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A Stochastic Model Approach to Study the Demeanor of Financial Markets and Impact of COVID-19 Pandemic on Spot and Forward Rates

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Abstract

This study explores the possibility of applying Discrete Time Markov Chain to predict the behaviour of financial markets, to obtain their steady state probabilities, and to apply Markov chains to predict the business cycle. The basic terminologies of Markov chain, as well as a brief introduction about mathematical finance are presented. The classifications of future markets and various types of business risks have also been analysed. The spot and forward rates were observed through a real data considered from the State Bank of India, before and after the impact of the novel Corona Virus (COVID-19), and analysed. Markov models will provide the best solution to deal the current situation. By using Markov models, one can approximately predict the future behaviour of the economic situations of financial markets. This study implies that every investor should make careful examination before investing in the financial market to minimise the risk, considering the impact of the contagious disease COVID-19.

Keywords: Markov Chain, Steady State, Financial Markets, Business Cycle, Spot Rates, Forward Rates, COVID-19

2010 Mathematics Subject Classification: 60J10, 60J20, 9100

Introduction

Financial markets are markets for financial instruments, in which buyers and sellers find each other and create or exchange financial assets. Financial markets transfer financial resources, such as capital, equity, and credit, between various areas of the economy. Investors participating in financial markets seek to benefit from transactions taking place. The operation of financial markets, the design and pricing of financial derivatives, and the analysis and management of risk become very important, and the research and development of financial mathematics are becoming more and more crucial. Therefore, it is of practical significance to analyse the specific application of mathematics in the financial field.

Stochastic processes have a big role in the study of behaviours of the financial markets. Markov chains, in particular, play a vital role in the fast emerging field of stochastic processes. It also functions as an important mathematical tool in this field. Markov chains possess a most important property known as the Markovian property, which enables simplifying predictions about stochastic processes, by viewing the future as independent of the past, given the present state of the process. This property is referred to as 'memory-less property or Markovian property'.

The spread of COVID-19 has severely impacted the global financial markets, with a massive change in asset prices and a drastic increase in volatility across the globe. Banks and capital markets institutions have no choice but to remain hyper vigilant and rewrite the pandemic playbook, as circumstances with COVID-19 evolve. Banks need to actively consider the immediate needs of their people, and simultaneously, the multiple near-, short-, and medium-term operational, financial, risk, and regulatory compliance implications.

A study of the relationship between spot and forward rates would help in determining the degree and the extent of predictability of the former on the basis of the latter. In commodities markets, the spot rate is the price for a product that will be traded immediately, or 'on the spot'. A forward rate is a contracted price for a transaction that will be completed at an agreed upon date in the future.

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The terms spot rate and forward rate are applied a little differently in bonds and currency markets. In bonds markets, the price of an instrument depends on its yield, that is, the returns on a bond buyer's investment as a function of time. If an investor buys a bond that is nearer to maturity, the forward rate on the bond will be higher than the interest rate on its face.

Moreover, the relationship between spot and forward rates may be affected by the efficiency of the financial and exchange markets in two countries. Controls, restrictions, and other interventions that can affect adjustments in exchange, and interest and inflation rates differential also influence the spot and forward rates. Theoretically, in the efficient market and in the absence of intervention of control in the exchange or financial markets, the forward rate is an accurate predictor of the future spot rate.

An adequate saving is essential for healthy economic performance; it is also critical to the economic well-being of individuals and families. The proposed mathematical model argues that how financial markets operate, how a rational individual can make a decision pertaining to the investment, and the consequences of these decisions for individual welfare, are very useful for helping to elucidate under what situations one can invest in the various scenarios of financial markets.

The proposed model provides an idea to a rational person in case of any natural disaster happened, how it reflects on his investment and returns. A study on the system performance measures, such as spot rates and forward rates, have been discussed in this article. Markov models will provide the best solution for facing the current scenario. By using Markov models, one can approximately predict the future behaviour of the economic situations of financial markets.

Literature Review

Various authors have analysed stochastic models to study the nature of financial markets. Hagan and Woodward (1999) studied a general procedure for creating Markovian interest rate models. Dacco and Satchell (2001) studied two bivariate threshold auto-regressive models, such as log difference of the two rates and spot no-arbitrage condition for the spot and forward exchange rates. Ghahramani (2005) discussed the concepts of stochastic processes in his book 'Fundamentals of Probability with Stochastic Processes'. Geng and Li (2009) analysed Markov process functional in finance and insurance. They studied the Markov property of Markov process functional, which are frequently used in economy, finance, engineering, and statistical analysis.

Grimshaw and Alexander (2011) discussed Markov chain models for delinquency: transition matrix estimation, and forecasting. Hoek and Elliott (2012) analysed asset pricing using finite state Markov chain stochastic discount functions. Using the semi-martingale dynamics for the chain, the proposed models can be calibrated and asset valuations derived. Kijima (2013) wrote a book on stochastic processes, with applications to finance. Multivariate high-frequency financial data via semi-Markov processes was studied by D'Amico and Petroni (2014). Markov chain models and applications, modelling and simulation of computer networks and systems methodologies and applications were studied by Trivedi et al. (2015). Kevin (2015) discussed introduction to financial mathematics.

