State Space Modeling of Price and Volume Dependence: Evidence from Currency Futures

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INTRODUCTION

In the financial literature, price–volume relationships have received a great deal of theoretical and empirical research attention. Studies have been conducted in stock markets [Ying (1966); Epps and Epps (1976)] and the futures markets [Clark (1973); Cornell (1981); Tauchen and Pitts (1983)] in an attempt to test the proposition that absolute changes in prices or changes in prices per se are positively correlated with volume. This relationship may be due to a joint dependence on a common event or variable. In other words, the volume and price change relation should be positive because of joint dependence on a common directing event or variable. This is referred to as the mixture of distributions hypothesis (MDH) [see Clark (1973)].

Harris (1986) suggests that this directing variable is the daily rate of information flow. Thus, when new information (unexpected) arrives, trading increases as the traders revise their positions. Consequently, both the price and trading volume change simultaneously regarding this new information. Additionally, Harris argues, since the variation in the directing variable (i.e., rate of information flow) may be random or seasonal, price variation may be changing through time. This is especially true of futures contracts since information arrival may be maturity dependent. In a later study, Harris (1987) supports the MDH by using transactions data for a sample of NYSE common stocks.

Another explanation for the existence of the price change–volume relationship is provided by the "sequential information" models of Copeland (1976); Jennings, Starks, and Fellingham (1981); and Smirlock and Starks (1984). In their models, information is disseminated to only one trader at a time in such a way that intermediate equilibriums occur before the final equilibrium is reached. Thus, the sequential model implies that price variability may improve forecasts of volume or vice versa.

Karpoff (1987) reports that the interdependence between volume and absolute price change is positive in the equity markets as well as in the futures markets. With respect to the price change per se–volume relations, a positive correlation exists in equity markets.

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However, no relationship is found for futures markets. As Karpoff (1987) points out, the price variability (absolute price change)–volume relations has important implications for research into futures markets. If the volume of trade in futures contracts affects price, then speculation could be a stabilizing or destabilizing factor in futures prices.

The purpose of this study is to apply state space modeling to determine the relationship between trading volume and price change per se as well as between trading volume and absolute price change. The state space procedure is utilized to test for the best (in Granger causality sense) relationship among the above variables using currency futures. There are several important advantages in using state space modeling. First, the state space procedure allows one to determine simultaneously the causal link and the relationship between the above variables. Next, while the identification of VARMA models is somewhat subjective, state space allows for the mathematical determination of the minimum number of dimensions necessary to span the Markovian representation of a multivariate autoregressive moving average process. This allows for greater insight into the lead/lag relationship between and among the variables of concern. In this way, when there is a disturbance in the pricing in the futures markets, one can measure how long this disturbance in pricing will impact trading volume. Finally, state space analysis allows one to determine whether causality is unidirectional or not.

LITERATURE REVIEW

Volume/Price Change Per Se Relationship

Epps (1975) argues that many prior tests on price and volume are not designed "to detect a relation between the volume on a transaction and the change in price from the previous transaction, or even between total volume and price change over an interval of time." His objective is to determine whether in a bull-market (uptick) the ratio of volume to price change exceeds the absolute value of the same ratio in a bear-market (downtick). Epps points out that since bulls are more optimistic about asset values they tend to react to positive or good news while discounting any bad news. The opposite is true for the bears who are pessimistic in nature and react only to bad news. In this framework, the transaction demand curve is made up of demand prices of bulls while the transaction supply curve depends on the bears. His testable hypothesis is that bulls consider assets to be riskier than bears do and, from this, the bull's demand function is steeper than that of the bears. This means that the ratio of volume to a positive price change would be greater than that of the ratio of volume to a negative price change. A major drawback to this hypothesis is that it implies investor irrationality where pertinent information is systematically ignored.

Copeland's (1975) sequential information arrival model is extended by Jennings, Starks, and Fellingham (1981) to include margin requirements and short selling. Since the short sale is more costly than a long position, it follows that those investors undertaking short positions face a demand curve which is less responsive to a change in prices. Their model shows that the volume generated from an optimistic trader will be greater than that of a pessimistic investor. They further argue that price increases are associated with optimists while price decreases are associated with pessimists. The result is that volume increases with increases in prices while falling prices are associated with volume declines. The drawback to this work is similar to that of Copeland (1975) and Epps (1975) in that it is assumed that the uninformed investor never learns from the previous actions of traders.

In two separate empirical works, Epps (1975) and Epps (1977), dealing first with the bond market and then with the stock market, finds that the ratio of volume to price change per se is larger for "bull" transactions (upticks) than for "bear" transactions (downticks). In contrast, an empirical work by Wood, McInish, and Ord (1985) where they investigate the transaction data for NYSE stocks, reveals that the ratio is higher for downticks. Jain and Joh (1988) find a positive relation in the ratio and further find that volume is more responsive to positive than negative changes in price. Rogalski (1978) tries to determine if security prices and volume are causally linked. He utilizes the Granger causality test using monthly data for stocks and their warrants. His results are consistent with Epps and Epps (1976) in that a positive dependence between volume and price change is found. However, he rejects the notion that causality runs from volume to the change in price. A criticism of this work is that it may be impossible to find causality with monthly data.

The overall implication from all these studies is that there appears to be a positive correlation between volume and a change in price per se. These tests are all conducted in the stock and bond markets. However, no correlation between price change per se and volume has been reported in the futures markets [see Karpoff (1988)]. A key difference between cash and futures markets resides in the area of the short sale constraint that some models (e.g., Copeland) impose. As Karpoff asserts, in the futures market, the costs of taking long or short positions are symmetric. Thus, the correlation between returns and volume should not be significant in the futures market.

Volume/Absolute Price Change Relationship

The sequential arrival model of Copeland (1976) argues that the expected number of trades is related to changes in absolute prices. One major assumption of the model is that traders receive news sequentially with each trader shifting his demand curve immediately. The trading period comes to an end when all traders have shifted their individual demand curves. Here, the price change is known with certainty but the price adjustment paths as well as the trade volume are random variables. Before any "news" is generated, traders face homogeneous demand curves. As long as the change in prices is anticipated, the results are just movements along the curve. Where price changes are unanticipated the demand curve shifts up if the trader is optimistic and shifts downward if the trader is pessimistic. Two influencing factors upon which the relationship depends are (1) the prior pattern of those who had been informed and (2) whether or not the next trader is an optimist or pessimist. In his simulation test, Copeland finds that volume is highest when investors are all optimists or all pessimists. The simulation supports a positive correlation. Jennings, Starks, and Fellingham (1981) modify Copeland's work by introducing a margin requirement. Given that short sales are more costly than long positions, the quantity demanded by a trader with a short position is less responsive to price changes than a trader with a long position. In addition, they find the relationship is affected by the number of investors and the mix between optimists and pessimists.

In an attempt to model the joint distribution of daily stock price changes and volume, Clark (1973) proposes the use of a mixture of normal distributions which assumes that events happen at random rates over time. A positive relation is found. Also, making use of the mixture of distribution hypothesis (MDH), Epps and Epps (1976), argue that price changes "are then mixtures of distributions with volume as the mixing variable." They find a positive volume and squared price change relationship using transaction data from common stock. Harris (1986) presents new tests of the MDH where he assumes that prices and volume develop at uniform rates. Using daily data from common stocks, he finds a positive correlation between volume and the squared price change.

Another explanation of the relationship is offered by Tauchen and Pitts (1983) in their test of the hypothesis that transactions time differs from calendar time. With daily data from the Treasury bills futures market, they report a positive correlation and also show that an increase in traders leads to a trade volume increase, which in turn results in a decrease in price variability. Using sample data of futures contracts, Grammatikos and Saunders (1986) argue that the variance of the price change process has an inverse relationship with the time to maturity of a contract. Maturity has a strong impact on volume but no such relationship is found regarding price variability.

Karpoff (1987) reports that the volume–price (absolute price change and or squared price change) correlation occurs in both the equity and futures markets. Even though there is a consistent positive pattern, the correlations are found to be relatively weak. Another observation is that the correlation is weaker over transaction data as opposed to calendar intervals. In a later study, Karpoff (1988) finds a positive correlation between volume and the absolute price change for twelve commodity futures contracts.

DATA AND METHODOLOGY

Data

Daily currency futures prices and volume between January, 1979 and May, 1990 are from the Chicago Mercantile Exchange (CME). Since most trading activities take place in the near-month contract, only near-month contract data are examined.[1] This procedure confines the data to the most actively traded contracts. Trading volume increases up until the delivery month. Once the delivery month is reached, volume shifts to the contract nearest to delivery. A continuous sequence of 2884 observations of futures prices data is gathered from the 11-year period. The natural logarithm of the price relative is used to calculate price change. Continuously compounded price changes are calculated for each currency futures as,

$$R_t = \text{Ln}(P_t/P_{t-1})$$

where P_{t-1} is the contract price at time $t - 1$.

Methodology

Multivariate ARMA models developed by Tiao and Box (1981) allow the modeling of both causality and feedback relations among the variables. However, model identification is difficult and uncertain. To solve the problem of identification, Akaike suggests several ways to solve the problem of identification.

Akaike is responsible for developing a definitive starting point for the initial Yule–Walker equations. While the use of a sufficiently large number of k-lags will cause convergence with probability one to the values estimated from the true probability

[1]Johnston, Kracaw, and McConnell (1991) argue that using the highest volume contracts would result in more correct measurement of equilibrium prices. Additionally, they argue, this procedure avoids the problem of contemporaneous correlation among the data that include more distant contracts. Under this procedure, contract prices with highest volume are used for each trading day. Generally, the outstanding contract that is nearest to delivery but not within one month of delivery is the contract in which the trading is most active. Under this method of calculating daily returns, the return on a contract is earned by holding the contract up to one month before delivery and then rolling it over into the contract with the next nearest delivery date. This method is also used by Karpoff (1988).

density function, such an approach does not guarantee an optimal starting point [see Akaike (1976) p. 41].[2] Through the use of Akaike Information Criterion (AIC), an initial sample period is determined by using autocovariances from an increasing number of k-lags of the initial Yule–Walker equations. This determines which k-lag structure of the initial Yule–Walker equations give the *best* AIC value, i.e., minimizes the prediction error subject to the number of parameters used. By way of analogy, AIC helps identify the initial Yule–Walker equations in a manner similar to adjusted R square.

Akaike (1974) also established that any multivariate autoregressive moving average process can be converted into a Markovian representation. However, the structure of the Markovian representation is generally not unique. He solved this problem by using canonical correlation analysis.

In the first step, canonical correlation is used to select the dimension of the state vector. Following Tatsuoka (1971) and Akaike (1974), canonical correlation is used to determine a linear combination of the variables of one set (Yule–Walker equations) with a linear combination of the variables in another set (multivariate stochastic system) in such a way that these linear combinations best express the correlation between the two sets of equations. Bartlett's chi square is also used to test the overall significance of this relationship. Next, the second smallest canonical correlate (i.e., the square of the second largest eigenvalue) is determined to compute the second eigenvector (independent of the first). The incremental change in Bartlett's chi square is then calculated to see if an additional dimension should be added to the state vector to adequately span the projection of the Markovian representation of the multivariate stochastic system.

An information criterion developed by Akaike (1976) confirms the amount of past information to be used in estimating the correct state space model. The order for which Akaike's Information criterion (AIC) is minimized is selected. Once a model is put in a state space form, the Kalman filter may be applied for predicting and smoothing. The Kalman filter is widely used in engineering and is a recursive procedure for computing the optimal estimator of the state vector at time t, based on the information available at time t. The filter is very close to Bayesian forecasting in that the current estimate is weighted given prior information. However, with the Kalman filter, the weights are continually revised and give more emphasis to the time period with greater uncertainty [see Makridakis, Wheelwright, and McGee (1983), p. 501]. The Kalman filter also allows for the maximum likelihood estimation of the unknown parameters in the model. This is done via the prediction error decomposition [see Harvey (1989), p. 100].

The state space procedure requires stationary, seasonally adjusted series. The researcher has to deseasonalize the series and specify the degree of regular and/or seasonal differencing, or the type of transformations necessary to achieve stationarity. The necessary and sufficient condition for stability is that the characteristic roots of the transition matrix are less than one [see Harvey (1989), p. 114].

The state space procedure can analyze and forecast univariate and multivariate time series data. The state space representation of a stationary multivariate time series X, of dimension r is of the form:

$$Z_{t+1} = FZ_t + Ge_{t+1}$$

[2]The first term in the definition of AIC asymptotically shows a downward bias of the amount equal to the number of the free parameters within the model. The fact that the maximum likelihood estimate introduces this amount of bias means that the fitted model shows on the average a deviation equal to this amount defined as $2N \times$ the negentropy. The second half of the second term in the definition of AIC is thus introduced to make AIC an estimate which compensates for the bias [see Akaike (1976), p. 42].

Where Z_t is a state vector of dimension s, whose first r components comprise X_t and whose remaining components contain all additional needed information to forecast future values of Z_t; F is an s by s transition matrix; G is an s by r input matrix; and e_t is a sequence of independent r-dimensional random vectors called innovations or shocks with a common variance matrix and mean zero.

Based on the data, the procedure solves for the state space form that succinctly spans a given multivariate time series; that is a form of F and G. The state vector (Z_t) contains all the information necessary from the present and past history of the system to predict its future behavior. The maximum likelihood estimates of the parameter values can then be obtained.

RESULTS

Volume/Price Change Per Se

State space modeling of the relationship between volume and price change for each currency futures trade on the CME from January, 1979 through May, 1990 is estimated. The results in Table I indicate that the lagged values of price change per se and volume do not provide any explanatory power for the current price change per se and vice versa.[3] Equations (1) indicate that the price changes per se are not affected by lagged values of price changes per se and volume for almost all the currencies used here. Equations (2) indicate the volume in futures market is a function of only lagged values of volume and is not affected by the price change per se. The results reported in Table I hold for all the currencies used in this article with the exception of the Canadian dollar.

The lack of a positive relation between price change per se and volume for currency futures is in contrast with the majority of empirical work in this area. [see Karpoff (1987)]. However, the results are consistent with studies by Granger and Morgenstern (1963); Godfery, Granger, and Morgenstern (1964); James and Edmister (1983); Wood, McInish, and Ord (1985). Empirical results presented here are indirectly supportive of the costly short sales hypothesis set forth by Karpoff (1988). Karpoff states that the positive relation between price change per se and volume reported for stock and bond market should be absent in futures markets since the cost of taking long and short positions are symmetric in futures markets.

Volume/Absolute Price Change

State space modeling of the relationship between absolute price change and volume is reported next. Maximum likelihood estimates of the final state space models for all currencies are reported in Table II. Note that in all cases for eqs. (1), there is no contemporaneous effect between the absolute price change and volume. The mixture of distribution hypothesis suggests that there is a contemporaneous impact between the variables. The results, therefore, are more consistent with the sequential arrival of information model suggested by Copeland (1976) and extended by Jennings, Starks, and Fellingham (1981). In this model, information is disseminated to only one trader at a time, which implies a positive correlation between volume and absolute price change.

