the predictability of the present and future of another time series. Testing for linear Granger causality can be conducted within the context of a vector auto regression (VAR) model. The benefit of VAR models is that they account for linear inter-temporal dynamics between variables, without imposing a priori restrictions of a particular model.

Hence, they are ideally suited to detect stylized facts in the data. A VAR model including

S&P CNX Nifty stock index returns and trading volume can be expressed as:

$$R_t = a_r + \sum_{i=1}^l b_{r,i} R_{t-i} + \sum_{i=1}^m c_r V_{t-i} + u_{r,t} \quad (1)$$

$$V_t = a_n + \sum_{i=1}^n b_{n,i} R_{t-i} + \sum_{i=1}^o c_n V_{t-i} + u_{n,t} \quad (2)$$

where R_t and V_t represent stock index returns and volume, $u_{o,t}$, $u_{s,t}$ are orthogonal error terms and l , n , m and o denote autoregressive lag lengths. Within the context of this VAR model, linear Granger causality restrictions can be defined as follows: If the null hypothesis that c_r 's jointly equal zero is rejected, it is argued that volume Granger causes returns. Similarly, if the null hypothesis that b_n 's jointly equal zero is rejected, returns Granger cause volume. If both of the null hypotheses are rejected, a bi-directional Granger causality, or a feedback relation, is said to exist between variables. Different test statistics have been proposed to test for linear Granger causality restrictions. This study relies on the conventional F-test for joint exclusion restrictions.

2.2. Testing for Nonlinear Granger Causality:

In addition to linear linkages, volume and returns could have nonlinear linkages. Hiemstra and Jones (1993) argue that the traditional Granger causality test of linear

causality is ineffective in uncovering certain nonlinear causal relationship. This study uses the modified Baek and Brock test, fully developed in Hiemstra and Jones (1994), to examine nonlinear causality relations. Baek and Brock method offers a nonparametric statistical method to detect nonlinear causal relations that, by construction, cannot be uncovered by linear causality tests. Hiemstra and Jones (1994) modify their test to allow the variables to which the test is applied to exhibit short-term temporal dependence, rather than the Baek and Brock assumption that the variables are mutually independent and identically distributed. Further they show using simulation study, that the modified version of the test is robust to a number of misspecifications of the models and nuisance parameter problem.

The Baek and Brock approach begins with a testable implication of the definition of strict Granger noncausality. Consider two strictly stationary and weakly dependent time series $\{X_t\}$ and $\{Y_t\}$, $t = 1, 2, \dots$. Denote the m -length lead vector of X_t by X_t^m and the L_x -Length and L_y length lag vectors of X_t and Y_t respectively. For given values of m , L_x , and $L_y \geq 1$ and for $\epsilon > 0$, Y does not strictly Granger cause X if:

$$\Pr\left(\|X_t^m - X_s^m\| < \epsilon \mid \|X_{t-L_x}^{L_x} - X_{s-L_x}^{L_x}\| < \epsilon, \|Y_{t-L_y}^{L_y} - Y_{s-L_y}^{L_y}\| < \epsilon\right) \equiv \Pr\left(\|X_t^m - X_s^m\| < \epsilon \mid \|X_{t-L_x}^{L_x} - X_{s-L_x}^{L_x}\| < \epsilon\right) \quad (3)$$

where $\Pr(\cdot)$ denotes probability and $\|\cdot\|$ denotes the maximum norm. The probability on the left side of equation (3) is the conditional probability that two arbitrary m -length lead vectors of $\{X_t\}$ are within a distance, ϵ , of each other, given that the corresponding L_x -length lag vectors of $\{X_t\}$ and L_y -length lag vectors of $\{Y_t\}$ are within, ϵ , of each other. The strict Granger non-causality condition in equation (3) can then be expressed as:

$$\frac{C1(m + L_x, L_y, \epsilon)}{C2(L_x, L_y, \epsilon)} = \frac{C3(m + L_x, \epsilon)}{C4(L_x, \epsilon)} \quad (4)$$

