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This chapter gives a brief introduction to the theory of entropy and hints the possible areas of financial studies, in which the entropic concept may be applied. A review of the existing literature on such areas and the importance of this study are explicated to justify this study. Then the exact objectives of the study and the methodology followed are spelt out. Further, this chapter mentions the limitations of this study and explains the arrangement of chapters in this thesis.

Evidence of non-linear dependence in financial time series has been reported very often in financial literature. Non-linear structure has been observed in the stock returns of various stock exchanges. Such observation may be likely due to the microstructure character of the stock market itself, the herding behaviour of market participants, the low frequency of information input in the market relative to the observed prices, varied abilities of the participants to process information, differential transaction costs of the participants, etc. Even simple non-linear relationships may yield extremely complex time paths so that the system appears to be random. If a signature of approximate non-linear determinism is found then the notions of phase space reconstruction, non-linear invariants, etc. may provide a convenient framework for time series analysis. This is so since non-linear time series methods which arise as extensions and generalizations of linear tools have been found to be insufficient and there are many references that indicate non-linear structure in financial time series which cannot be extracted with a Generalised Auto Regressive Conditional Heteroskedastic model. Hence financial markets may be
treated as non-linear dynamical systems to characterise their intrinsic nature and various characteristic measures like entropy, Lyapunov exponent and correlation dimension may be used to study the markets. One of the reasons for the relevance of the characteristic measures is their invariance under smooth coordinate transformations of the phase space. The values of these measures for an approximately noise-free and sufficiently long time series remain the same irrespective of the details of the measurement process and of the phase space reconstruction.

(i) Entropy of a dynamical system is the amount of disorder in the system, as described in Thermodynamics and also is the amount of information needed to predict the next measurement with a certain precision, as described in Information Theory. Entropy does not measure the shape of the distribution of the realizations of a system but provides information about how the system fluctuates with time – in frequency space or phase space. The concept of embedding the one-dimensional signal in a phase space which is achieved by comparing the time series of realizations with itself but lagged by a specified time interval, is used to estimate the entropy of a system. In an irregular signal, the prediction of the next point using the knowledge of previous points is not easy and in a regular signal such prediction is more reliable. The number of previous (lagged) points required to make the prediction is the embedding dimension. Using these embeddings, various versions of entropy such as Shannon entropy and KS entropy are estimated.

(ii) Lyapunov exponent (LE) is the inverse of time scale and quantifies the rate by which two typically nearby trajectories converge or diverge in time. In a predominantly
periodic system, this divergence will be very slow whereas in a chaotic system, this separation will be exponentially fast. LE is a properly averaged exponent of this increase and is characteristic of the system underlying the data and quantifies the strength of chaos. There are as many LEs for a dynamical system as there are phase space dimensions and generally the maximal LE is measured to study a dynamical system. The maximal LE of a dissipative system may be negative, indicating the existence of a stable fixed point and two trajectories approaching a fixed point also approach each other exponentially fast. If the maximal LE is zero, the system is marginally stable and settles down to a limit cycle and two trajectories can separate or approach each other only slower than exponentially. A predominantly deterministic system, perturbed by small scale random noise behaves like a diffusion process and the corresponding maximal LE is large and positive. LE is invariant under all smooth transformations of shifting, rescaling or otherwise processing of data since it describes long term behaviour.

(iii) The portrayal of a data set as a geometrical object in phase space as represented by the trajectories of the system, leads to the concept of dimension of the data set. Non-integer dimensions are assigned to geometrical objects which exhibit unusual kind of self-similarity (a part of an object when magnified resembling the object itself) and which show structure on all length scales. The trajectories of a dissipative (contraction of volume elements) dynamical system do not fill the phase space and are confined to lower dimensional sub-sets which possess a fractal structure i.e. which are self-similar in a non-trivial way. Generalised dimensions are a class of quantities to characterize the fractal nature of a data set. Hausdorff dimension is the most natural concept to characterise a
fractal set, from mathematical point of view. Information dimension is more attractive for physical systems since it takes into account the relative visitation frequencies. Correlation dimension is useful for the characterization of measured data. Dimensions are invariant under smooth transformations and thus computable in time delay embedding spaces.

Of the commonly used non-linear invariants (i) entropy measures irregularity or complexity of the data (ii) Lyapunov exponent measures sensitive dependence on initial conditions and (iii) correlation dimension measures spatial correlation in the phase space. The last two are used to study the presence of chaotic structure in very large data sets and perform poorly with small samples. Entropy is used to study the presence of repetitive patterns or shifts in data structure and some versions of entropy like approximate entropy and sample entropy may be measured for very short and noisy time series also. Hence entropy may be well suited to analyse time series of stock prices or the values of other financial instruments.

The concept of entropy has been applied in financial economics by researchers for various purposes like describing financial market dis-equilibrium, devising a methodology for programmed trading of equities, prediction of stock market returns by detecting non-linear dependence within the returns series, assessment of subtle and potentially exploitable changes in the serial structure of a financial variable and explanation of many empirical evidences about market behaviour. However, there appears to be no research about the potential of entropy to study stock price manipulation and only a few research papers using entropy to study price discovery in securities market.
or transfer of information between different segments of financial market. In the present study, the suitability of the entropic concept and the different versions of entropy for such applications in the financial market are studied.

(a) For the purpose of our study, stock price manipulation means planned buying / selling of a security by a person or a group acting in concert for the purpose of creating a false appearance of transactions in a security, to cause or maintain an artificial increase or decrease in the value of the security and thus influencing other investors to buy or sell at disadvantageous prices, with the aim of gaining undue profits. Essentially, price manipulation may be defined as intentional interference with the free forces of supply of or demand for a security. For example, one may deflate the price of a security by placing small orders at significantly lower price as compared to the one at which it has been trading. This gives investors the impression that there is something wrong with the issuer of the security, so they sell, thereby pushing the prices further down. Another example of manipulation is to place simultaneous buy and sell orders through different brokers, that cancel each other but give the perception that there is increased interest in the security, because of the high volume.

(b) Between the equities and the derivatives segments of the securities market, the question as to where security’s price is discovered may be resolved by identifying the segment which leads the other in terms of pricing the security by the participants. Price discovery thus means determination in a market segment of the security’s price which is trailed in the other segment after a lag in time.
(c) The price movements in the stock market are supposed to influence or be influenced by the price movements in other financial markets like foreign exchange market and commodities market, due to economic and other reasons. Such causal interactions at price level between stock market and other markets are proposed to be analysed in this study.

LITERATURE REVIEW

(A) PRICE MANIPULATION IN STOCK MARKET
The recent interest in stock market microstructure in general and market manipulation in particular suggests that a review of the literature on the subject is an essential requirement. However, since the research involves both theoretical and empirical investigations, any attempt to survey market manipulation in its entirety would be doomed to failure. Hence an attempt is made to review published research papers on the subject, based on a study of books on the topic like Handbooks in Operations Research and Management Science and journals like Econometrica, Economic Letters, European Economic Review, Journal of Financial and Quantitative Analysis and Journal of Finance and also based on various Working Papers available in the internet and interaction with various scholars. It is observed that although the Indian stock market has witnessed price manipulation now and then, there has not been much literature on such instances.

A few articles have, interestingly, questioned the justification of the aspersions cast on price manipulation in stock markets and raised doubts on basic premises like whether stock price manipulation is bad and whether such manipulation is to be prohibited.
Fischel and Ross (1991)\(^1\) argues that stock manipulation effected by actual trades, as distinguished from fictitious trades, should not be considered as illegal and bases the attack on both legal and normative grounds. On the legal front, it is argued that manipulation does not meet the legal definition of fraud and that even if the manipulator has a fraudulent intent his trades are real and thus the prosecution cannot allege any bad conduct that constitutes the actus reus of this offence. On the normative front, it is suggested that the cost of regulating manipulation exceeds the benefits because (a) actual trades hardly affect price (b) manipulation has a negative expected return and is therefore self-deterred and (c) in any case, market regulator / courts of law can hardly distinguish between manipulation and investment.

Omri Yadlin (1999)\(^2\) argues that stock manipulation is not socially harmful, should not be treated as fraud and hence it is not clear if a ban on stock manipulation would be warranted. The author has addressed each of the three potential objections - to the approach that informed manipulators, more than informed investors are conducive to market efficiency since uninformed traders would prefer trading with informed manipulators because unlike investors they do not try to disguise their information - viz. (a) informed traders should have no interest in manipulating the market (b) informed manipulators could achieve the same effect by releasing their information rather than by employing the expansive means of manipulation (c) there is no way to distinguish between informed and uninformed manipulators. The author has provided the results of an empirical study of the performance of manipulated shares traded on the Tel Aviv Stock Exchange, Israel.
Whatever be the conclusions of these papers, stock price manipulation has been barred by legal provisions and / or regulations in both the developed and the developing markets on the premise that such manipulations are against the interest of the market participants and weaken the market. Now, we consider the important publications on the subject in a chronological order.

Kyle Albert S. (1985) has considered manipulation in which a single insider has unique access to a private observation of the ex-post liquidation value of a risky asset and the market makers set a price and trade the quantity which makes markets clear and their information consists of observations of the current and the past aggregate quantities (called the order flow) traded by the insider and noise traders combined. The conditions for equilibrium in sequential trading and continuous trading have been studied, with linear functions for the insider’s trading strategy and the market makers’ pricing rule.

Lawrence Glosten and Paul R. