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Application of Markov Chain to Model and Predict Share Price Movements: A Study of HBL Share Price Movements in Pakistan's Stock Market

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Abstract

Volatility and randomness of stock prices makes them risky investments and investors need a lot of information to make capital gains on their investments. With the objective to cover the research gap of having limited application of Markov chains to share prices traded at PSX and to aid investors in their decision making, this paper assuming share volatility as a stochastic process with Markovian property. Hence, this study attempts to propose a first order, time homogenous Markov chain model for trend prediction of HBL closing share prices on and between 24-9-2007 and 20-02-2015 i.e.1723 trading days. The paper also has attempted to evaluate the accuracy of the prediction of Markov chain model. To this effect, the study has derived a transition probability matrix with three states i.e. (Decrease, Unchanged, and Increase) as well as determine the state probabilities for the HBL share prices followed by comparison to the actual share prices to evaluate the prediction accuracy of the first order Markov chain model. Furthermore, an attempt has also been made to estimate the long run steady state behavior of the share prices of the HBL and the expected return time for the stock. The methodology is applied to the daily share prices using MS excel and R.

Key Words: Markov Chains, Stock Market Prediction, Stochastic Analysis, Steady State, Transition Probability Matrix, Ergodic Markov Chain, MS Excel, R Statistical Software.

Introduction:

Stock markets comprise of exchanges and markets where various financial instruments like equity, stocks, bonds etc. are issued and traded. Primarily, they provide great support to the growth of industry and economy of a country by not only being the platform where businesses can raise funds for

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their expansion but also serve as a platform for investors with excess funds looking for capital gains on their investments. Stock markets and stock prices are highly volatile, chaotic, and non-linear which makes them complex and difficult to predict (Abu-Mustafa & Atiya, 1996). Hence, investors try to understand the behavior of stock market making use of market and other relevant information and various stock analysis methods to make predictions about stock price movements to device profitable investment strategies. In fact not only investors, many researches in the fields of finance, economics and statistics have tried to predict stock price trends with their studies and proposed models, making this an extensively explored subject in literature (Fama, 1991). This is why it has become all the more important now to propose statistical models to predict stock prices and market accurately.

Innumerable studies have been conducted to understand and predict stock market behavior. A lot of credible prediction approaches and models with significant insights and high accuracy have been proposed in many studies for developed stock markets and the stocks traded on them. Various methods like Fundamental and technical analysis, Variable models, Time series analysis and recently machine learning as well as data mining ,sentimental analysis to name a few have been explored and tweaked, modified as well as combined in different ways to fit ,map and derive an accurate prediction model for the stochastic nature of these stock market and prices. To this effect, recent studies have also proposed Markov chain models for stock market and price prediction. All these above mentioned tradition prediction methods mostly predict stock market prices whereas Markov model predict trends i.e. bullish bearish for stock prices and market. In many instances the studies have inferred that Markov chains have outperformed other methods as a prediction model. This characteristic of Markov model as a prediction method can be useful to an investor since the foremost decision to invest in a stock is highly influenced by its future trend prediction and then by prices.

Brief Literature Review:

There exists limited literature on prediction of Pakistan stock markets and in particular on application of Markov chain modeling for trend prediction of Pakistani Stocks price movements. However, there is enough literature in context of other Stock markets showing application of Markov chains as stock prediction techniques. For instance, Zhang & Zhang (2009) applied Markov chain to forecast stock prices in China, Choji, Eduno, & Kassem (2013) to predict share prices of two banks of Nigeria, Idolor (2011) examined five random securities from banking sector of NEPSE index (Nepal Stock Exchange), Onwukwe & Samson (2014) examined the steady state

behaviors of eight Nigerian bank stocks traded on NEPSE index using the same research design as Idolor (2011) and Vasanthi et al. (2011) performed an empirical study to determine the level of accuracy of traditional trend forecasting methods in comparison with Markov chain trend prediction method. All of these studies showed that Mark chain model performs better to forecast. Vasanthi et al., (2011) explained that the reason that Markov chain Model displays relatively accurate results in comparison to traditional trend forecasting method is that Markov model takes in to account daily changes in the stock indices values in order to find the bullish and the bearish states. Bhusal (2017) forecasted and analyzed the Nepal stock exchange index (NEPSE) by applying Markov Chain Model. Svoboda & Lukas (2012) used Markov Chain aken up in their study modeling of Prague stock exchange index and its trend development by Markov chain. Mettle, Quaye & Laryea (2014) have modeled Ghana Stock Exchange (GSE) as Markov Chains, arguing that due to unusual volatilities in the equity prices, can be viewed and analyzed as stochastic processes. Assuming further, they describe stock prices behaving with Markovian property.