for given values of m , L_x , and $L_y \geq 1$ and $\epsilon > 0$, where $C1, \dots, C4$ are the correlation-integral estimates of the joint probabilities. Hiemstra and Jones (1994) discuss how to

derive the joint probabilities and their corresponding correlation-integral estimators. Assuming that X_t and Y_t are strictly stationary, weakly dependent, and satisfy the mixing conditions given by Denker and Keller in 1983, if Y_t does not Granger cause X_t , then,

$$\sqrt{n} \left(\frac{C1(m + Lx, Ly, e, n)}{C2(Lx, Ly, e, n)} - \frac{C3(m + Lx, e, n)}{C4(Lx, e, n)} \right) \approx N(0, \mathbf{s}^2(m, Lx, Ly, e)), \quad (5)$$

Hiemstra and Jones (1994) show that a consistent estimator of the variance is,

$$\mathbf{s}^2(m, Lx, Ly, e) \equiv \mathbf{d}(n) \cdot \Sigma(n) \cdot \mathbf{d}(n)' \quad (6)$$

To test for nonlinear causality between volume and returns per se, the test in equation (6) is applied to obtained residual series from the VAR models. Since the VAR model accounts for any linear dependencies, any remaining predictive power of one residual series for another can be considered nonlinear predictive power.

This test holds under the general case where the errors are allowed to be weakly dependent. Though this test may provide nonlinear causal dependence, it does not provide any clue of the sources of the dependence.

3. 0. Data:

The data used in this study are based on time series of daily stock returns as well as trading volumes obtained from the National Stock Exchange. We compute stock returns from daily closing prices for the S&P CNX Nifty index for a period of more than six years from 1-Jan 1996 to 6-August 2002, for a total of 1649 data points. During this period Indian stock markets have undergone substantial policy changes related to clearing and settlement of trades in the markets. These changes have affected the movement in index and magnitude of volume trades in the market in different ways. To account the effect of shift from account settlement to rolling settlement we classify the period of study into three sub-periods:

1. 01/01/1996 to 31/12/1999 refers to the period before rolling settlement was introduced,
2. 01/01/2000 to 01/07/2001 refers to the period when rolling settlement was introduced in phased manner, and
3. 02/07/2001 to 06/08/2002 refers to the period when rolling settlement was compulsory for around 414 large scrips that account for substantial trading on the NSE (all scrips were brought under compulsory rolling settlement from December 31, 2001).

As followed by earlier studies that have evaluated trading volume and stock returns simultaneously (see Hiemstra, and Jones (1994), Cambell, Grossman, and Wang (1993), and Gallant, Rossi, and Tauchen (1992)) we take total daily trading volume in the stock exchange (in this case National Stock Exchange) for the trading volume series. The daily stock returns are continuous rates of return, computed as 100 times the first difference of the natural logarithm of the daily stock price, P_t , in the successive time periods.

$$R_t = 100.\ln(P_t/P_{t-1}) \quad (7)$$

Because, causality tests can be sensitive to nonstationarities associated with structural breaks, it is important to study periods when the univariate and bivariate stochastic processes generating stock prices and trading volume can be considered stationary. The augmented Dickey-Fuller (ADF) regressions are estimated with a linear time trend and intercept. Results of the ADF test are provided in table 1.

The null hypothesis of the ADF tests is non-stationarity. The alternative hypothesis is specified as stationary around a linear trend with an intercept. The results indicate that the null hypothesis of unit root is rejected for R_t but fails to reject for V_t in all the sub-periods. For the first order difference series of the volume ΔV_t the null hypothesis of unit root is rejected for all the sub-periods. Based on the augmented Dickey-Fuller test results, percentage change in trading volume is used for further investigation in place of volume series.

$$\Delta V_t = 100.(V_t/V_{t-1}) \quad (8)$$

Table 1 also reports sample statistics for returns and volume change for the three sub-periods. It is observed that stock index returns (except for first sub-period) and stock market trading volume change have negative skewness, and significant excess kurtosis is observed for trading volume change.

Table 1.

