Journal of the American Statistical Association

ISSN: 0162-1459 (Print) 1537-274X (Online) Journal homepage: https://www.tandfonline.com/loi/uasa20

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Thomas W. Epps

To cite this article: Thomas W. Epps (1979) Comovements in Stock Prices in the Very Short Run, Journal of the American Statistical Association, 74:366a, 291-298, DOI: 10.1080/01621459.1979.10482508

To link to this article: https://doi.org/10.1080/01621459.1979.10482508

Published online: 05 Apr 2012.

Comovements in Stock Prices in the Very Short Run

THOMAS W. EPPS*

Correlations among price changes in common stocks of companies in one industry are found to decrease with the length of the interval for which the price changes are measured. This phenomenon seems to be caused by nonstationarity of security price changes and by the existence of correlations between price changes in the same stock—and in different stocks—in successive periods. Although such correlations are not necessarily inconsistent with market efficiency, the data do reveal the presence of lags of an hour or more in the adjustment of stock prices to information relevant to the industry.

KEY WORDS: Efficient-markets hypothesis; Portfolio theory; Financial markets; Fisher effect.

1. INTRODUCTION

It is well known that changes in prices of different common stocks during intervals of a day or longer are often highly correlated and that the correlations tend to be particularly high for firms in the same industry (King 1966). This article is a study of the covariation among stock prices during very short periods in response to the normal flow of economic and political news during the course of the trading day. In Section 2, evidence is presented that the contemporaneous correlations of changes in (the logarithms of) prices of four stocks in one industry (automobiles) virtually disappear as the measurement interval becomes very short. In Section 3 we investigate the causes of this phenomenon. Evidence is presented that the price-change process is nonstationary and that correlations exist between short-term price changes in any stock and price changes in all four stocks in the previous period. Several explanations for these correlations are considered in Section 4, where it is shown (paradoxically) that such correlations are not necessarily inconsistent with market efficiency. Results of empirical tests of market efficiency are presented in Section 5. In the final section we review conclusions of the study.

2. CORRELATIONS AMONG STOCK PRICE CHANGES DURING SHORT INTERVALS

The stocks of the four major automakers in the United States—AMC, Chrysler, Ford, and GM—were chosen as sources of data for the study of short-term relationships among stock price changes. Because these four companies, which essentially constitute the domestic auto industry, are not highly diversified, their yields during long intervals were expected to be highly correlated. Because it was suspected ex ante that the correlations between yields decline as the holding period decreases, high correlations during long intervals were desired to enhance the contrast with short-period correlations. Prices of each stock were recorded at 10-minute intervals during each of the 125 trading days in the first six months of 1971. The data were obtained from records of price and transaction time for each transaction on the New York Stock Exchange, published by F.E. Fitch, Inc. Each $5\frac{1}{2}$-hour trading day contained thirty-three 10-minute intervals, the first ending at 1010, the last at 1530 (Eastern U.S. time). The price at any time t_0 (to the nearest minute) was taken to be the price on the last trade before or at t_0.

Contemporaneous correlations of changes in the logarithm of price, computed for intervals from 10 minutes to three days, are shown in Table 1. Logarithms were taken to make the series more nearly stationary (see Granger and Morgenstern 1970, pp. 73–75, 107–108, 177–178). In the remainder of the article, price changes will mean changes in log price.

Although price changes for AMC seem only weakly related to those for the other three stocks, the correlations among Chrysler, Ford, and GM are fairly large when the price changes pertain to intervals of three hours or longer. As the interval declines from three hours, all the correlations decrease markedly and approximately monotonically. For the 10-minute interval, not even Ford and GM exhibit a relationship that is likely to be of economic significance.

It is interesting to investigate the causes of the marked instability of the correlations for intervals of less than

1. Correlations of Changes in Log Price for Four Stocks During Intervals of 10 Minutes to Three Days

	Pairs of Stocks					
Interval	AMC-Chrysler	AMC-Ford	AMC-GM	Chrysler-Ford	Chrysler-GM	Ford-GM
10 minutes	.001	.009	−.009	−.014	.007	.055
20 minutes	.009	.018	.011	.017	.026	.118
40 minutes	.006	.012	.014	.041	.040	.197
One hour	−.043	.057	.064	.023	.065	.294
Two hours	.029	.060	.094	.112	.129	.383
Three hours	.031	.158	.111	.361	.518	.519
One day	−.067	.170	.078	.342	.442	.571
Two days	−.020	.223	.186	.336	.449	.572
Three days	−.098	.203	.100	.334	.542	.645

* Thomas W. Epps is Associate Professor, Department of Economics, University of Virginia, Charlottesville, VA 22901. The author is grateful to Alan Hess for making available the data used in this article; to an anonymous referee and to members of the Micro Workshop at the University of Virginia for critical review; and to Richard Roll for suggesting the Fisher effect as a possible source of observed correlation between changes in stock prices.