A number of applications of Markov models in financial mathematics have been studied by various authors, such as Cui et al. [12] and Li (2018), in different scenarios. Ross (2019) discussed various characteristics of Markov models in his book 'Introduction to Probability Models'.

Tariq et al. (2017) studied the impact of leverage on the profitability of the Indian banking industry. They have made an attempt to analyse the leverage position of the Indian banking industry and its impact on EPS, its risk, and returns and profitability. From the real data, the value of leverages was calculated, and on the calculated leverages value, mean, standard deviation, skewness, and kurtosis was estimated; the relationship between all leverages with EPS value was also computed. Tesfaye (2018) studied a review on the empirical evidences on structure-conduct-performance relationship in the banking sector. The author studied the behaviour of banks within the given structure, banking, and macro environment.

The impact of risk tolerance and demographic factors on financial investment decision was discussed by Mitali et al. (2018). In this article, the authors proposed a model for understanding the impact of investment risk tolerance, capital risk tolerance, speculative risk tolerance, and six important demographic variables, jointly, on investment decision, which can be used for designing a strategy or investment product to offer to the investors with different levels of financial risk tolerance and different demogr-aphic profiles. An application and comparison of bankruptcy models in the Indian banking sector was conducted by Reshma et al. (2019). In this article, the authors analysed credit risk assessment of public banks, private banks, and merged banks in India.

Kaur (2019) analysed financial distress and bank performance of selected Indian banks. The author assessed the financial performance of the banking sector in India using Altman (1968) Z-score model, for the period 2012-2017. Z-score has been used as a tool to evaluate the credibility of banks, by estimating the Z-score values of the select banks in India. This value is useful when these banks demand loans from the RBI or any other funding agency. Haridass and Harshini (2020) discussed the annuity and mortgage loan in finance, through the techniques of linear difference equations. Various performance measures of annuity and mortgage loan were derived. The impact of the contagious COVID-19 on mortgage loan was analysed, with various scenarios, in the article.

Since epidemics are unlikely to disappear in the future, proactive international actions are required, to not only save lives, but also preserve economic prosperity. In countries without global health coverage, the economic impact of the COVID-19 epidemic will be multifaceted in the country's income distribution. The impact of the contagious COVID-19 on spot and forward rates are analysed with various scenarios in the article.

A review of literature clearly reveals that only a few authors have studied discrete time Markovian models to predict the limiting probabilities of market trends, as well as nature of exchange rates, in finance. This stimulated the author to study the expertise of discrete state, discrete time stochastic processes, with Markovian property, in financial applications.

The structure of this paper is as follows: The introduction and literature survey are presented in Sections 1 and 2, respectively. The basic terminologies of stochastic processes, classifications of Markov process, financial mathematics, and markets are dealt with in Section 3. Section 4 discusses the applications of Markovian models pertaining to finance, with its transition probability matrix, the development of state transition diagrams, and the process of obtaining steady state probabilities. The spot and forward rates with real data are discussed in Section 5. The conclusion and future enhancements are presented in Section 6.

Basic Terminologies

Probabilistic models prove to be much more realistic than deterministic models when it comes to studying the real world phenomena in which systems revolve randomly. Such systems are usually studied as a function of time, using mathematical models known as stochastic models. In the following section, the basic terminologies and pre-requisites pertaining to this research article are discussed.

Stochastic Processes and State Space

Stochastic processes are a family of random variables $\{X_n; n \in I\}$ for a finite or countable index set/parameter set I, or $\{X(t); t \in T\}$ for an uncountable index set/parameter set T. The set of all possible values assigned/assumed by the random variables is called state space. A stochastic process can be classified according to the nature of the time parameter and the state values.

Markov Processes

Markov processes are widely used in engineering, science, and financial models. Whenever the future state of a system depends on the present state only, and not on the past state, it is called Markovian/Memory-less property. A stochastic process with Markovian property is called a Markov process. A discrete state Markov process is called a Markov chain.

Discrete Time Markov Chain

Markov chains are used for modelling phenomena in a broad variety of academic fields, such as life sciences, arts, medicine, engineering, and social sciences. These chains are particularly useful to model degrees of randomness while predicting the value of an asset in the field of financial markets.

A stochastic process $\{X_n; n = 0,1,2,3,4,......\}$ with a finite or countably infinite state space is said to be a Markov chain, for all $i, j, i_0, i_1, ...i_{n-1} \in$ State space, and

$$P\left\{X_{n+1} = j \middle/ X_n = i, X_{n-1} = i_{n-1}, ..., X_0 = i_0\right\}$$

$$= P\left\{X_{n+1} = j \big/ X_n = i\right\} = P_{ij}^n \quad (1)$$

The term P_{ij} represents the state transition probability in one step and P_{ij}^n represents the state transition probability in 'n' steps. The state transition probability matrix is defined as:

$$P = \begin{pmatrix} p_{11} & p_{12} & p_{13} & \cdots\cdots & p_{1n} \\ p_{21} & p_{22} & p_{23} & \cdots\cdots & p_{2n} \\ : & : & : & : & : \\ : & : & : & : & : \\ : & : & : & : & : \\ p_{m1} & p_{m2} & p_{m3} & \cdots\cdots & p_{mn} \end{pmatrix} \text{subject to,}$$

for any row, $P_{ij} \geq 0; \sum_j P_{ij} = 1$ (2)

A Markov chain in which all states communicate with each other is called an irreducible Markov chain. If state 'i' is a recurrent state, then the process enters the state 'i' with probability 1, infinitely, many times. A recurrent state 'j' is called a positive recurrent state if, starting at state j, the expected time until the process returns to state j is finite. Let d = GCD $\{n; P_{ii}^n > 0\}$. Then, 'd' is called period of the state 'i'. A state with period one is called an aperiodic state.

Theorem 3.1: Let {Xn: n = 0, 1,...} be an irreducible, positive recurrent, aperiodic Markov chain, with state space {0, 1,...} and transition probability matrix P = (p_{ij}). Then, for each $j \geq 0$, $\lim_{n\to\infty} p_{ij}^n$ exists and is independent of

i. Let $\pi_j = \lim_{n\to\infty} p_{ij}^n;\ j \geq 0$ and $\begin{pmatrix}\pi_0 \\ \pi_1 \\ \pi_2 \\ : \\ :\end{pmatrix}$. We have:

- $\Pi = P^T \Pi$ and $\sum_{j=0}^{\infty} \pi_j = 1$. Furthermore, these equations determine the stationary probabilities or steady-state probabilities, π_0, π_1, π_2, ... uniquely.
- π_j is the long-run proportion of the number of transitions to state j, $j \geq 0$.
- The expected number of transitions between two consecutive visits to state j is $\frac{1}{\pi_j}$, $j \geq 0$.

Remark: The property that the limiting probability $\pi_j = \lim_{n\to\infty} p_{ij}^n; j \geq 0$ exists and is independent of the initial state i is called ergodicity. Any Markov chain with this property is called ergodic.

Financial Mathematics

The terminology 'Financial Mathematics' is a branch of Applied Mathematics/Mathematical tool that refers to the study of problems arising in the field of finance. The term financial mathematics could also be termed as investment science or investment theory.

Financial Market

Financial market deals with the trading of financial (but not limited to) instruments, including equities, bonds, currencies, and derivatives. It provides a platform to both the buyers and sellers, to meet, and to trade assets at a price determined by the demand and supply forces in the market. The major classifications of financial market include stock market, over-the-counter market, bonds market, money market, commodities market, derivatives market, and Forex market.

The most commonly used term 'index' in the financial market is computed with a 'Weighted Average Market Capitalisation'. Market capitalisation is based on multiplying the stock price and the outstanding shares. A stock index or stock market index is a measurement of the value of a section of the stock market. It is computed from the prices of selected stocks (typically a weighted average). This market index is a tool used by investors and financial managers to describe the market, and to compare the returns on specific investments.

Applications of Discrete Time Markov Chains in Financial Mathematics

Application of Markov chains are quite common in most of the fields, and have become a standard tool for decision making. The Transition Probability Matrix (TPM) and the respective transition diagrams of Markov chains can be used to model certain financial market climates, and thus predict future market trends. With globalisation of business being the mission of various firms across the world, firms are expanding businesses from local markets in domestic currencies to global markets in multiple currencies. The major types of business risks that the firms face are:

- *Price Risk:* All markets, whether commodities, stocks or materials, are dynamic in nature.
- *Exchange Rate Risk:* A firm or an individual generally tends to face uncertainty regarding the exchange rate at which the foreign currency will be converted in the domestic currency, or vice versa.
- *Interest Rate Risk:* The variations in interest rates are dependent on various national and international macro-economic factors.

When modelling to predict the behaviour of certain financial market climates using Discrete Time Markov chains and their respective diagrams, we identified the following future market conditions, where they could be applied:

- *Bull Markets:* The term is used when a market experiences price rise or when it is expected to rise. Though the term 'bull market' is most often used to refer to the stock market, it can also be applied to anything that is being traded, such as bonds, real estate, currencies, and commodities.
- *Bear Markets:* A bear market is a term used when a market experiences prolonged price declines. Bear markets are generally associated with declines in an overall market or index. However, the term could also be used for individual securities or commodities, if they experience a decline of 20% or more over a sustained period of time.
- *Stagnant Markets*: The term refers to periods of time characterised neither by a decline, nor by a rise, in general prices.