As the review of the literature above shows that Markov chains have been found as a very efficient and accurate tool to forecast stock prices trends of single shares portfolios as well as indices. We applied Markov chain on share prices of HBL to forecast the share prices which is very important for investors.

Methodology

As mentioned earlier, this study has the objective to apply first order Markov chain model to historical closing share prices of a banking company HBL, in order to evaluate the accuracy of the prediction of Markov chain model in the context of Pakistan's share market. To this effect, share price data was first collected, examined and handled, a First order Markov Chain Model for share prices was constructed and applied to the data set and the results were compared to actual data to evaluate accuracy of the model.

In this study the data of banking company, Habib bank limited (HBL) was taken from the official website of Pakistan Stock Exchange (PSX).The data used for the study is secondary data comprising of closing share prices of HBL for trading days on and between 24-9-2007 and 20-02-2015.The data includes closing share prices of 1723 trading days. The period for which stock prices were collected had no specific interest except the data being conveniently available.

The data of 1724 trading days of closing share prices of HBL once collected were examined on MS Excel. First of all, the daily change in share price was calculated for all 1723 days by $dt = Y_t - Y_{t-1}$ i.e. subtracting the share

price by its proceeding day's price. This was followed by application of IF functions in MS excel to automatically label the increase, decrease and no change in comparison to preceding day share prices. The total count of decrease, increase and no change in share prices was found out by applying COUNTIF function in Excel. This data was created to construct initial state vectors for the Markov chain model. Furthermore, the Transition from each state to other was automatically labeled and counted in Microsoft excel to construct transition probability matrix for the model. For matrix multiplication to arrive at state matrices, MMULT function of excel was used while for finding higher powers of transition probability matrices MMULT function was used in iteration and the results were validated by powers calculated by R software. The software packages used for data, handling, analysis and calculation were MS Excel and R. The tables of data handled are included in the appendices as appendix A.

Construction of Markov chain Model:

In order to check the accuracy of Markov chain model as a prediction model and achieve other objectives of this study, a Markov chain model needs to be constructed for predicting the trend of the share prices. Construction of a Markov chain Model includes:

Handling and initial analysis of the data set for the specified period, movement of the closing share prices occurs and is assumed to be in three states:

Share prices Increase =I
Share prices Decrease =D, and
Share prices remain Unchanged U.

The state space of the Markov model can be written as *E*(D,U,I).As earlier mentioned, initial state vector, also known as initial state distribution can be defined as:

$$\Pi_0 = [\pi_i(i_i), \pi_2(i_2), \pi_3(i_3)]$$

Where $\pi_i(i_i), \pi_2(i_2), \pi_3(i_3)$, provide the Increase (I), Decrease (D), and Unchanged (U) in the probability of the closing share prices. Summary of the initial analysis of the data for 1723 trading days' shows following:

Table 1: Frequency of Increase,unchanged and decrease in share prices

Decrease	No change	Increase
890	**40**	792

The initial state probability can be calculated by finding out probability of each state in the following manner:

$$\pi_i(i_i) = 890/1722$$
$$\pi_2(i_2) = 40/1722$$
$$\pi_3(i_3) = 792/1722$$

Thus, the initial state vector for the HBL closing share prices is

$$\Pi_0 = [0.5168 \quad 0.023 \quad 0.4599]$$

Derivation of Transition Probability Matrix

As movement of the closing share prices have been divided in to three states,(D, U,I)the transition probability matrix also will involve these three states. The transition probability matrix gives great insight into the behavior of a Markov Chain. For this study, the closing share prices have been assumed to have first order Markovian properties; hence derivation of Transition probability matrix for the data set will give great insight as to how the data behaves when assumed to have first order Markovian properties. In a transition probability matrix, each element signifies the transition from that specific state to the next state. There are different ways to derive a transition probability matrix for a Markov chain. Mostly it is derived empirically, while in other stances as well as in this study, it is derived by analyzing and interpreting historical data that is assumed to behave like a Markov chain. A transition probability matrix for our three states will be written mathematically as:

$$P = \left[p_{ij}\right] = \begin{bmatrix} p_{11} & p_{12} & p_{13} \\ p_{21} & p_{22} & p_{23} \\ p_{31} & p_{32} & p_{33} \end{bmatrix}$$

For the three state transition probability matrix with state space *E* (D,U,I),the following table shows the transitions that each probability p_{ij} in the above mentioned transition probability matrix signifies ,for example $\mathbf{p_{11}}$ is a transition from a decrease I share price to a decrease in share price the next day.

State D U I

D	p_{11}	p_{12}	p_{13}
U	p_{21}	p_{22}	p_{23}
I	p_{31}	p_{32}	P_{33}

To derive the probabilities of the transition probability matrix, the raw closing share prices for 1723 days was handled and each transition shown in the above table, for example the transition of the share price from decrease to a decreased state or from decreased to a increased state so on and so forth was observed in Ms Excel and represented in the table below:

Table 2: Transition Matrix of share prices

State	Decrease in share price	Unchanged	Increase in share price
Decrease in share price	481	11	400
Unchanged	10	24	6
Increase in share price	401	5	386

The transition probabilities will be calculated as follows:

$$P_{HBL} = \begin{bmatrix} \frac{481}{892} & \frac{11}{892} & \frac{400}{892} \\ \frac{10}{40} & \frac{24}{40} & \frac{6}{40} \\ \frac{401}{792} & \frac{5}{792} & \frac{386}{792} \end{bmatrix}$$

$$P_{HBL} = \begin{bmatrix} 0.534 & 0.0123 & 0.448 \\ 0.25 & 0.6 & 0.15 \\ 0.506 & 0.0063 & 0.4873 \end{bmatrix}$$

Transition probability obtained above shows that all states communicate with each other because there exists a non-zero probability to go from each state to another. Hence, Transition probability shows that the Markov chain is irreducible since all state belong to one class i.e. communicate with each other. Graphically the transition probability matrix can be represented as

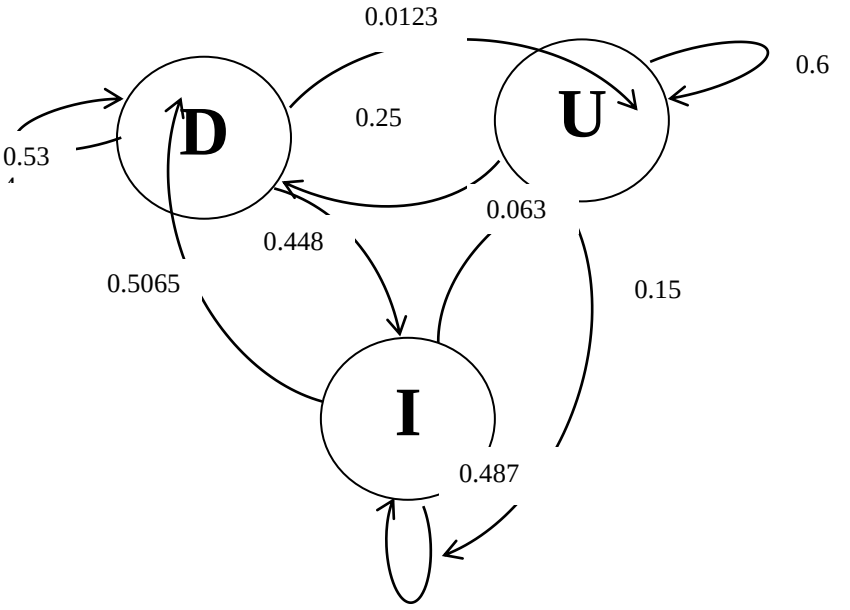

Figure 1: Trasition Diagraph of HBL closing share

Derivation of State probability matrix:

State probabilities according to Markov chain model can be found out by multiplying initial probability matrix with transition probability matrix. In mathematical notation it can be written as:

$$\Pi(1) = \Pi(0)P$$
$$\vdots$$
$$\vdots$$
$$\Pi(n+1) = \Pi(n)P$$

Consequently, the state probability matrix for HBL closing price shares can for 1724th day will be:

$$\Pi(1) = \Pi(0)P_{HBL} = [0.5168 \quad 0.023 \quad 0.4599]\begin{bmatrix} 0.534 & 0.0123 & 0.448 \\ 0.25 & 0.6 & 0.15 \\ 0.506 & 0.0063 & 0.4873 \end{bmatrix}$$

$$= [0.51466 \quad 0.023191 \quad 0.459409]$$

The above state probability shows that HBL closing share prices have a probability of 0.51466 to undergo decrease, 0.023191 probability to remain

unchanged and a probability of 0.459409 to increase from their previous closing day price. Similarly, the state probability for 1725th day will be:

$$\Pi(1) = \Pi(0)P_{HBL}$$

$$= [0.51466 \quad 0.023191 \quad 0.459409]\begin{bmatrix} 0.534 & 0.0123 & 0.448 \\ 0.25 & 0.6 & 0.15 \\ 0.506 & 0.0063 & 0.4873 \end{bmatrix}$$

$$= [0.513227 \quad 0.2313982 \quad 0.4581732]$$

The above state probability shows that HBL closing share prices have a probability of 0.0513227 to undergo decrease, 0.02313982 probability to remain unchanged and a probability of 0.4581732 to increase from their previous closing day price.

Long or steady state behavior of share prices:

As mentioned earlier, this study has made the assumption that the data set of HBL closing share prices form an Ergodic Markov chain i.e. An irreducible, positive recurrent, aperiodic, time homogenous Markov chain. The assumption helps in forecasting the long run behavior of the closing share prices as Ergodic Markov chains always has a unique stationary distribution and such a chain will converge independent of initial distribution as $n \to \infty$ to its unique stationary distribution. i.e.

$$\lim_{n\to\infty} {p_{ij}}^n = \pi_j$$

In other words, for an irreducible, positive recurrent, aperiodic Markov chain, no matter where we start from, if we let the chain run for a long time n then the distribution of $X_n$will converge to π_j i.e. its stationary distribution independent of its initial distribution. Because the convergence occurs independent of where the chain started, the rows of the transition probability matrix P^n converge to π_j as n approaches infinity

$$\lim_{n\to\infty} P^n = \begin{bmatrix} \pi_0 & \cdots & \pi_n \\ \vdots & \ddots & \vdots \\ \pi_0 & \cdots & \pi_n \end{bmatrix}$$

where $\pi = [\pi_0 \ldots\ldots \pi_n]$ is the stationary distribution in matrix form as the p_{ij}'s of P^n have converged to $\pi = [\pi_0 \ldots\ldots \pi_n]$.

In case of Ergodic Markov Chains, such questions can easily be answered by computing stationary distribution of Ergodic chains as for such chains $\lim_{n\to\infty} {p_{ij}}^n = \pi_j$ exists. The solution can be computed by the equations $\pi_j =$

$\sum_{i=0}^{\infty} \pi_i p_{ij}$ and $\sum_{i=0}^{n} \pi_j = 1$ or in vector form by $\pi = \pi P$ which will give rise to n equation with n unknowns and $\sum_{i=0}^{n} \pi_j = 1$.
The solution can also be found out for Ergodic Markov Chains by taking higher powers of the transition matrix because the convergence to stationary distribution occurs independent of where the chain started, the rows of the transition probability matrix P^n converge to π_j as n .But in this study the solution will be found out by taking higher powers of the transition matrix to find the stationary distributions. The higher powers of the transition probability matrix are obtained using R statistical software.