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three hours. Note that changes in price for intervals longer than 10 minutes are merely nonoverlapping sums of price changes for successive 10-minute intervals. For example, the one-hour price change in Table 1 is computed as the sum of six successive 10-minute changes, no account being taken of the fact that the length of the trading day is not an integral number of hours. If we consider the two covariance-stationary processes, x_t and y_t (assumed for convenience to have mean zero) and the nonoverlapping sums, $X_{tk} = \sum_{i=0}^{k-1} x_{tk-i}$ and $Y_{tk} = \sum_{i=0}^{k-1} y_{tk-i}$, it is easily seen that the correlation between X_{tk} and Y_{tk} equals that between x_t and y_t if

$$\begin{aligned} E(x_{t-i}y_{t-j}) &= \sigma_{xy}\ , & i &= j \\ &= 0\ , & i &\neq j \\ E(x_{t-i}x_{t-j}) &= \sigma_x^2\ , & i &= j \\ &= 0\ , & i &\neq j \\ E(y_{t-i}y_{t-j}) &= \sigma_y^2\ , & i &= j \\ &= 0\ , & i &\neq j\ . \end{aligned}$$

Thus, the instability of the correlations of overlapping sums of changes in log price for intervals up to three hours implies either that the 10-minute price-change series are nonstationary or that correlations exist between price changes at different periods. The latter could be either (or both) autocorrelations (between price changes for one stock in different periods) or lagged cross-correlations (between price changes of different stocks in different periods). We shall refer to both types as lagged correlations.

3. EVIDENCE CONCERNING NONSTATIONARITY AND LAGGED CORRELATIONS

In constructing the 10-minute price-change series from which the correlations in Table 1 were calculated, the first of the thirty-three 10-minute price changes on any day was taken to be the difference between the (log of the) 1010 price and the (log of the) 1530 closing price on the previous trading day. In view of the evidence (Granger and Morgenstern 1970, pp. 122–129) that the process that generates price changes continues to operate during periods when the market is closed, one may expect the variance of this first price change to exceed the variances of the other price changes of the day, but it is interesting to ask whether the first daily price change is the only source of nonstationarity. To reduce the computational burden I chose to try to answer such a question (and to analyze the lagged-correlation structure) for hourly, rather than 10-minute, price changes. Each trading day was redivided into six periods, ending at 1030, 1130, 1230, 1330, 1430, and 1530. Each day's price data for each stock produced one observation of the overnight-to-1030 price change (the log 1030 price minus the log 1530 price of the previous day) and one observation of each of the five hourly price changes.

2. Variance of Hourly Changes in Log Price (× 10⁴)

Period Ending at	Stock			
	AMC	Chrysler	Ford	GM
1030	2.25	1.28	.34	.27
1130	3.10	1.39	.28	.20
1230	2.02	.66	.19	.13
1330	1.93	.59	.10	.08
1430	1.93	.58	.10	.09
1530	2.02	.72	.16	.15

Clearly, one expects the 1030 price change to behave differently from the five hourly price changes because it pertains to a different time interval, but it is interesting that not even the sequence of 125 days of five hourly price changes seems to have been produced by a stationary process. Table 2 shows for each stock the variances of the 1030 price change and the five hourly price changes. Among the latter in all four cases the variance is greatest at 1130, declines steadily until 1330, then rises in the final hour of the day. The low variances in the early afternoon probably just reflect reduced trading activity caused by breaks for the noon meal.[1] At any rate, it is clear that the price-change process in each hour has its own special characteristics, so that the sequence of hourly price changes (omitting the 1030 price change each day) must be regarded as nonstationary.

The next question is whether hourly price changes exhibit lagged correlations. In searching for these correlations, the finding of nonstationarity dictates that each hourly price change must be treated as a separate variable, for which each of the 125 days of price data provides one observation. Table 3 presents the correlations matrix for the five hourly price changes in the four stocks. Coefficients for which $H_0\colon \rho = 0$ is rejected at the 0.10 level in two-tailed tests are marked with asterisks. For these tests, $(1 + r)/(1 - r)$ was taken to be distributed as $F(n - 2, n - 2)$ under H_0 (Kymn 1968), and the interrelationships among the coefficients were ignored.

Two features of the results are interesting. First, the frequency of significant coefficients in the six off-diagonal blocks of cells is much lower than that for coefficients in the four diagonal blocks, which contain correlations between price changes in successive hours. Second, in the diagonal blocks, 13 of the 16 coefficients in the diagonal cells are negative—these being correlations between price changes one hour apart in the same stock, while 33 of the 48 coefficients in off-diagonal cells are positive—these being correlations between price changes in different stocks.

These patterns and the frequency of rather large coefficients suggest that there are relationships over time between price changes of auto-industry stocks. These relationships imply that past price changes in the four stocks can be of predictive value for future price changes. To

[1] Assuming normality, the likelihood-ratio test for equality of the five variances yields tail-area probability values of .028 for AMC, $.25 \times 10^{-6}$ for Chrysler, $.25 \times 10^{-8}$ for Ford, and $.13 \times 10^{-5}$ for GM. One should note, however, that the log-price-change variables are probably not well represented by the normal distribution, as the test requires.