Markov Chain to Predict Market Trends

Consider a hypothetical market with a Markovian property, where historical data has given us the following patterns: When a particular week is characterised by a bull market trend, there is 85% chance that another bullish week will follow. Additionally, there is a 9.5% chance that the bull week will be followed by a bearish one instead, or a 5.5% chance that it will be a stagnant one. After a bearish week, there is a 60% chance that the upcoming week also will be bearish. Similarly, chances are that a stagnant week will be followed by a bearish week, with a 30% likelihood. After a stagnant week, there is a 70% chance to follow bullish week and a 15% chance to follow the same in the ensuing week. Let $\{X_n ; n = 1,2,3,4,......\}$ be a Markov chain that represents the status of the market at time 'n', where 'n' represents week. Therefore, the market status can be defined as

$$X_n = \begin{cases} 1, \text{ if the market is Bull} \\ 2, \text{ if the market is Bear} \\ 3, \text{ if the market is stagnant} \end{cases}$$

Thus, the state space of the Markov chain is {1, 2, 3}. By compiling the given probabilities, we can arrive at the following transition probability matrix (TPM):

$$P = \begin{pmatrix} \pi_1 \\ \pi_2 \\ \pi_3 \end{pmatrix} = \begin{pmatrix} 0.850 & 0.095 & 0.055 \\ 0.100 & 0.600 & 0.300 \\ 0.700 & 0.150 & 0.150 \end{pmatrix}^T \begin{pmatrix} \pi_1 \\ \pi_2 \\ \pi_3 \end{pmatrix}.$$

A state transition diagram is given in Fig. 1, which helps to understand and visualise the proposed application.

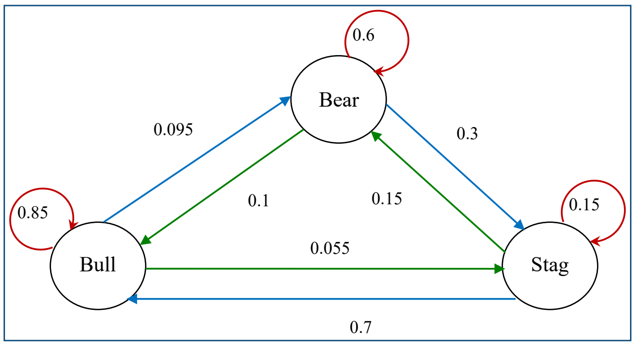

Fig. 1: State Transition Diagram

Let π_1, π_2 and π_3 be the proportion of the periods or limiting probabilities or steady state probabilities of the market, devoted to bull, bear, and stagnant, respectively.

By theorem 3.1, $\begin{pmatrix} \pi_1 \\ \pi_2 \\ \pi_3 \end{pmatrix} = \begin{pmatrix} 0.850 & 0.095 & 0.055 \\ 0.100 & 0.600 & 0.300 \\ 0.700 & 0.150 & 0.150 \end{pmatrix}^T \begin{pmatrix} \pi_1 \\ \pi_2 \\ \pi_3 \end{pmatrix}$ and $\pi_1 + \pi_2 + \pi_3 = 1$

Which implies,

$$-0.150\pi_1 + 0.100\pi_2 + 0.700\pi_3 = 0$$
$$0.095\pi_1 - 0.400\pi_2 + 0.150\pi_3 = 0$$
$$0.055\pi_1 + 0.300\pi_2 - 0.850\pi_3 = 0$$

and $\pi_1 + \pi_2 + \pi_3 = 1$

The above system of equations can be solved numerically, upon which we arrive at the following values: $\pi_1 = 0.6789$; $\pi_2 = 0.2048$ and $\pi_3 = 0.1162$. It can be concluded that as $n \to \infty$, the probabilities will converge to a steady state probability. This implies that 67.89% of all weeks will be bullish, 20.48% bearish, and 11.62% stagnant, with the steady state probabilities being independent of the initial state.

Markov Chain to Predict Business Cycle

Consider the attributes pertaining to the business cycle of the tourism and development department of a country in a hypothetical market, with the Markovian property. Let $\{X_n; n = 0,1,2,3,4,......\}$ be a Markov chain that represents the status of the department at time n. We can define the following economic status of the department:

$$X_n = \begin{cases} 1, \text{ if the department has peak} \\ 2, \text{ if the department has recession} \\ 3, \text{ if the department has trough} \\ 4, \text{ if the department has re cov ery} \end{cases}$$

Thus, the state space of the Markov chain can be given as $\{1, 2, 3, 4\}$.

Let the department be in the same state with probability 0.25. The probabilities for changing to any of the other states, i.e., the probability of engagement in any one of the other states during the next period is given by the transition probability matrix (TPM):

$$P = \begin{pmatrix} 0.25 & 0.45 & 0.25 & 0.05 \\ 0.15 & 0.25 & 0.35 & 0.25 \\ 0.03 & 0.40 & 0.25 & 0.32 \\ 0.69 & 0.05 & 0.01 & 0.25 \end{pmatrix}$$

Clearly, the Markov chain $\{X_n; n = 1,2,3,4,......\}$ is irreducible, aperiodic, and recurrent. Since it is a finite state Markov chain, it also happens to be a positive recurrent. Let π_1, π_2, π_3 and π_4 be the limiting probabilities or steady state probabilities of the department, devoted to peak, recession, trough, and recovery, respectively. A state transition diagram is given in Fig. 2.