Summary statistics for the daily stock index (S&P CNX Nifty) prices and daily stock exchange (National Stock Exchange) trading volume: log difference, 1/1/1996 ~ 6/8/2002 (sub divided into three time periods).

Time Period (No. of Observations)	S&P CNX NIFTY		National Stock Exchange	
		Return on Daily Stock Index Price (R _t)	Total Daily Trading Volume - INR crore (V _t)	Change in Total Daily Trading Volume (ΔV_t)
01/01/96	Mean	0.04903	1653.76216	0.26702
to	Std. Dev.	1.72553	847.08890	29.07870
31/12/99	Skewness	0.00401	1.46246	-0.00792
(996)	Kurtosis	2.69569	3.27126	10.84178
	ADF (τ)	-30.44392*	-2.98652	-48.46576*
01/01/00	Mean	-0.07730	4737.21523	-0.10316
to	Std. Dev.	1.93495	1984.19107	28.41535
01/07/01	Skewness	-0.12388	0.08023	-0.27799
(374)	Kurtosis	1.52235	-0.60505	3.39706
	ADF (τ)	-17.70489*	-1.87495	-27.53795*
02/07/01	Mean	-0.04941	2168.04862	-0.00633
to	Std. Dev.	1.29602	637.16888	31.52511
06/08/02	Skewness	-0.50398	0.28102	-0.87118
(277)	Kurtosis	2.88531	0.52994	46.86197
	ADF (τ)	-15.14389*	-2.92208	-26.75077*

The ADF test for unit roots is calculated with an intercept and a time trend. ADF (τ) is the calculated value of Dickey-Fuller test statistics. The critical values of ADF (τ) are -3.41 at 0.05 and -3.96 at 0.01.

* indicates significant difference of test statistic from tabulated value at 0.05 level of significance.

The results of ADF test for unit root for the sub-periods indicate that first difference of volume series are stationary. Hence, we test linear and non-linear Granger causality between returns in S&P CNX Nifty and volume change in the NSE for the three sub-periods, the results for which are presented in the next section.

4. 0. Empirical Findings:

This section reports the results of the linear and nonlinear causality between stock returns and volume changes.

4.1. Linear Granger Causality:

The system of equations 1 & 2 is determined using Hsiao's sequential procedure for causality, enumerated in detail by Silvapulle and Choi, 1999. This method follows stepwise procedure where firstly R is treated as a one-dimensional process in equation 1 with all $\phi = 0$. The Akaike's final predictive criterion (FPE) is calculated from 1 to L_a . L_a is chosen arbitrarily which in our case is 30. That lag length, l_a is selected which gives the smallest FPE. In second stage R is treated as a controlled variable with lag length l_a and V is manipulated in equation 1. The FPEs are computed by varying order of lags of V from 1 to L_b . L_b is chosen arbitrarily which in our case is 15. The lag length l_b that corresponds to the lowest FPE is selected. Similarly the lag lengths l_a and l_b can be found for equation 2. The VAR model is estimated by OLS and heteroscedasticity consistent covariance matrix estimates of standard errors are used to estimate the appropriate VAR equation.

Table 3 reports the lag lengths and F-statistic for linear Granger causality between returns and volume change. The results of the F-test support bi-directional linear Granger causality from returns to volume change and from volume change to returns for first two sub-periods. This corresponds to the time when rolling settlement was either not introduced or was introduced in a limited manner. The null hypothesis of non-causality is accepted for the third sub-period when rolling settlement was widely introduced.

Table 2.
Linear Granger Causality Test Results (F Statistic)

	Time Period	Lv	Lr	F Statistic
H0: Stock returns do not cause volume change	01/01/96-31/12/99	8	10	1.98680*
	01/01/00-01/07/01	10	2	4.56570*
	02/07/01-06/08/02	4	10	0.92912
	Time Period	Lr	Lv	F Statistic
H0: Volume change do not cause stock returns	01/01/96-31/12/99	1	1	8.54347*
	01/01/00-01/07/01	2	8	2.02030*
	02/07/01-06/08/02	1	2	1.15038

F-test for joint exclusion restrictions are calculated.
* indicates significant value at 0.05 level of significance.