3. *Correlations Matrix for Hourly Price Changes*

1230 AMC	1230 C[a]	1230 F[a]	1230 GM	1330 AMC	1330 C	1330 F	1330 GM	1430 AMC	1430 C	1430 F	1430 GM	1530 AMC	1530 C	1530 F	1530 GM		
−.38*	.02	−.13	−.13	.35*	−.07	.03	−.06	.29*	−.01	−.08	−.02	−.09	−.24*	.02	−.07	AMC	1130
.14	−.03	.26*	.20*	−.00	−.19*	.03	.02	.03	.06	−.04	.02	−.12	.06	.07	−.01	C	
.03	.10	−.03	.04	−.06	−.07	−.09	.02	.02	−.13	.03	.09	.02	.02	−.03	−.00	F	
.10	.18*	.19*	.03	−.10	−.18*	−.18*	−.04	−.06	−.08	.05	−.08	.20*	.02	.01	−.14	GM	
				−.36*	−.11	−.18*	.03	−.08	−.08	−.07	.03	.12	−.00	−.06	−.05	AMC	1230
				.04	−.31*	.06	−.13	.06	−.06	−.05	−.07	.02	−.02	−.06	−.18*	C	
				−.05	−.02	−.06	.21*	−.05	.09	.07	.03	.14	.06	.04	−.11	F	
				−.06	−.15*	−.09	−.02	.13	−.04	.02	−.22*	−.19*	−.01	.05	−.02	GM	
								−.27*	.11	−.00	.13	.05	−.01	.12	.02	AMC	1330
								−.06	−.19*	.04	.22*	−.03	.07	.04	.11	C	
								.00	.18*	−.20*	.02	−.01	.09	.03	.09	F	
								−.12	.08	.08	−.06	.10	.05	−.05	.01	GM	
												−.33*	−.15*	.11	−.04	AMC	1430
												.08	.13	.08	.15*	C	
												.03	.03	−.02	.16*	F	
												.02	.14	.17*	.19*	GM	

* Significant at .10 level in two-tailed test.
[a] C = Chrysler; F = Ford.

examine the question of predictability, a separate linear regression model was formulated for each hourly price change in each stock, regressors consisting of all previous hourly price changes on the same day and the overnight-to-1030 price changes for all stocks. Thus, letting $A_{10,d}$, $C_{10,d}$, $F_{10,d}$, and $G_{10,d}$ denote the 1030 price changes on day d for AMC, Chrysler, Ford, and GM, respectively, and letting $A_{11,d}$ be the 1130 AMC price change, the model for $A_{11,d}$ is

$$A_{11,d} = \alpha_0 + \alpha_1 A_{10,d} + \alpha_2 C_{10,d} + \alpha_3 F_{10,d} + \alpha_4 G_{10,d} + u_d \ .$$

The same regressors appeared in the models for $C_{11,d}$,

4. *Regression Results for Hourly Price Changes*

1130 AMC	1130 C[a]	1130 F[a]	1130 GM	1230 AMC	1230 C	1230 F	1230 GM	1330 AMC	1330 C	1330 F	1330 GM	1430 AMC	1430 C	1430 F	1430 GM	1530 AMC	1530 C	1530 F	1530 GM		
−.24*	.03	.00	.00	−.13*	−.02	−.01	−.01	−.01	.01	−.00	−.02	.00	.02	.01	.03*	.01	−.02	.00	−.00	AMC	1030
.24*	−.19*	.04	.02	.06	−.05	−.02	−.00	.10	.01	.04*	.02	−.06	−.01	−.00	−.04*	−.14*	.04	.02	−.01	C	
−.06	.10	−.07	.06	−.03	−.12	−.01	.02	−.13	−.11	−.01	.01	.02	.04	.01	−.04	−.12	.01	−.02	.01	F	
−.05	.00	−.02	−.10	.13	.09	.02	−.01	.04	.03	−.01	.01	.05	−.13	−.02	−.02	.14	−.02	.07	.04	GM	
				−.29*	.05	.01	.01	−.09	.01	−.02	−.03	.02	.05	.02	.01	.00	.01	.02	−.05*	AMC	1130
				.26*	−.23*	−.03	.00	−.24*	−.14*	.00	.04	.03	.00	−.04	−.00	−.00	−.00	−.10*	−.01	C	
				−.00	−.03	−.05	.07	.07	.07	.01	−.03	.08	−.15*	−.03	−.04	−.11	.12	.05	.01	F	
				.27	.48*	.07	−.05	−.04	−.00	−.00	−.04	−.16	−.17*	.08	.01	.21	.21*	.08	.04	GM	
								−.26*	.05	−.01	−.02	−.11*	−.00	.01	.00	−.08	−.01	.02	−.02	AMC	1230
								.01	−.17*	.02	.07*	.07	−.02	−.01	.02	.21*	.18*	−.02	−.03	C	
								.18	.15	−.11*	.03	.25	−.04	−.05	−.04	−.02	−.01	.13	.12*	F	
								.42*	.16	.10	−.08	−.28	.02	.06	−.11*	−.02	.00	.03	−.06	GM	
												−.33*	−.03	−.04*	−.02	−.20*	.02	−.04	.01	AMC	1330
												.21*	−.12*	.10*	.02	.16	.02	.05	−.01	C	
												.35	.31*	−.10	.09	.01	.49*	−.04	.13	F	
												.45*	.21	.14*	−.07	.26	.08	.26*	.12	GM	
																−.42*	−.05	−.05*	−.01	AMC	1430
																.30*	−.01	.11*	.09*	C	
																.49*	.12	−.01	.14*	F	
																.27	.36*	.10	−.00	GM	
.00	.01	.54	.46	.01	.00	.85	.82	.00	.09	.49	.54	.00	.12	.14	.21	.00	.00	.03	.08	P[b]	
.10	.06	.01	.01	.08	.13	.02	.02	.19	.08	.05	.05	.17	.09	.09	.08	.17	.17	.14	.12	R^2[c]	