Table II also reports the state space modeling of the causality between volume and absolute price changes. Rogalski (1978) did not detect the direction of causality between

[3]To select the appropriate model for each currency, AIC along with canonical correlation analysis are considered. The results are available from authors upon request.

Table I
STATE SPACE ESTIMATES OF THE RELATIONSHIP BETWEEN PRICE CHANGE PER SE AND VOLUME FOR CURRENCY FUTURES

British pound

(1) $RBP_t = 0.025RBP_{t-1} + 0.020BPVOL_{t-1} + \varepsilon_{1,t}$

(2) $BPVOL_t = 0.021RBP_{t-2} - 0.403BPVOL^a_{t-2} + 1.408BPVOL^a_{t-1} + 0.508\varepsilon^a_{1,t-1} + \varepsilon_{2,t}$

Canadian dollar

(1) $RCD_t = 0.062RCD^a_{t-1} + 0.007CDVOL_{t-1} + \varepsilon_{1,t}$

(2) $CDVOL_t = 0.023RCD_{t-2} - 0.377CDVOL^a_{t-2} + 1.381CDVOL^a_{t-1} + 0.484\varepsilon^a_{1,t-1} + \varepsilon_{2,t}$

Jananese yen

(1) $RJY_t = -0.002RJY_{t-1} + 0.011JYVOL_{t-1} + \varepsilon_{1,t}$

(2) $JYVOL_t = -0.006RJY_{t-2} - 0.034JYVOL_{t-2} + 0.382JYVOL^a_{t-1} - 0.481\varepsilon_{1,t-1} + \varepsilon_{2,t}$

Swiss franc

(1) $RSF_t = -0.025RSF_{t-1} - 0.012SFVOL_{t-1} + 0.527^a\varepsilon_{2,t-1} + \varepsilon_{1,t}$

(2) $SFVOL_t = -0.008RSF_{t-2} - 0.406SFVOL^a_{t-2} + 1.414SFVOL^a_{t-1} + 0.016\varepsilon^a_{1,t-1} + \varepsilon_{2,t}$

Deutsche mark

(1) $RDM_t = -0.023RDM_{t-1} + 0.018DMVOL_{t-1} + 0.517^a\varepsilon_{2,t-1} + \varepsilon_{1,t}$

(2) $DMVOL_t = 0.006RDM_{t-2} - 0.344DMVOL^a_{t-2} + 1.346DMVOL^a_{t-1} + \varepsilon_{2,t}$

RBP = price change for British pound = $Ln(P_t/P_{t-1}) \times 100$, BPVOL = Ln (British pound volume).
RCD = price change for Canadian dollar = $Ln(P_t/P_{t-1}) \times 100$, CDVOL = Ln (Canadian dollar volume).
RJY = price change for Japanese yen = $Ln(P_t/P_{t-1}) \times 100$, JYVOL = Ln (Japanese yen volume).
RSF = price change for Swiss franc = $Ln(P_t/P_{t-1}) \times 100$, SFVOL = Ln (Swiss franc volume).
RDM = price change for Deutsche mark = $Ln(P_t/P_{t-1}) \times 100$, DMVOL = Ln (Deutsche mark volume).
[a]Indicates statistically significant at the 1% level.

price change and volume using monthly data. The use of daily data along with a more robust methodology provides a powerful test for detecting causality. The results in Table II indicate that there is a significant relationship between volume and lagged absolute returns (up to two lags) [eqs. (2)]. These results are consistent with Jain and Joh (1988) for the stock market.