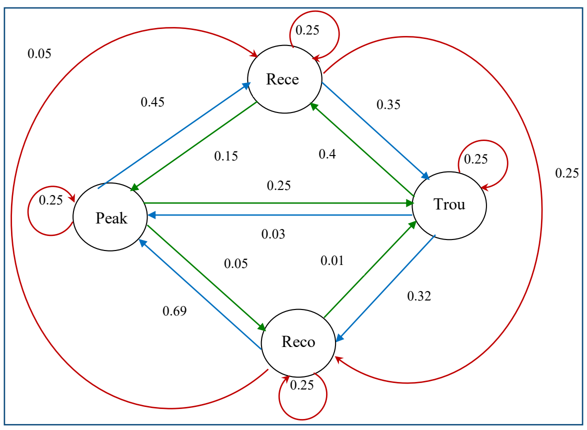

Fig. 2: State Transition Diagram

By theorem 3.1, $\begin{pmatrix} \pi_1 \\ \pi_2 \\ \pi_3 \\ \pi_4 \end{pmatrix} = \begin{pmatrix} 0.25 & 0.45 & 0.25 & 0.05 \\ 0.15 & 0.25 & 0.35 & 0.25 \\ 0.03 & 0.40 & 0.25 & 0.32 \\ 0.69 & 0.05 & 0.01 & 0.25 \end{pmatrix}^T \begin{pmatrix} \pi_1 \\ \pi_2 \\ \pi_3 \\ \pi_4 \end{pmatrix}$ and

$$\pi_1 + \pi_2 + \pi_3 + \pi_4 = 1$$

Which implies,

$$\begin{aligned} 0.25\pi_1 + 0.15\pi_2 + 0.03\pi_3 + 0.69\pi_4 &= \pi_1 \\ 0.45\pi_1 + 0.25\pi_2 + 0.40\pi_3 + 0.05\pi_4 &= \pi_2 \\ 0.25\pi_1 + 0.35\pi_2 + 0.25\pi_3 + 0.01\pi_4 &= \pi_3 \\ 0.05\pi_1 + 0.25\pi_2 + 0.32\pi_3 + 0.25\pi_4 &= \pi_4 \end{aligned}$$

and $\pi_1 + \pi_2 + \pi_3 + \pi_4 = 1$

The above system of equations can be solved numerically, upon which we arrive at the following values: $\pi_1 = 0.3060$; $\pi_2 = 0.2804$; $\pi_3 = 0.1484$ and $\pi_4 = 0.2652$.

Hence, we can conclude that as $n \to \infty$, the probabilities will converge to a steady state, implying that 30.60% of the period is likely to be the peak season, 28.04% would be a season of recession. On the same lines, 14.84% of the time is likely to be representing a trough and 26.52%, the recovery season. The steady-state probabilities of this Markov chain do not depend upon the initial state. In other words, for certain Markov chains, after a large number of transitions, the probability of entering a specific state becomes independent of the initial state of the Markov chain.

Hence, one can apply the aforesaid process to obtain long-run probabilities for any real-time situations, satisfying the constraints mentioned in theorem 3.1.

Spot Rates and Forward Rates

Transactions in foreign exchange can either be spot or forward, depending on the time of settlement. If a transaction is to be settled immediately, it is known as a spot transaction, and the rates applicable for such a transaction are known as spot rates.

Transactions in foreign currency can also be taken up for settlement at a much later date. Such transactions, where the rate is fixed during the time of contract, but currencies are delivered at a later stage, are referred to as forward contracts; the corresponding rates are known as forward rates. Spot rates and forward rates, as quoted by the State Bank of India (Real Data), have been considered for discussion, and are shown in Tables 1-5. These results are also given in Fig. 3-6.

Discussion of the Real Data of Spot and Forward Rates before COVID-19

This section presents the real data of spot rates and forward rates of the State Bank of India at various time instances, before the pandemic of the novel Corona Virus (COVID-19).

Effect of Spot Rates of Various Currencies

The real data of the State Bank of India, before COVID-19, are considered. The data pertaining to spot rates for various currencies at different time instances, namely Tue., April 23, 2019, Wed., April 24, 2019, Thur., April 25, 2019, and Fri., April 26, 2019 are tabulated in Table 1. The comparisons between import and export have also been made and tabulated. It can be observed from the table that the spot rates are fluctuating over various time periods.

Effect of Forward Rates (vs.) Actual Rates for Import and Export

The forward rates and actual rates of currencies, for both imports and exports, on April 24, 2019 (date of spot rate), before COVID-19, are compared to the rates on Wednesday. The forward rates and actual rates at various time instances, such as Fri., May 24, 2019 (one month from the date of spot rate), Wed., July 24, 2019 (three months from the date of spot rate), and Thur., Oct 24, 2019 (six months from the date of spot rate), are tabulated in Tables 2 and 3, respectively. These results are also shown in Fig. 3 and 4. From the tables and figures, it can be understood that the actual rates are lower than the forward rates for both import and export in the currencies of Indian Rupees and Japanese Yen, whereas with all other currencies, the actual rates are higher than the forward rates.