Weighted Averages[d]

AMC	C	F	GM	
−.30	.01	−.02	−.01	AMC
.20	−.16	.04	.04	C
.14	.12	−.07	.07	F
.25	.23	.07	−.06	GM

* Significant at .10 level in two-tailed test.
[a] C = Chrysler; F = Ford.
[b] Probability value from *F* test of hypothesis that all slope coefficients are zero.
[c] Coefficient of determination (not adjusted).
[d] Weighted average of coefficients in corresponding cells of diagonal blocks with inverse standard errors as weights.

$F_{11,d}$, and $G_{11,d}$. For 1230 price changes, all four 1130 price changes were added as regressors, and so on, so that in models for the 1530 price changes there were 20 regressors.

Table 4 presents the regression results for the 20 hourly price changes in a format similar to that of Table 3, entries with asterisks again being significant at the .10 level in two-tailed tests. Regressand variables appear at the column heads, and regressor designations are given at ends of rows. (Thus, entries in the first column are coefficients in the regression of A_{11} on A_{10}, C_{10}, F_{10}, and G_{10}.) Intercepts are not reported for the sake of brevity. Entries in the next-to-last row are probability values associated with standard F tests of the hypotheses that the regressors in the respective equations possess no explanatory power. (For reasons unimportant to the conclusions of this study, empirical results presented in Table 4 and the remainder of the article are from data for the full year 1972 rather than for the first half of 1971. Regressions with 1971 data produced results quite similar to those shown.)

Like the simple correlation coefficients, the regression coefficients in Table 4 display a remarkable regularity. Most of the significant coefficients are again in the diagonal blocks, which suggest that price changes in the previous hour have the most predictive value for current-period price changes. In the diagonal blocks most of the coefficients in the diagonal cells are again negative, while most in off-diagonal cells are positive. Thus, all other things equal, a price change in one stock tends to be followed in the next hour by a price change of opposite sign for that stock but by price changes of the same sign for the other three stocks.

The regularities in the coefficients in Table 4 and the apparent statistical significance of the linear models clearly indicate that available information—namely, price changes in previous periods—is of value in predicting future price changes. The obvious question is whether this fact is really indicative of market inefficiency, that is, whether a trading strategy based on predictions of such models can produce abnormal returns, even for traders who can avoid brokers' fees. To answer this question, we must first consider possible causes of the sign patterns observed in the regression coefficients.

4. ALTERNATIVE EXPLANATIONS FOR THE EMPIRICAL RESULTS

Consider first the pattern of negative coefficients in the diagonal cells, which are coefficients of lagged price changes in the regressand stocks. One cause of the negative relationship between successive price changes in the same stock is undoubtedly the persistence for short periods of a similar effect that exists among changes in price from one transaction to the next. Niederhoffer and Osborne (1966) argued that the negative correlation in transaction-to-transaction price changes is due to the presence of queues of limit orders (orders to buy and sell at stated prices, or better). These queues act as temporary barriers, between which market price moves back and forth as each order in a flow of randomly arranged market orders to buy or sell (at the best available price) transacts with one of the limit orders. For example, if a downtick occurs in one period as a market sell order is executed at the bid price, then in the following period (if the barriers remain fixed, as they do on average) another market sell order leads to no price change at all, while a buy order (excuted at the asked price) produces an uptick. Similarly, if the initial observation is an uptick, then in the next period price normally either declines or remains constant, hence, the negative correlation in successive price changes.

If this effect accounts entirely for the observed negative correlation among successive hourly price changes, then there is no apparent way to profit from awareness of that correlation. For example, if we observed a downtick in one hour and placed a market order to buy at the beginning of the next hour, we would pay the asked price. On selling at the end of the hour, our market order would be executed at the bid price, which would be lower, on average, than the price at which the shares were purchased. Clearly, what is relevant for trading profits is not the behavior of execution prices over time but the behavior of bid and asked prices. The negative partial correlation between successive hourly price changes in the same stock could be consistent with randomly fluctuating—and even static—bid and asked prices.

One possible source of negative serial correlation among bid and asked prices, however, is the occurrence of so-called block trades, involving large quantities of stock. As explained by Kraus and Stoll (1972), these trades are often accompanied by price reversals. Although prices seem to readjust quickly following the block trade (Dann, Mayers, and Raab 1977; Raab 1976), the occasional execution of block trades near the ends of the six daily periods in our sample would contribute to the observed negative correlation.