Equations (1) in Table II indicate that the causality between returns and volume is not unidirectional in the case of the British pound, the Canadian dollar, the Swiss franc, and the Deutsche mark. The results suggest that there is some evidence of volume having a stabilizing influence on returns. Jain and Joh (1988) also report a weak causal relationship between volume and returns. Grammatikos and Saunders (1986) also find some evidence of bidirectional causality between price variability and volume for foreign currency futures. However, the results of this study are quite strong and statistically significant for the British pound, the Canadian dollar, the Swiss franc, and the Deutsche mark. Note that the coefficients of volume in eqs. (1) are negative at time $t - 1$ (and statistically significant) for the British pound, the Swiss franc, and the Deutsche mark. This negative sign of the volume coefficients indicates that higher volume is associated with smaller absolute price changes the following day. This stabilizing influence is absent in the Japanese yen contract and in the wrong direction for the Canadian dollar contract.

Table II
STATE SPACE ESTIMATES OF THE RELATIONSHIP BETWEEN ABSOLUTE PRICE CHANGE AND VOLUME FOR CURRENCY FUTURES[a]

British pound

(1) $|RBP_t| = 0.033BPVOL^a_{t-2} + 1.045|RBP^a_{t-1}| - 0.035BPVOL^a_{t-1} + \varepsilon_{1,t}$

(2) $BPVOL_t = -0.090|RBP^a_{t-2}| - 0.318BPVOL^a_{t-2} + 0.145|RBP^a_{t-1}| + 1.308BPVOL^a_{t-1} + 0.499\varepsilon^a_{1,t-1} + \varepsilon_{2,t}$

Canadian dollar

(1) $|RCD_t| = -0.062|RCD^a_{t-2}| + 0.016CDVOL^a_{t-1} + 1.077|RCD^a_{t-1}| + \varepsilon_{1,t}$

(2) $CDVOL_t = -0.403|RCD^a_{t-2}| + 0.415|RCD^a_{t-1}| + 0.309CDVOL^a_{t-1} + 0.246\varepsilon^a_{1,t-1} + \varepsilon_{2,t}$

Japanese yen

(1) $|RJY_t| = 0.435|RJY^a_{t-2}| + 0.372|RJY^a_{t-1}| + \varepsilon_{1,t}$

(2) $JYVOL_t = 0.083JYVOL^a_{t-2} - 0.678|RJY^a_{t-1}| + 0.413JYVOL^a_{t-1} + \varepsilon_{2,t}$

Swiss franc

(1) $|RSF_t| = 1.020|RSF^a_{t-1}| - 0.110SFVOL^a_{t-1} - 0.064^a\varepsilon_{2,t-1} + \varepsilon_{1,t}$

(2) $SFVOL_t = -0.052|RSF^a_{t-2}| + 0.043|RSF^a_{t-1}| + 0.345SFVOL^a_{t-1} + 0.027\varepsilon^a_{1,t-1} + \varepsilon_{2,t}$

Deutsche mark

(1) $|RDM_t| = 1.027|RDM^a_{t-1}| - 0.123DMVOL^a_{t-1} - 0.054^a\varepsilon_{2,t-1} + \varepsilon_{1,t}$

(2) $DMVOL_t = -0.075|RDM^a_{t-2}| + 0.024|RDM^a_{t-1}| + 0.293DMVOL^a_{t-1} + 0.036\varepsilon^a_{1,t} + \varepsilon_{2,t}$

|RBP| = absolute price change for British pound = $Ln(P_t/P_{t-1}) \times 100$, BPVOL = Ln (British pound volume).

|RCD| = absolute price change for Canadian dollar = $Ln(P_t/P_{t-1}) \times 100$, CDVOL = Ln (Canadian dollar volume).

|RJY| = absolute price change for Japanese yen = $Ln(P_t/P_{t-1}) \times 100$, JYVOL = Ln (Japanese yen volume).

|RSF| = absolute price change for Swiss franc = $Ln(P_t/P_{t-1}) \times 100$, SFVOL = Ln (Swiss franc volume).

|RDM| = absolute price change for Deutsche mark = $Ln(P_t/P_{t-1}) \times 100$, DMVOL = Ln (Deutsche mark volume).

[a]Indicates statistically significant at the 1% level.

This implies that an increase in volume actually reduces the price volatility (absolute price change) in futures markets for the majority of the currency futures contracts studied.