Discussion of the Real Data of Spot and Forward Rates after COVID-19

In this section, the real data of spot rates and forward rates of the State Bank of India at various time periods are considered, after the impact of the COVID-19 pandemic.

Effect of Spot Rates and Forward Rates

As in the earlier case, the real data of the State Bank of India, after COVID-19 are considered. The spot rates and forward rates of currencies on Fri., December 27, 2019 (date of spot rate) are analysed, for both import and export. The results at different time instances, such as Mon., January 27, 2020 (one month from the date of spot rate), Thur., March 27, 2020 (three months from the date of spot rate), and Fri., June 26, 2020 (six months from the date of spot rate), are tabulated in Table 4 and also shown in Fig. 5. From the table and figure, it can be observed that with currencies Euro and Japanese Yen, when time increases, the forward rates tend to decrease for both imports and exports, whereas for all other currencies, the forward rates tend to increase.

The spot rates and forward rates of currencies for import and export on Fri., March 20, 2020 (date of spot rate) are analysed. The results at different time instances, such as Mon., April 20, 2020 (one month from the date of spot rate), Fri., June 19, 2020 (three months from the date of spot rate), and Mon., Sep 21, 2020 (six months from the date of spot rate), are tabulated in Table 5 and also shown in Fig. 6. From the table and figure, it can be observed that with currencies Euro and Japanese Yen, when time increases, the forward rate decreases for both imports and exports, whereas currency Indian Rupees tends to increase. When time increases, the forward rates of all other currencies are fluctuating.

Economic Implications

The COVID-19 pandemic has caused direct as well as indirect impacts. In addition to the substantial burden on healthcare systems, COVID-19 has had major economic consequences for the affected countries. Global financial markets have been heavily impacted by the effect of COVID-19 spread. Following the lockdown, certain essential supply chains broke down.

COVID-19 is not only a global pandemic and public health crisis, it has also gravely affected the world economy and financial markets. Remarkable reductions in income, rising unemployment, and disruptions in the transportation, service, and manufacturing industries are among the consequences of the disease, belittling activities that have been implemented in many countries.

It is evident that communicable diseases such as COVID-19 have the potential to inflict severe economic and financial costs on regional and global economies. Because of high transportation connectivity, globalisation, and economic interconnectedness, it has been extremely difficult and expensive to contain the virus and mitigate the importation risks once the disease started to spread in multiple locations.

As the spread of the virus negatively impacts the manufacturing and service industries, especially in developed countries, we expect that financial markets will continue to be volatile. Thus, from the above analysis, it can be understood that every investor should make proper and careful examination before investing in the financial market, such as the stock market, over-the-counter market, bonds market, money market, commodities market, derivatives market, Forex market, and so on, to minimise the risk, considering the impact of the contagious COVID-19, which is the unique contribution of the study.

Conclusion

The preceeding paragrahs dicussed the applications of Discrete Time Markov Chain in the emerging field of financial mathematics, in connection with financial markets; their steady state probabilities have also been obtained and state transition diagrams were presented. Further, the classification of future markets and various types of business risks have been analysed. The real data of spot rates and forward rates of the State Bank of India have been considered and analysed at various time instances, both before and after the impact of the novel Corona Virus (COVID-19) pandemic.

The classical models discussed in this study can also be extended to (i) Adaptive Markov chains, systems in which the transition matrix is adjusted depending on the entire history of the system or some statistical summary of that history; (ii) Non-linear Markov Chain, in which the distribution of X_n depends on both X_{n-1} and its distribution. This is the evaluation of a Feynman-Kac system. These two models are essential in modelling complex systems.

Table 1: Spot Rates of Currencies: Import (vs.) Export

Tue., April 23, 2019	*Wed., April 24, 2019*	*Thur., April 25, 2019*	*Fri., April 26, 2019*	*Currency*	*Tue., April 23, 2019*	*Wed., April 24, 2019*	*Thur., April 25, 2019*	*Fri., April 26, 2019*
IMPORT (Buying)					*EXPORT (Selling)*			
Spot rates					*Spot rates*			
0.8892	0.8926	0.8990	0.8983	Euro	0.8890	0.8923	0.8985	0.8979
111.8818	111.8343	111.8162	111.7544	Japanese Yen	111.917	111.8514	111.8509	111.7891
7.8468	7.8397	7.8471	7.8466	Hong Kong Dollar	7.8455	7.8472	7.8458	7.8453
1.4065	1.4228	1.4296	1.4216	Australian Dollar	1.4056	1.4224	1.4293	1.4206
9.3405	9.3740	9.5530	9.4946	Swedish Kroner	9.3409	9.3745	9.5668	9.4953
69.6800	69.9300	70.3100	70.0700	Indian Rupees	69.5900	69.8400	70.2200	69.9800

Source: State Bank of India, Chennai, India.