$$P^2 = \begin{bmatrix} 0.512175 & 0.019299 & 0.457703 \\ 0.422289 & 0.224567 & 0.349921 \\ 0.515946 & 0.01716 & 0.461442 \end{bmatrix}$$

$$P^3 = \begin{bmatrix} 0.510061 & 0.020763 & 0.455642 \\ 0.458809 & 0.142139 & 0.393595 \\ 0.513433 & 0.019549 & 0.458834 \end{bmatrix}$$

$$P^4 = \begin{bmatrix} 0.508255 & 0.021602 & 0.453909 \\ 0.479816 & 0.093406 & 0.418892 \\ 0.511368 & 0.020935 & 0.456795 \end{bmatrix}$$

$$\vdots$$

$$P^{40} = \begin{bmatrix} 0.460049 & 0.020757 & 0.4107 \\ 0.464153 & 0.020942 & 0.414363 \\ 0.462541 & 0.020869 & 0.412924 \end{bmatrix}$$

Raising the transition probability matrix to higher power i.e. 40 reveal a matrix with its all rows converging to the same probabilities i.e.

$$\lim_{n\to\infty} P^n = \pi = [0.460049 \quad 0.020757 \quad 0.4107].$$

This is the stationary distribution that the shows that after 40 days since 1723 trading days, it converges to its steady state distribution. The steady state distribution shows the following information about the trading days coming in future, that:

- The chances that the closing share prices will decrease in future for HBL are 0.460049.
- The chances that the closing share prices will remain unchanged in future for HBL are0.020757.
- The chances that the closing share prices will increase in future for HBL are 0.460049.

To validate that the above distribution is the steady state distribution, if we assume that our chain starts with its initial vector i.e.

$$\Pi_0 = [0.5168 \quad 0.023 \quad 0.4599]$$

And, we want to find out the distribution for the 41th day since 1723 trading days, we will see that the

$$\Pi(41) = [0.51466 \quad 0.023191 \quad 0.459409] \begin{bmatrix} 0.460049 & 0.020757 & 0.4107 \\ 0.464153 & 0.020942 & 0.414363 \\ 0.462541 & 0.020869 & 0.412924 \end{bmatrix}$$

$$= [0.461291 \quad 0.020813 \quad 0.4118]$$

is same as the steady state distribution i.e. after the chain has reached its steady distribution from that onwards despite its initial vector, the distribution for the chain remains the same which is the steady state distribution of the chain. This also validates our assumption of taking the Markov chain for HBL closing share prices as Ergodic i.e. an irreducible, positive recurrent, aperiodic, time homogenous Markov chain is called an Ergodic Markov Chain, as the chain has a steady state distribution that is independent of its initial distribution.

The forecast made this way on the long run steady state behavior of HBL closing share prices can provide decision makers significant information on the trend of the HBL share prices and hence can be really helpful in decision making by investors. The predictions also serve to motivate future experimental tests of the model.

Determination of mean recurrence time:

Limiting distributions or steady state distribution can also help us compute the expected return time μ_{jj} i.e. the time the chains takes to visit j once it left j. The relation between limiting probabilities and expected return time is given by

$$\mu_{jj} = 1 / \pi_j$$

μ_{jj} and can also be called mean recurrence time.

Since our Markov chain consisting of closing share prices of HBL is Ergodic i.e. Have a limiting distribution so we can calculate a mean recurrence times for the chain, also known as expected return times. Expected return times give information about the expected stay time of HBL closing prices in all of the three states i.e. D, U, I.

The expected return time to the decreasing state is denoted and given by:

$$\mu_D = 1/0.460049 = 2.173681$$

The expected return time to the unchanged state is denoted and given by:

$$\mu_U = 1/0.02075 = 48.19277$$

The expected return time to the increasing state is denoted and given by:

$$\mu_I = 1/0.41070 = 2.43486$$

The expected decreasing return time signifies that the chain for HBL share prices should make a visit to decreasing state on average in 2 days. The expected unchanged return time signifies that the chain for HBL share prices should make a visit to unchanged state on average in 48 days. The expected increasing return time signifies that the chain for HBL share prices should make a visit to increasing state on average in 2.5 or 2 days approximately. This also shows that the share prices are very volatile and there is no stability in the share prices as the high return time to unchanged state of the share prices depicts.