CONCLUSIONS

This study investigates the joint generating processes of daily currency futures trading volume and price change using state space modeling. The state space procedure allows one to simultaneously test for the causal link between the above variables. In other words, rather than imposing the structural model on the data, the data is allowed to decide the direction of the causality. The state space procedure also allows one to obtain the minimum number of parameters necessary to span the state space of the time invariant linear relationship which best describes a given set of observations.

This study finds no relationship between trading volume and price change per se. The results are consistent with studies by Granger and Morgenstern (1963); Godfery, Granger, and Morgenstern (1964); James and Edmister (1983); Wood, McInish, and Ord (1985) for the stock market. Empirical results of this study are indirectly supportive of the costly short sales hypothesis set forth by Karpoff (1985) i.e., the positive relation between price change per se and volume reported for the stock and the bond market should be absent in the futures markets since the cost of taking long and short positions are symmetric in futures markets.

This study finds a positive causal relationship between volume and absolute price change for all currencies except the yen. In all cases examined, volume is positively dependent upon the trading volume of the previous day which is consistent with the sequential models of Copeland (1976). In this model, information is disseminated to only one trader at a time, which implies a positive correlation between volume and absolute price change.

Finally, state space is used to detect causality between price change and volume. Previous studies have encountered difficulties in detecting the direction of causality in the data. The use of daily data along with a more robust methodology provides a powerful test for detecting causality. The results indicate that there is a significant relationship between lagged absolute returns (up to two lags) and volume. Evidence is found also that the causality between returns and volume is not unidirectional for the British pound, the Swiss franc, and the Deutsche mark. The results suggest that there is some evidence of volume stabilizing returns.

Bibliography

Akaike, H. (1974): Markovian Representation of Stochastic Processes and its Application to the Analysis of Autoregressive Moving Average Processes," *Annals of the Institute of Statistical Mathematics,* 26:363–387.

Akaike, H. (1976): "Canonical Correlations Analysis of Time Series and the Use of an Information Criterion," in *System Identification: Advances and Case Studies,* Mehra, R. K., and Lainiatis, D. G. (eds.), New York: Academic Press.

Aksu, E., and Narayan, J. (1984): "Model Building and Forecasting with a State Space Procedure," Working Paper Series WP 84-59 Management Research Center, Syracuse University.

Clark, P. K. (1973, Jan.): "A Subordinated Stochastic Process Model with Finite Variance for Speculative Prices," *Econometrica,* 41:135–155.

Copeland, T. E. (1976, September): "A Model of Asset Trading under the Assumption of Sequential Information Arrival," *Journal of Finance,* 31:1149–1168.

Cornell, B. (1981, Fall): "The Relationship between Volume and Price Variability in Futures Markets," *The Journal of Futures Markets,* 1:303–316.

Epps, T. W. (1975, September): "Security Price Changes and Transaction Volumes: Theory and Evidence," *American Economic Review,* 65:586–597.

Epps, T. W. (1976, Spring): "The Demand for Brokers' Services: The Relation between Security Trading and Volume Transaction Cost," *Bell Journal of Economics,* 7:163–194.

Epps, T. W. (1977, March): "Security Price Changes and Transaction Volumes: Some Additional Evidence," *Journal of Financial and Quantitative Analysis,* 12:141–146.

Epps, T. W., and Epps, M. L. (1976, March): "The Stochastic Dependence of Security Price Changes and Transaction Volumes: Implication for the Mixture-of-Distributions Hypothesis," *Econometrica,* 44:305–321.

Godfery, M. D., Granger, C. W. J., and Morgenstern, O. (1964): "The Random Walk Hypothesis of Stock Market Behavior," *Kyklos,* 17:1–30.

Grammatikos, T., and Saunders, A. (1986, April): "Futures Price Variability: A Test of Maturity and Volume Effect," *Journal of Business,* 59:319–330.