We now consider the positive relationship between successive hourly price changes in different stocks, as indicated by the predominantly positive off-diagonal coefficients in the diagonal blocks of Table 4. Three mechanisms that could account for this phenomenon will be considered. Two of these imply market inefficiency, because they imply that knowledge of past price changes is useful in predicting future changes in bid or asked prices. Like the Niederhoffer-Osborne effect, the third mechanism is such that the relationships among successive price changes in different stocks provide no economically relevant information.

The first two mechanisms require that information relevant to traders' valuations of securities diffuse slowly through the market—specifically, that a large proportion of traders in auto-industry shares (at least occasionally) receive news an hour or more after it is acted on by some trader or traders. The existence of information lags is not sufficient to account for the observed behavior, however. If each trader who received news relevant to the valuation of auto-industry shares were to transact simultaneously in all four stocks and if prices were free to adjust instantaneously, then all prices would adjust at the same time, without any lags. In addition to information lags, the first mechanism requires that there be lags in the process by which prices adjust, and the second mechanism requires, in addition to information lags, that traders specialize their transactions in certain stocks of an industry group.

To explain the first mechanism, suppose that for each stock one or more orders to buy (sell) must typically be executed before market price can move up (down). Let Q_A be the number of transactions required to trigger a price change in AMC and let Q_C, Q_F, and Q_G be corresponding numbers for the other three stocks. Suppose that, as traders receive some relevant news, each one transacts in all four stocks. Then whenever Q_A happens to be less than Q_C, Q_F, and Q_G, the price of AMC shares is first to adjust. Similarly, whenever Q_C is least, the price of Chrysler shares undergoes the first change, and so on. If the Q's vary over time in such a way that each stock sometimes has the smallest Q, then in a large time sample of transactions one would expect to find just the sort of joint feedback among hourly price changes that is actually observed.

The Niederhoffer-Osborne model gives reason to expect such lags in the price-adjustment process because it implies that a queue of limit orders to buy (sell) must be exhausted before a sequence of market orders to sell (buy) can lead to a change in price. The lengths of such queues (measured in numbers of transactions) may well vary over time in such a way as to produce joint feedback, because considerable variability over time is likely in the numbers of shares represented by the orders in the queues and in the numbers of shares contained in the market orders with which the limit orders interact. Thus, for example, following good news, a price increase might occur first in GM's shares because the number of shares in the queue of limit sell orders is small or because some of the market orders to buy are large.

To understand the second way of accounting for the feedback in price changes, suppose each trader tends to specialize in just one of the four auto stocks, confining transactions in any short period to just this security. Suppose, further, that the order in which traders receive news is not always the same. (Each trader might have nonzero probability of being the first to receive information relevant to the value of auto-industry shares.) In such a model whenever the first recipient of news happens to specialize in AMC stock, then (ignoring lags in the adjustment process) the price of AMC's shares will be the first to change, prices of the other stocks reacting only when those who specialize in them receive the information. Naturally, a symmetry will exist: Sometimes those who specialize in Chrysler stock will be the first recipients, sometimes those who specialize in Ford, and so on. Thus, even in the absence of inherent price-adjustment lags, there can be mutual feedback among price changes if traders specialize. Of course, not everyone has to specialize in just one auto stock or even specialize at all. Hourly price changes in each stock will have some predictive value for price changes in the other three stocks so long as there are *some* traders who do not transact in all four stocks each time they receive relevant news, provided the flow of information through the market is sufficiently slow.

Although such specializing behavior would be irrational if information costs and transaction costs did not exist, it can be justified in the presence of such market imperfections. Some individuals may feel that they have special skills in predicting the effects of news relevant to the industry as a whole on earnings of particular companies. Employees of the firms are obvious examples. Also, specialization is promoted by oddlot fees (markups on purchases and markdowns on sales of fractions of round lots—typically, 100 shares) and by commission discounts offered by brokers for trades of more than one round lot in a single stock. Finally, institutional restrictions on selling short may induce traders who receive unfavorable news to sell only the shares of stocks they already hold.

Some empirical evidence about specialization is available. Inspection of 1968 through 1972 annual reports and prospectuses of 49 mutual funds that held at least one auto stock showed that 28 held just one stock, 15 held two, 6 held three, and none held all four. Looking at the portfolios of 10 funds on two or more reporting dates, we found that 13 of 16 observed net portfolio changes involved just one or two stocks and that none involved all four. (Because only net changes were observed, it is not certain that the funds did not sometimes trade all four stocks simultaneously, but it is clearly unlikely that doing so was common practice.)

If information lags and either (or both) price-adjustment lags or specialization exist, then knowledge of past price changes in auto-industry stocks can be valuable in predicting not just future price changes but also changes in bid and asked prices. Thus, if these phenomena occur and if the lags they produce are substantial, profitable trading rules might be constructed. The third explanation for the relationships between successive price changes in different stocks is entirely consistent with market efficiency. It relies on the purely technical fact that, in computing hourly price changes, the price at the end of each hour is taken as the price on the last previous transaction.