Table 2: Forward Rates (vs.) Actual Rates of Currencies (Import), as on Wednesday, April 24, 2019

Spot Rate	*Forward Rates as on Wednesday, April 24, 2019*			*Currency*	*Spot Rate*	*Actual Rates*		
Wed., April 24, 2019	*Fri., May 24, 2019*	*Wed., July 24, 2019*	*Thur., Oct 24, 2019*		*Wed., April 24, 2019*	*Fri., May 24, 2019*	*Wed., July 24, 2019*	*Thur., Oct 24, 2019*
	1 Month	*3 Months*	*6 Months*			*1 Month*	*3 Months*	*6 Months*
0.8926	0.8903	0.8858	0.879	Euro	0.8926	0.8941	0.8974	0.8987
111.8343	111.5397	110.9944	110.1818	Japanese Yen	111.834	109.6957	108.0607	108.5370
7.8397	7.8426	7.8285	7.8175	Hong Kong Dollar	7.8397	7.8444	7.8100	7.8357
1.4228	1.4228	1.4194	1.4159	Australian Dollar	1.4228	1.4478	1.4324	1.4645
9.3740	9.3444	9.3735	9.2416	Swedish Kroner	9.3740	9.5840	9.4446	9.6171
69.9300	70.2700	70.7700	71.5300	Indian Rupees	69.9300	69.5800	69.0400	71.0700

Source: State Bank of India, Chennai, India.

Table 3: Forward Rates (vs.) Actual Rates of Currencies (Export), as on Wednesday, April 24, 2019

Spot Rate	*Forward Rates as on Wednesday, April 24, 2019*			*Currency*	*Spot Rate*	*Actual Rates*		
Wed., April 24, 2019	*Fri., May 24, 2019*	*Wed., July 24, 2019*	*Thur., Oct 24, 2019*		*Wed., April 24, 2019*	*Fri., May 24, 2019*	*Wed., July 24, 2019*	*Thur., Oct 24, 2019*
	1 Month	*3 Months*	*6 Months*			*1 Month*	*3 Months*	*6 Months*
0.8923	0.8926	0.8902	0.8857	Euro	0.8923	0.8938	0.8970	0.8984
111.8514	111.8425	111.5196	110.9851	Japanese Yen	111.8514	109.7347	108.0643	108.5653
7.8472	7.8402	7.8435	7.8322	Hong Kong Dollar	7.8472	7.8525	7.8169	7.8431
1.4224	1.4227	1.4216	1.4195	Australian Dollar	1.4224	1.4478	1.4322	1.4635
9.3745	9.3685	9.3479	9.3008	Swedish Kroner	9.3745	9.5723	9.4445	9.6179
69.8400	70.1700	70.6700	71.4300	Indian Rupees	69.8400	69.4950	68.9450	70.9800

Source: State Bank of India, Chennai, India.

Table 4: Spot Rates and Forward Rates of Currencies: Import (vs.) Export, as on Friday, December 27, 2019

IMPORT				*Currency*	*EXPORT*			
Spot Rate	*Forward Rates as on Friday, December 27, 2019*				*Spot Rate*	*Forward Rates as on Friday, December 27, 2019*		
Fri., December 27, 2019	*Mon., January 27, 2020*	*Thur., March 27, 2020*	*Fri., June 26, 2020*		*Fri., December 27, 2019*	*Mon., January 27, 2020*	*Thur., March 27, 2020*	*Fri., June 26, 2020*
	1 Month	*3 Months*	*6 Months*			*1 Month*	*3 Months*	*6 Months*
0.8968	0.8948	0.8914	0.8864	Euro	0.8964	0.8967	0.8948	0.8914
109.5063	109.3030	108.9248	108.3890	Japanese Yen	109.5286	109.5078	109.3087	108.9430
7.7884	9.2003	9.2593	9.3710	Hong Kong Dollar	7.7866	9.1846	9.2555	9.3671
1.4341	102.3857	103.0429	104.2857	Australian Dollar	1.4331	102.3429	103.0000	104.2429
9.3482	7.6652	7.73100	7.8410	Swedish Kroner	9.3480	7.7282	7.7112	7.8210
71.4200	71.6700	72.1300	73.0000	Indian Rupees	71.3250	71.6400	72.1000	72.9700

Source: State Bank of India, Chennai, India.

Table 5: Spot Rates and Forward Rates of Currencies: Import (vs.) Export, as on Friday, March 20, 2020

IMPORT				*Currency*	*EXPORT*			
Spot Rate	*Forward Rates as on Friday, March 20, 2020*				*Spot Rate*	*Forward Rates as on Friday, March 20, 2020*		
Friday, March 20, 2020	*Mon., April 20, 2020*	*Fri., June 19, 2020*	*Mon., Sep 21, 2020*		*Friday, March 20, 2020*	*Mon., April 20, 2020*	*Fri., June 19, 2020*	*Mon., Sep 21, 2020*
	1 Month	*3 Months*	*6 Months*			*1 Month*	*3 Months*	*6 Months*
0.9333	0.9316	0.9292	0.9267	Euro	0.9330	0.9333	0.9318	0.9294
110.3534	109.9913	109.6760	109.3311	Japanese Yen	110.3848	110.3625	110.0420	109.7843
7.7577	7.7569	7.7566	7.7601	Hong Kong Dollar	7.7554	7.7605	7.7602	7.7636
1.7040	1.7041	1.7029	1.7031	Australian Dollar	1.7037	1.7041	1.7040	1.7042
10.3365	10.3179	10.3774	10.2914	Swedish Kroner	10.3370	10.3297	10.3189	10.3168
75.2500	75.6300	76.1700	76.9800	Indian Rupees	75.1500	75.5100	76.0500	76.8600

Source: State Bank of India, Chennai, India.

