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INFORMATION FROM DAILY CLOSING PRICES ON THE TOKYO STOCK EXCHANGE

Malek K. LASHGARI*

Abstract. This paper illustrates an information theoretic approach for calculating serial dependence within a time series of daily prices. By calculating an index value which indicates the degree of diversity between actual and predicted prices of stocks listed on the Tokyo Stock Exchange, optimal predictors of prices were computed from prior empirical observations. The empirical findings show that serial dependence between successive changes in price for the Tokyo Stock Price Index is surprisingly large.

INTRODUCTION

According to the efficient market hypothesis, price is a function of information available at each point in time. Information may include; historical information (e.g., past changes in price), publicly announced information (e.g., earnings announcements), and inside, non-public material information. The weak form of market efficiency contends that stock prices contain no memory, since prices fluctuate randomly. The weak form concerns only historical information. Most tests of the weak form are based on serial correlation and runs tests. This paper concerns a test of weak form efficiency of the Tokyo Stock Exchange in the context of information theory.

BACKGROUND

Inofrmation implies more knowledge regarding variable at hand, e.g., probability associated with a future (possible) price. Shannon (1948) defines information as the logarithm of the reciprocal of the probability;

$$I = \log(1/p_i) = -\log p_i \tag{1}$$

where

p_i denotes the probability of an event.

I denotes information of the distribution of which p_i's are the probabilities. The logarithmic measure is mathematically more suitable and practically more useful. When logarithm on base two is used (binary) the resulting measure is in "bits," and when the base of e, the "natural number," is used the resulting

* I am very grateful to Fred B. Renwick for his inspiration.

measure is in "nits." When $p_i = .50$, the information contained in the message regarding the outcome of the event is $\log 2$ or .30103 bits. For the case when $p_i = .20$, the information transmitted by the occurance of the event is $\log 5$ or .69897 bits. It is clear that in the latter case, an event with probability of .20, the uncertainty associated with the outcome is greater than the former. Thus, more information is needed to increase our knowledge regarding the event which is expected to occur. Average information can be defined as the mathematical expected value of information;

$$H(p) = -\sum_{i=1}^{n} p_i \log p_i \tag{2}$$

where

p_i denotes the probability of an event.

H denotes the expected or average information.

If the message transmitted by the market states that the odds in favor of the event have changed such that the prior probability p is replaced by the posterior probability q, then the state of knowledge of the recipient of information has been changed. The difference between the state of knowledge of the recipient before and after the communication of information is referred to as entropy and can be represented as follows;

$$S(p) = \sum_{i=1}^{n} q_i \log (q_i/p_i) \tag{3}$$

where

p_i denotes prior probabilities.

q_i denotes posterior probabilities.

S denotes the entropy.

Entropy is a measure of the average amount of information which must be supplied in order to have no uncertainty in the event which is expected to occur. The higher the entropy is, the higher is the amount of uncertainty involved.

Information theoretic design has been applied to analyze the extent to which it is possible to predict short term fluctuations on a stock exchange. Theil and Leenders (1965) studied the behavior of the securities prices trading on the Amsterdam Stock Exchange and examined the degree of predictability of the changes in securities prices. Theil and Leeders considered the fractions of prices advancing, declining, or remaining unchanged over a 1007 trading days from November 2, 1959 to October 31, 1963. Theil and Leeders conclude that the Amsterdam Stock Exchange has a memory of one day and that the best prediction for tomorrow is halfway between the observed fractions today and the long run averages. Under Random Walk Hypothesis, these relations would not have existed.

DESIGN OF EXPERIMENT

This paper applies Theil and Leeders methodology to daily prices from the Tokyo Stock Price Index. It searches for the degree of dependence of changes in prices and its prediction thereof so that deviations between actual and predicted values are minimal. The degree of dependence, alpha, is shown in equation (4).

$$p_{i,t} = \alpha q_{i,t-1} + (1-\alpha)\bar{q}_i \tag{4}$$

where

α alpha denotes the degree of dependence.

p denotes the forecasted changes in prices percentagewise increasing (p_1), unchanged (p_2), and decreasing (p_3).

q denotes the actual changes in prices percentagewise increasing (q_1), unchanged (q_2), and decreasing (q_3).

$\bar{q}$ represents the average values of q_i's over the time period under study.

Computations of the "p" and "q" proportions include a one percent tolerance limit; changes less than one percent are not taken into account.

The prediction model for changes in prices, as stated in equation (4) above, assumes that changes in prices are correlated over time, and that the best forecast depends upon all historical information, with more weight given to the most recent past. The higher the weight alpha is, the higher is the degree of dependence over time.

A measure of information inaccuracy, based on entropy in the context of information theory, is shown in equation (5).

$$S = 1/(T-1) \sum_{t=2}^{T} \sum_{i=1}^{3} q_{i,t} Ln(q_{i,t}/p_{i,t}) \tag{5}$$

where

S represents the information inaccuracy or entropy.

T represents the total number of days under study.

Ln represents the natural logarithm.

An optimal value of alpha (α) corresponding to the minimum value of the information inaccuracy (S) represents the degree of dependence between changes in share prices over time. The optimal value of alpha can be found by a numerical search, where different values (between zero to one) are assigned to alpha to estimate the predicted changes in prices ($p_i s$) in equation (4). These predictions, together with later observed values are inserted into equation (5) to calculate the degree of information inaccuracy (S). The optimal value of alpha, is that alpha which minimizes the degree of information inaccuracy for the following three reasons:

(1) entropy is a measure of the average amount of information that must be supplied to have no uncertainty in the event which is expected to occur.

Uncertainty here is tantamount to randomness (DeLuca 1979). Thus, the minimum entropy corresponds to a non-random pattern and the value of alpha corresponding to this minimum entropy, represents the degree of dependence between the actual and predicted values.

(2) minimum entropy corresponds to higher correlation (dependence) over time (Nawrocki 1984, pp. 279–80). Thus, the value of alpha corresponding to the minimum entropy, represents the degree of dependence between the actual and predicted values.

(3) tests employed by entropy presented here are extensions of the familiar Chi-Square tests of independence.

Among the advantages of employing the entropic design one can also include that entropy measures are non-linear in nature and are distribution-free.

EMPIRICAL RESULTS

This study uses daily closing prices of the Tokyo Stock Price Index during January, 1981 to December, 1986. Exhibit 1 shows the calculated optimal values of alpha, the degree of dependence, for the Tokyo Stock Price Index.

From Exhibit 1, for the Tokyo Stock Price Index during 1981, tomorrow's prices are 20 percent dependent on today's prices and 80 percent on the historical long run average over the year. For 1982, the price index shows 24 percent dependence on the immediate past and 76 percent on the historical long run average over the year. Over the entire time period under study, 1981–86, the level of the Index is 22.5 percent dependent on the immediate past and 77.5 percent on the historical long run average. The existence of relatively high values of alphas, degrees of dependence, for the Tokyo Stock Price Index contradicts the existence of random walk on the Tokyo Stock Exchange.

Exhibit 2 shows the calculated optimal values of alpha, the degree of dependence, for the New York Stock Exchange Price Index. Data on New York Stock Exchange are daily closing prices during January 1981 to December 1986.

From Exhibit 2, for the New York Stock Exchange Price Index during 1981, tomorrow's prices are 8 percent dependent on today's prices and 92 percent on the

EXHIBIT 1. TOKYO STOCK EXCHANGE: THE OPTIMAL VALUE OF ALPHA, THE DEGREE OF DEPENDENCE, OVER TIME

	1981	1982	1983	1984	1985	1986
1981	0.20	0.215	0.175	0.150	0.130	0.225
1982		0.240	0.140	0.125	0.105	0.230
1983			0.000	0.080	0.060	0.230
1984				0.090	0.080	0.240
1985					0.000	0.320
1986						0.270

EXHIBIT 2. NEW YORK STOCK EXCHANGE: THE OPTIMAL VALUE OF ALPHA, THE DEGREE OF DEPENDENCE, OVER TIME

	1981	1982	1983	1984	1985	1986
1981	0.080	0.130	0.130	0.090	0.100	0.080
1982		0.130	0.140	0.100	0.100	0.080
1983			0.050	0.000	0.000	0.000
1984				0.000	0.000	0.000
1985					0.000	0.003
1986						0.000

historical long run average over the year. For 1982, the New York Stock Exchange Price Index shows 13 percent dependence on the immediate past and 87 percent on the historical long run average over the year. Over the entire time period under study, 1981–86, the level of the index is 8 percent dependent on the immediate past and 92 percent on the historical long run average.

Comparison of optimal values of alpha, the degree of serial dependence in share prices, for the two stock price indices reveals that the degree of serial dependence in stock prices, during 1981–86, has been lower for the New York Stock Exchange Index as compared with the Tokyo Stock Price Index.

CONCLUSIONS

This paper applies information theory to test serial dependence between successive changes in daily prices of the securities traded on the Tokyo Stock Exchange, during 1981–86. Because of a relatively high degree of dependence in changes in share prices over time, the weak form of market efficiency cannot be supported for the Tokyo Stock Index. Application of the same methodology to the New York Stock Exchange Index, during 1981–86, reveals a much lower degree of serial dependence.