The effect of sampling prices at fixed intervals on the behavior of price indices was investigated originally by Lawrence Fisher (1966). In the present situation it is easy to see that the Fisher effect can lead to a correlation between observed price changes in different stocks in successive hours, even when no relation exists between changes in the stocks' bid and asked prices. Suppose information is actually disseminated throughout the market instantaneously. Then news relevant to the valuation of auto shares leads to an instantaneous adjustment in bid and asked prices of all auto stocks, because specialists (here meaning the official market makers at the exchange) and others who submit limit orders immediately revise the terms of their bids and offers. Nevertheless, the stock that is first to trade after the simultaneous shift of barriers will seem to be the first to reflect the information that causes the shift. For example, suppose an upward shift in bid and asked prices of all four stocks occurs at 1125 and that GM's stock is the only one to trade between 1125 and 1130, trades in the other stocks occurring in the next hour. Then the price increase in GM will seem to lead increases in prices of the other three stocks. In a large time sample of price changes, price changes in each of the four stocks would be expected to have predictive value for price changes of all the others, because occasionally each stock will be the first to trade after a simultaneous shift in the barriers. Clearly, however, knowledge of past price changes does not help in predicting future changes in bid and asked prices if these prices in fact adjust instantaneously to new information.

5. TESTS OF THE COMPETING HYPOTHESES

Two kinds of tests were used to determine whether the predictive power of lagged price changes displayed in Table 4 arises solely from the Fisher and Niederhoffer-Osborne effects or whether this predictive value extends also to bid and asked prices. Both tests are necessarily indirect because the unavailability of hourly stock quotations precludes direct study of the behavior of bid asked prices.

The first test is based on the observation that the Fisher effect can cause the hourly price change in, say, Ford to have predictive value for the next hourly price change in, say, GM only if the last trade in Ford in the first hour occurs after the last trade in GM; for only in this case can a simultaneous shift in the bid-asked barriers of both stocks in the first hour be manifested in the observed price of Ford alone. The first test removes the Fisher effect by regressing the hourly price change in a stock (e.g., GM) on price changes of all four stocks in earlier hours of the day, as before, but with data for just those trading days in which the regressand stock (e.g., GM) was last to trade in the previous hour. Although the Niederhoffer-Osborne effect would still be present in such regressions, all the off-diagonal coefficients should be insignificantly different from zero if the Fisher effect accounts entirely for the positive off-diagonal elements in Table 4. The results of the first test (Table 5) are clearly consistent with this interpretation, but there are two reasons to reserve judgment. First, there is the familiar pattern of positive off-diagonal coefficients in the diagonal blocks (42 of 60). Second, these tests are not very power-

5. *Results of First Test*

1130				*1230*				*1330*				*1430*				*1530*					
AMC	*C*[a]	*F*[a]	*GM*	*AMC*	*C*	*F*	*GM*	*AMC*	*C*	*F*	*GM*	*AMC*	*C*	*F*	*GM*	*AMC*	*C*	*F*	*GM*		
-.27	.10	.05	.13*	.11	-.03	-.18*	-.01	.08	- 07	.00	-.01	-.22*	-.06	-.04	.01	-.78*	-.09	[b]	.09	AMC	1030
.07	-.18	.24	.15	.02	-.17	.32*	-.01	-.32	.03	.07	-.06	-.09	.05	.01	-.10	.15	.10	—	.08	C	
.33	.44*	.21	-.06	.11	.14	-.47*	.02	-.07	-.34	.30	.08	.06	.17	.20	.01	.31	.05	—	.01	F	
-.09	-.06	-.39	.00	-.66	.35	-.19	-.07	.26	-.12	-.19	.10	.37	-.17	.03	.06	-.60	.03	—	-.33	GM	
				-.14	.05	.02	.01	.30	-.01	.07	.04	-.00	.00	-.09	-.04	-.51	.04	—	-.04	AMC	1130
				.39	-.45*	.24	-.01	-.60*	-.16	-.26	-.08	.01	.01	-.14	-.04	.24	-.10	—	.08	C	
				.43	.24	-.38	.13	.29	-.17	-.07	.11	.23	-.19	.28	-.02	.20	.12	—	-.04	F	
				-.17	.81*	.18	-.22*	-.04	-.07	.40	-.22*	-.08	-.12	-.14	-.19	-.44	.14	—	.18	GM	
								-.22	.13	.01	-.03	-.22*	-.04	.14	-.04	-.51	.04	—	.05	AMC	1230
								.04	-.46*	-.10	.13	.09	.00	-.03	.01	.13	.14	—	-.11	C	
								.24	.32	-.08	.12	-.20	.22	.13	.02	-.78	-.15	—	.39	F	
								.30	.37	.49	-.05	-.07	-.26	-.40	.14	1.14	-.36	—	-.32	GM	
												-.56*	-.08	-.06	-.10*	-.20	.11	—	.01	AMC	1330
												.28	-.48*	.27	.06	.84	.14	—	-.01	C	
												-1.02	.17	.19	.03	-2.38*	.31	—	.51	F	
												.41	.50	-.01	.28	1.27	.08	—	-.10	GM	
																-.60*	-.03	-.05	.01		1430
																.24	.04	.20	.20		
																-.50	-.02	.33	.48		
																1.39	.85*	-.82	.54*		
26	42	18	47	23	41	21	53	40	52	27	46	52	56	23	48	39	45	17	44	N[c]	
.75	.07	.41	.16	.52	.04	.05	.94	.60	.29	.51	.50	.61	.82	.42	.71	.33	.60	.49	.91	P[d]	

Weighted Averages[e]

AMC	*C*	*F*	*GM*	
-.34	.04	-.00	-.00	AMC
.19	-.32	.15	.09	C
.01	.26	.05	.11	F
.20	.49	-.01	.03	GM

* Significant at .10 level in two-tailed test.
[a] C = Chrysler; F = Ford.
[b] Degrees of freedom insufficient for estimating all 20 coefficients. Only 1430 price changes were used as regressors.
[c] Sample size.
[d] Probability value associated with null hypothesis that all off-diagonal coefficients are zero.
[e] Weighted average of coefficients in corresponding cells of diagonal blocks with inverse standard errors as weights.

6. Results of Second Test

1130				1230				1330				1430				1530					
AMC	*C*[a]	*F*[a]	*GM*	*AMC*	*C*	*F*	*GM*	*AMC*	*C*	*F*	*GM*	*AMC*	*C*	*F*	*GM*	*AMC*	*C*	*F*	*GM*		
−.08	.01	.02	−.00	−.06	−.04	−.01	−.02	.01	.02	−.01	−.03*	−.01	.03	.01	.02	.06	−.01	.00	−.00	AMC	1030
.19*	−.19*	.03	.01	−.06	−.02	−.01	.02	.11	.01	.04*	.02	−.08	.01	−.01	−.04*	−.11	.00	.02	−.00	C	
−.03	.11	−.07	.04	−.02	−.15*	−.02	−.00	−.07	−.11*	−.00	.01	.09	.00	.03	−.03	−.11	.02	.00	.01	F	
−.30*	−.00	−.06	−.08	.18	.08	.04	−.01	−.04	.01	−.01	.01	.04	−.11	−.01	−.02	−.04	−.04	.05	.01	GM	
				−.01	.04	.02	.01	−.05	.02	−.03	−.01	.09	.03	.02	−.00	.11	.02	.02	−.05*	AMC	1130
				.10	−.18*	−.02	−.02	−.13	−.11*	−.01	.05*	.05	.04	−.03	−.01	.02	−.03	−.12*	−.01	C	
				.07	−.03	−.02	.07	.05	.03	−.03	−.05	.00	−.20*	−.03	−.02	−.31*	.10	.04	−.01	F	
				.28	.41*	.03	−.01	−.10	.04	.02	−.03	−.02	−.12	.11*	.02	.25	.26*	.11	.03	GM	
								−.02	.05	−.00	−.02	−.01	−.02	.00	.00	.02	.01	.02	−.02	AMC	1230
								−.04	−.12*	.01	.07	−.04	−.01	−.00	.03	.12	.18*	−.05	−.02	C	
								.13	.13	−.05	.03*	.15	.01	.01	−.04	−.10	−.12	.13*	.13*	F	
								.29	.13	.07	−.09	−.19	.05	.01	−.10	−.05	−.04	.07	−.04	GM	
												.04	−.03	−.04*	−.02	−.10	.03	−.05*	.01	AMC	1330
												.11	−.02	.09*	.04	.20	.06	.04	−.01	C	
												.23	.26*	.03	.07	−.10	.42*	−.05	.12	F	
												.26	.08	.03	−.02	.43	.13	.28*	.10	GM	
																−.11	−.06	−.04	−.00	AMC	1430
																.15	.13	.06	.07	C	
																.44	−.07	.06	.09	F	
																.20	.29*	.02	.02	GM	
.02	.00	.23	.68	.47	.00	.96	.55	.48	.30	.54	.42	.70	.33	.09	.26	.13	.00	.00	.23	P_1[b]	
.02	.47	.35	.69	.34	.00	.90	.36	.34	.37	.43	.25	.63	.14	.05	.36	.08	.03	.01	.32	P_2[c]	
.05	.07	.02	.01	.03	.10	.01	.03	.05	.06	.05	.05	.05	.07	.10	.08	.11	.18	.16	.10	R^2[d]	

Weighted Averages[e]

AMC	*C*	*F*	*GM*	
−.03	.01	−.01	−.01	AMC
.11	−.10	.03	.01	C
.13	.08	−.02	.05	F
.11	.17	.02	−.02	GM

* Significant at .10 level in two-tailed test.
[a] C = Chrysler; F = Ford.
[b] Probability value from *F* test that all slope coefficients are zero.
[c] Probability value from *F* test that coefficients in off-diagonal cells are zero.
[d] Coefficient of determination (not adjusted).
[e] Weighted average of coefficients in corresponding cells of diagonal blocks with inverse standard errors as weights.

ful. Even with a full year's transaction data, the number of periods in which a given stock trades last is often small. Moreover, if there really were lags in the movements of bid and asked prices of different stocks, in choosing only observations for which the regressand stock was last to trade in the preceding hour some evidence of lagged response would inevitably be lost.

The second test eliminates both the Fisher and Niederhoffer-Osborne effects and yet uses all the data. In this test the regressand price change is calculated as the difference in the (logs of) prices on the first and last trades in the hour, rather than as the difference in the (logs of) prices on the final trades in successive hours. Clearly, if stocks' bid-asked barriers really do shift simultaneously, off-diagonal coefficients in such regressions should be insignificantly different from zero. Similarly, if the Niederhoffer-Osborne effect alone accounts for the negative coefficients in the diagonal cells of Table 4, these too should now be close to zero, because the existence of bid-asked barriers gives no apparent reason to expect any correlation between the price change in one hour and the difference between initial and final prices in the next hour. Results of the test (Table 6) show, however, that the tendency toward negative diagonal and positive off-diagonal coefficients in the diagonal blocks persists when the sources of spurious correlation are removed, as is consistent with the hypothesis that price-adjustment lags, trader specialization, and effects associated with block trades cause bid-asked prices to be predictable from available information.

Although, collectively, the results in Table 6 seem statistically significant,[2] the relationships exhibited by the data are weak. To examine the practical significance of the relationships for trading profits, a trading simulation was conducted with data for the last half of 1972, using coefficients corresponding to those in Table 6 but estimated from data for the first half of the year. Whenever the magnitude of a predicted price change exceeded a certain tolerance (0, $\frac{1}{8}$, $\frac{1}{4}$ or $\frac{3}{8}$ dollars), a purchase or sale of 100 shares was assumed to have been made at the first actual, recorded price in the hour, followed by a sale or purchase at the last recorded price in the hour. Before transaction costs, such rules generally produced small positive trading profits, ranging up to about $23 per trade on average for Chrysler with a $\frac{1}{4}$-point tolerance. Al-

[2] If we can regard the 20 regressions in Table 6 as independent tests, then R.A. Fisher's (1973) procedure for aggregating such tests implies that all the regressions, taken together, are significant at the .001 level. The same is true of the 20 sets of off-diagonal coefficients in all the blocks.

though the assumption that one could consistently trade at the first and last recorded prices in an hour is manifestly suspect, specialists and floor traders might profitably use such a trading rule; but it is clear that transaction costs would render its use unprofitable for nonmembers of the Exchange.[3]

6. CONCLUSIONS

Despite the possibility that small but persistent profit opportunities exist for privileged members of the Exchange, the clear picture conveyed by the evidence presented in this article is that of a highly efficient marketplace, which rapidly and accurately registers information relevant to auto-industry shares. The slight predictive value of lagged price changes, however—even after the elimination of the Fisher and Niederhoffer-Osborne effects—shows that information is not instantaneously transmitted. The evidence in Table 6 suggests that the predictive value of a price change in one stock endures not much more than one hour. Similar regressions of initial-to-final-transaction price changes during a 10-minute interval on final-to-final-transaction price changes in the single preceding 10-minute period had no detectable explanatory power. Although further work (requiring extensive data-handling capability) is needed to support reliable inferences about such very short-term price movements, the limited evidence indicates that the average lag in the response of prices is more than 10 minutes.

[3] Detailed results of the simulations and further analysis of the possibility of trading profits after transaction costs will be furnished on request.

[Received August 1977. Revised January 1979.]

REFERENCES

Dann, L.Y., Mayers, D., and Raab, R.J., Jr. (1977), "Trading Rules, Large Blocks and the Speed of Price Adjustment," *Journal of Financial Economics*, 4, 3–22.

Fisher, Lawrence (1966), "Some New Stock Market Indexes," *Journal of Business*, 39, 191–225.

Fisher, R.A. (1973), *Statistical Methods for Research Workers* (14th ed.), New York: Hafner Publishing Co.

Granger, Clive W.J., and Morgenstern, Oskar (1970), *The Predictability of Stock Market Prices*, Lexington, Mass.: D.C. Heath and Co.

King, Benjamin F. (1966), "Market and Industry Factors in Stock Price Behavior," *Journal of Business*, 39, 139–190.

Kraus, Alan, and Stoll, Hans (1972), "Price Impacts of Block Trading on the New York Stock Exchange," *Journal of Finance*, 27, 569–588.

Kymn, Kern O. (1968), "The Distribution of the Sample Correlation Coefficient Under the Null Hypothesis," *Econometrica*, 36, 187–189.

Niederhoffer, V., and Osborne, M.F.M. (1966), "Market Making and Reversal on the Stock Exchange," *Journal of the American Statistical Association*, 61, 897–916.

Raab, R.J., Jr. (1976), "The Speed of Stock Price Adjustment to New Information," Paper presented at the Seminar on the Analysis of Security Prices, University of Chicago, November 1976.