Granger, C. W. J., and Morgenstern, O. (1963): "Spectral Analysis of Stock Market Behavior," *Kyklos,* 16:1–27.

Harris, L. E. (1986): "A Transaction Data Study of Weekly Intradaily Pattern in Stock Returns," *Journal of Financial Economics,* 16:99–117.

Harris, L. E. (1987): "Transaction Data Tests of the Mixture of Distributions Hypothesis," *Journal of Financial and Quantitative Analysis,* 22:127–141.

Harvey, A. C. (1989): *Forecasting, Structural Time Series Models and the Kalman Filter,* Cambridge: Cambridge University Press.

Jain, P. C., and Joh, G. (1988, Sept.): "The Dependence between Hourly Prices and Trading Volume," *Journal of Financial and Quantitative Analysis,* 23:269–283.

James, C., and Edmister, R. O. (1983, Sept.): "The Relation between Common Stock Returns Trading Activities and Market Value," *Journal of Finance,* 38:1075–1086.

Jennings, R. H., and Barry, C. (1983, December): "Informational Dissemination and Portfolio Choice," *Journal of Financial and Quantitative Analysis,* 19:395–402.

Jennings, R. H., Starks, L. T., and Fellingham, J. C. (1981, March): "An Equilibrium Model of Asset Trading with Sequential Information Arrival," *Journal of Finance,* 36:143–161.

Johnston, E. T., Kracaw, W. A., and McConnell, J. J. (1991, March): "Day-of-the-Week Effects in Financial Futures: An Analysis of GNMA, T-Bond, T-Note, and T-Bill Contracts," *Journal of Financial and Quantitative Analysis,* 26:23–44.

Karpoff, J. M. (1986, Dec.): "A Theory of Trading Volume," *Journal of Finance,* 41:1069–1088.

Karpoff, J. M. (1987, March): "The Relation between Price Changes and Trading Volume: A Survey," *Journal of Financial and Quantitative Analysis,* 22:109–126.

Karpoff, J. M. (1988, Fall): "Costly Short Sales and the Correlation of Returns with Volume," *Journal of Financial Research,* XI:173–188.

Makridakis, S., Wheelwright, S., and McGee, V. (1983): *Forecasting: Methods and Applications* (2nd ed.). New York: Wiley.

Mittnik, S. (1990): "Forecasting With Balanced State Space Representations of Multivariate Distributed Lag Models," *Journal of Forecasting,* 9:207–218.

Newbold, P. (1983): "ARIMA Model Building and the Time Series Analysis Approach to Forecasting," *Journal of Forecasting,* 2:23–35.

Priestly, M. D. (1980): "System Identification, Kalman Filtering, and Stochastic Control," in *Directions in Time Series,* Brillinger, D. R., and Tiao, G. C. (eds.), Institute of Mathematical Statistics.

Rogalski, R. J. (May, 1978): "The Dependence of Price and Volume," *The Review of Economics and Statistics,* 36:268–274.

Smirlok, M., and Starks, L. (1985, Fall): "A Further Examination of Stock Price Changes and Transaction Volume," *Journal of Financial Research,* 8:217–255.

Tatsuoka, M. M. (1971): *Multivariate Analysis: Techniques for Educational and Psychological Research,* New York: Wiley.

Tauchen, G. E., and Pitts, M. (1983, March): "The Price Variability-Volume Relationship on Speculative Markets," *Econometrica,* 51:485–505.

Tiao, G. C., and Box, G. E. P. (1981): "Modeling Multiple Time Series with Applications," *Journal of American Statistical Association,* 76:802–816.

Wood, R. A., McInish, T. H., and Ord, J. K. (1985, July): "An Investigation of Transaction Data for NYSE Stocks," *Journal of Finance,* 60:723–739.

Ying, C. (1966, July): "Stock Market Prices and Volume of Sales," *Econometrica,* 34:676–685.