4.2. Nonlinear Granger Causality:

The results of the modified Baek and Brock test statistics, applied to residuals from the VAR model identified for linear causality test, are reported in Table 3. To

implement the modified Baek and Brock test, lead and lag truncation lengths (m , L_x and L_y) and the length scale parameter, e , have to be selected. Unlike in linear causality analysis, there are no established criteria to determine the optimal values for these parameters. We follow the evidence of Hiemstra and Jones (1993), that for sample sizes of 500 or more: $m = 1$, $L_x = L_y$ and $e = 1.5\sigma$ with $\sigma = 1$ provide good finite-sample size and power properties. We use lag lengths $L_x = L_y$ from 1 to 8.

For all the sub-periods the null hypothesis is accepted at all lags (except lag1 for first sub-period and lag 8 for second sub-period), which implies that there is no evidence in support of nonlinear Granger causality in either direction (Return to volume change & volume change to return). These results are in contrary to evidences from U.S. (Hiemstra and Jones, 1994), Canada etc. But the result from developing economies like Korea (Silvapulle and Choi, 1999) are mixed.

Table 3.
Nonlinear Granger Causality Test Results: CS (TVAL)

Lags: Equal univariate and bivariate lags ($L_x = L_y$)

Time Period		1	2	3	4	5	6	7	8
H0: Stock returns do not cause volume change	01/01/96 to 31/12/99	-0.0049 (2.253)*	-0.0043 (1.254)	-0.0003 (0.056)	-0.0034 (0.606)	-0.0051 (0.746)	0.0001 (0.014)	-0.0037 (0.434)	-0.0049 (0.504)
	01/01/00 to 01/07/01	0.0103 (1.546)	0.0146 (1.55)	0.005 (0.506)	0.0077 (0.75)	0.0092 (0.796)	0.0062 (0.516)	0.0048 (0.373)	0.0053 (0.401)
	02/07/01 to 06/08/02	0.0032 (0.504)	0.0014 (0.201)	-0.0001 (0.006)	-0.0008 (0.08)	-0.0061 (0.586)	-0.0025 (0.211)	-0.0053 (0.448)	0.0019 (0.13)
	01/01/96 to 31/12/99	0.006 (1.643)	0.0016 (0.338)	-0.0007 (0.131)	-0.0047 (0.677)	-0.0054 (0.677)	-0.0162 (1.804)	-0.0182 (1.686)	-0.0215 (1.645)
H0: Volume change do not cause stock returns	01/01/00 to 01/07/01	0.0081 (1.209)	0.0079 (0.948)	0.0184 (1.756)	0.0179 (1.425)	0.0172 (1.303)	0.0148 (0.945)	0.0276 (1.692)	0.0444 (2.471)*
	02/07/01 to 06/08/02	0.0062 (1.035)	0.007 (0.938)	0.0065 (0.678)	0.013 (1.354)	0.0124 (1.151)	0.0132 (1.087)	0.0134 (1.027)	0.0087 (0.577)

CS and TVAL denote the difference between the two conditional probabilities and the standard test statistic in equation (5) respectively. The table gives CS value and standardized test statistic TVAL is given within the brackets. $L_x = L_y$ denotes the number of lags used. The lead length m is set to unity and the length scale e is set to 1.5. TVAL is asymptotically distributed $N(0,1)$. * indicates significant value at 0.05 level of significance.

Much of the non-linear structure in daily returns is related to ARCH dependence (Hsieh, 1991) and it is possible that the non-linear Granger causality from trading volumes to stock returns could be due to simple volatility effects associated with information flow, hence the use of modified Baek and Brock test for testing un-filtered

return series is cautioned. Where there is significant presence of non-linear causality from volumes to returns one should check if it could be due to ARCH dependence. In our case the residuals used for Baek and Brock non-linear Granger test are filtered using White's heteroscedasticity-consistent covariance matrix method.