Accuracy of the Markov chain as a prediction Model:

The state probability for 1724th day predicted that HBL closing share prices have a probability of 0.51466 to undergo decrease, 0.023191 probability to remain unchanged and a probability of 0.459409 to increase from their previous closing day price .In other words the probability of the share prices to decrease is higher and hence the model is predicting a Bearish trend which is consistent with the actual trend observed in closing share prices on 1724th day,as shown in the table below. Similarly, the state probability for 1725th day predicted that HBL closing share prices have a probability of 0.0513227 to undergo decrease, 0.02313982 probabilities to remain unchanged and a probability of 0.4581732 to increase from their previous closing day price. In other words the probability of the share prices to decrease is higher and hence the model is predicting a Bearish trend which is consistent with the actual trend observed in closing share prices on 1725th day, as shown in the table below.

Table 3: Actual Change in in Share prices compared to forecasted trend

Day	Date	Closing Price	Change In prices	Symbol	Markov Chain Prediction
1725	25-Mar-15	185.94	-0.00832	D	Decrease
1724	24-Mar-15	187.5	-0.08559	D	Decrease
1723	20-Mar-15	205.05	-0.0044	D	

Thus Markov chain as a prediction model has made correct trend predictions for HBL closing share prices and proves that actually a Markov chain model can be used by investors as a forecasting model with various changes made to the model proposed in this study, so that trend as well as the price intervals forecast could be made as well.

Results

The interpretation of the transition probability matrix and the limiting probabilities derived show that the probability for no change in share prices is the lowest making the stock really volatile. The probabilities for increase and decrease in share prices are very close 0.46 for decrease and 0.4118 for increase. This can also be represented as that out of 1722 days the share prices decreased for 794 days ,remain unchanged for 36 days while increase for 709 days. This makes investing in the shares of HBL a wrong choice for investors as the share prices are highly volatile and with a higher tendency to decrease than increase in price and consequently will result into capital losses. The mean recurrence times also validate the same result by depicting that the return time to decreased state i.e. 2 days is shorter than the increase state i.e. 2.5-3 days approximately.

Conclusion & Recommendations

This study applied and proposed a first order Markov chain model to historical share prices of a banking company HBL in order to evaluate the accuracy of the prediction of Markov chain model in the context of Pakistan's share market. The results showed that the historical share price dataset of a banking company HBL behaved with Markovian property and exhibited Ergodicity validated by the convergence of the transition probability matrix to a steady state distribution, hence proving that Markov chain model can be applied to shares traded on Pakistan stock exchange (PSX). Furthermore, the accuracy of the Markov model was validated when trend predictions made by the model i.e. state distributions turned out accurate when compared to the actual Share prices. This study has made it evident that Markov chain modeling of stock prices and market is a credible approach for accurate prediction of financial time series. The Markov chain model can be used by investors as a reliable prediction technique as well as improve investor's knowledge to make well informed decisions and chances of making higher return on those investment decisions. The expected return time and expect number of visits for the share prices has been determined and has been shown how to be interpreted to get maximum information out of the Markov prediction model.

The Markov chain model proposed in this study is nevertheless an efficient trend prediction model for stock prices but it does not makes predictions about absolute values of stock prices, which also are needed by investors to make well informed decisions. To get prediction on absolute values of stock prices, a slight change in terms of dividing changes in stock prices in intervals that can best represent changes in data and forming states of transition probability out of those intervals is recommended. Furthermore, studies on the variables that affect the stock market and prices have not been able to achieve absolute explanation. Stock prices according to literature can be affected by many micro and macro variables in economy, fundamentals of companies, government policy and interventions, and psychological factors. So, accurate predictions cannot only be made by assuming although there is significant literature backing this assumption that the historical prices can unveil behavior of stock market and prices. Therefore, results of other prediction models that be combines other prediction techniques with Markov chain Models is recommended for further research to improve upon stock prediction accuracy. It is also suggested that Markov models should be applied to bond and future markets to find out if it is applicable to them as a prediction method and should be checked for its accuracy as a prediction method in order to introduce Markov model as a prediction model for these markets. This study has been conducted using First order Markov chain model as a prediction method but it is suggested to conduct further studies that propose higher order Markov chain models as a prediction model for stock prices, indices and market.

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