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APPENDIX A. TOKYO STOCK EXCHANGE

Time interval	Optimal value of alpha	Average value of						Value of "S" indicator
		q_1	q_2	q_3	p_1	p_2	p_3	
1981	0.200	0.06861	0.90278	0.04472	0.06878	0.90250	0.04482	0.13426
1982	0.240	0.06028	0.91667	0.03917	0.06045	0.91639	0.03927	0.10205
1983	0.00	0.03639	0.95833	0.02319	0.03639	0.95833	0.02319	0.06319
1984	0.09	0.07194	0.88889	0.05542	0.07202	0.88875	0.05547	0.17745
1985	0.00	0.02333	0.96111	0.03417	0.02333	0.96111	0.03417	0.07961
1986	0.27	0.13347	0.78889	0.09014	0.13394	0.78809	0.09044	0.20802
1981–82	0.215	0.06444	0.90972	0.04194	0.06453	0.90959	0.04199	0.11791
1981–83	0.175	0.05509	0.92593	0.03569	0.05497	0.92603	0.03572	0.10293
1981–84	0.150	0.05931	0.91667	0.04063	0.05933	0.91663	0.04064	0.12263
1981–85	0.130	0.05211	0.92556	0.03933	0.05213	0.92553	0.03934	0.11659
1981–86	0.225	0.06567	0.90278	0.04780	0.06570	0.90273	0.04782	0.13832
1982–83	0.140	0.04833	0.93750	0.03118	0.04818	0.93764	0.03120	0.08624
1982–84	0.125	0.05620	0.92130	0.03926	0.05623	0.92125	0.03928	0.11875
1982–85	0.105	0.04799	0.93125	0.03799	0.04800	0.93123	0.03800	0.11168
1982–86	0.230	0.06508	0.90278	0.04842	0.06512	0.90272	0.04844	0.13935
1983–84	0.080	0.05417	0.92361	0.03931	0.05419	0.92357	0.03932	0.12657
1983–85	0.060	0.04389	0.93611	0.03759	0.04390	0.93609	0.03760	0.11382
1983–86	0.230	0.06628	0.89931	0.05073	0.06633	0.89923	0.05076	0.14861
1984–85	0.080	0.04764	0.92500	0.04479	0.04766	0.92496	0.04481	0.13625
1984–86	0.240	0.07625	0.87963	0.05991	0.07632	0.87950	0.05996	0.17038
1985–86	0.320	0.07840	0.87500	0.06215	0.07856	0.87472	0.06227	0.16487

APPENDIX B. NEW YORK STOCK EXCHANGE

Time interval	Optimal value of alpha	Average value of						Value of "S" indicator
		q_1	q_2	q_3	p_1	p_2	p_3	
1981	0.080	0.09500	0.79231	0.12423	0.09513	0.79198	0.12441	0.16671
1982	0.130	0.16942	0.70000	0.13962	0.16983	0.69924	0.13995	0.20764
1983	0.050	0.10212	0.83462	0.07635	0.10221	0.83445	0.07641	0.15606
1984	0.000	0.09135	0.85769	0.06519	0.09135	0.85769	0.06519	0.15046
1985	0.000	0.07962	0.90385	0.03192	0.07962	0.90385	0.03192	0.09924
1986	0.000	0.12404	0.77308	0.11385	0.12404	0.77308	0.11385	0.17787
1981–82	0.130	0.13221	0.74615	0.13192	0.13237	0.74583	0.13208	0.19173
1981–83	0.130	0.12218	0.77564	0.11340	0.12227	0.77545	0.11348	0.18532
1981–84	0.090	0.11447	0.79615	0.10135	0.11452	0.79606	0.10139	0.18276
1981–85	0.100	0.10750	0.81769	0.08746	0.10746	0.81770	0.08749	0.17267
1981–86	0.080	0.11026	0.81026	0.09186	0.11028	0.81026	0.09183	0.17465
1982–83	0.140	0.13577	0.76731	0.10798	0.13594	0.76699	0.10811	0.19265
1982–84	0.100	0.12096	0.79744	0.09372	0.12103	0.79731	0.09377	0.18681
1982–85	0.100	0.11063	0.82404	0.07827	0.11058	0.82405	0.07830	0.17208
1982–86	0.080	0.11331	0.81385	0.08538	0.11334	0.81385	0.08535	0.17503
1983–84	0.000	0.09673	0.84615	0.07077	0.09673	0.84615	0.07077	0.15729
1983–85	0.000	0.09103	0.86539	0.05782	0.09103	0.86539	0.05782	0.14157
1983–86	0.000	0.09928	0.84231	0.07183	0.09928	0.84231	0.07183	0.15608
1984–85	0.000	0.08548	0.88077	0.04856	0.08548	0.88077	0.04856	0.12702
1984–86	0.000	0.09833	0.84487	0.07032	0.09833	0.84487	0.07032	0.15383
1985–86	0.003	0.10183	0.83846	0.07288	0.10183	0.83846	0.07288	0.15488

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