5. 0. Summery and Conclusion:

This study tests linkages between S&P CNX NIFTY index returns and aggregate trading volume on the National Stock Exchange (NSE) to examine the nature of the dynamic relation between aggregate daily stock returns and volume in Indian stock markets. The tests are applied to NSE data over the period January 1996 to August 2002, which is sub divided into three sub-time periods. The relationship between volume and returns is examined by means of linear and nonlinear causality tests.

Linear causality tests show bi-directional (i.e. from returns to volume change and volume change to returns) linear Granger causality during the period when rolling settlement was either not introduced or introduced in limited manner. The causality in either direction is not observed for the period when rolling settlement is introduced in most of the high value and high volume stocks. However, the non-linear Granger causality is absent in either direction for all the time periods, suggesting that non-linear effect are not significant in NSE and linear effects could be sufficient for predicting causality. The linear causality test results also suggest that efficiency of NSE is improving with introduction of rolling settlement in majority of stocks.

The finding of linear relation between volume and returns series can be explained theoretically. Large positive price changes that imply higher capital gains, encourage transactions by traders leading to increase in volumes. On the other hand the volume can be an important source of information to traders leading to price changes based on volume information. Both these phenomena if present can be used for predicting future movements of the price and volume series.

There is need to further study the relationship between returns and volume change by controlling for effects of different forms of volatilities in the price and volume series like calendar effects etc.

References:

Blume, L., D. Easley, and M. O'Hara, 1994, Market statistics and technical analysis: The role of volume, *Journal of Finance*, Vol. 49 (1), 153-181.

Campbell, J., S. Grossman and J. Wang, 1993, Trading volume and serial correlation in stock returns, *Quarterly Journal of Economics*, 108, 905-939.

Copeland, T. E., 1976, A model of asset trading under the assumption of sequential information arrival, *Journal of Finance*, 31, 1149-1168.

Cromwell, J. B., Hannan, M. J., Labys, W. C., and Terraza, M., *Multivariate tests for time series models*, a Sage University Paper, Series: Quantitative Applications in the Social Sciences (100), Sage Publications, 1994.

Epps, T. and M. Epps, 1976, The stochastic dependence of security price changes and transaction volumes: Implications for mixture-of-distribution hypothesis, *Econometrica*, 44, 305-321.

Epps, T. W., 1977, Security price changes and transaction volumes: some additional evidence, *Journal of Financial and Quantitative Analysis*, 12, 141-146.

Gallant, R., P. Rossi, and G. Tauchen, 1992, Stock prices and volume, *Review of Financial Studies*, 5, 199-242.

Granger, C.W.J., 1969, Investigating causal relations by econometric models and cross-spectral methods, *Econometrica*, 37, 424-438.

Hiemstra, C. and J. D. Jones, 1994, Testing for linear and nonlinear Granger causality in the stock price-volume relation, *Journal of Finance*, 49, 1639-1665.

Hsieh, D., 1991, Chaos and nonlinear dynamics: Application to financial markets, *Journal of Finance*, 46, 1839-1877.

Jennings, R., L. Starks and J. Fellingham, 1981, An equilibrium model of asset trading with sequential information arrival, *Journal of Finance*, 36, 143-161.

Karpoff, J., 1987, The relation between price changes and trading volume: A survey, *Journal of Financial and Quantitative Analysis*, 22, 109-126.

Lakonishok, J., and S. Smidt, 1989, past price changes and current trading volume, *The Journal of Portfolio Management*, 15, 18-24.

Rogalski, R. J., 1978, The dependence of prices and volume, *Review of Economics and Statistics*, 60, 268-274.

Silvapulle, P. and J. S. Choi, 1999, Testing for linear and nonlinear Granger causality in the stock price-volume relation: Korean evidence, *Quarterly Review of Economics and Finance* 39, 59-76.

Smirlock, M. and L. Starks, 1985, A further examination of stock price changes and transactions volume, *Journal of Financial Research*, 8, 217-225.

Smirlock, M. and L. Starks, 1988, An empirical analysis of the stock price-volume relationship, *Journal of Banking and Finance*, 12, 31-41.