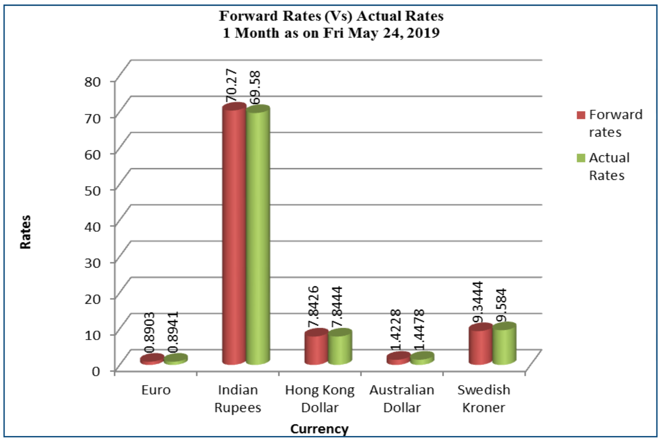

Fig. 3: Forward Rates (vs.) Actual Rates of Currencies (Import), as on Wednesday, April 24, 2019

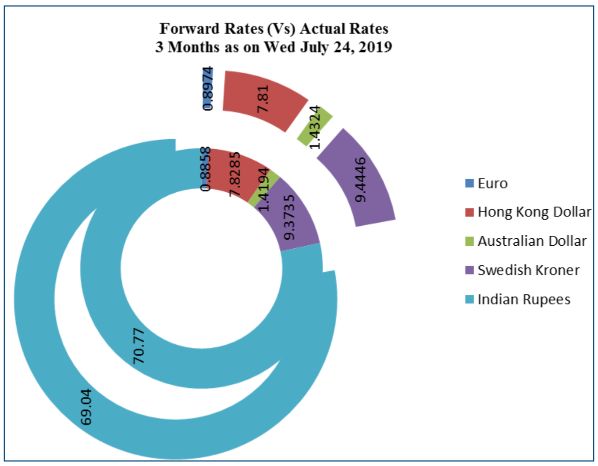

Fig. 4: Forward Rates (vs.) Actual Rates of Currencies (Export), as on Wednesday, April 24, 2019

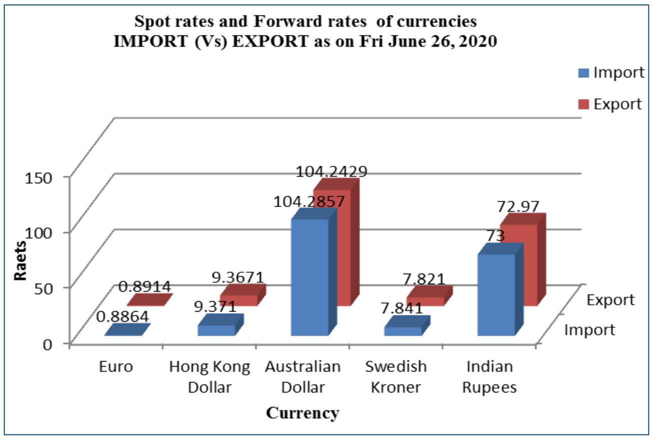

Fig. 5: Spot Rates and Forward Rates of Currencies: Import (vs.) Export, as on Friday, December 27, 2019

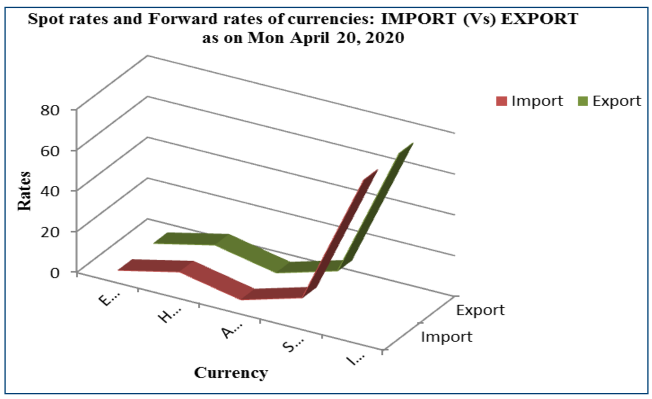

Fig. 6: Spot Rates and Forward Rates of Currencies: Import (vs.) Export, as on Friday, March 20, 2020

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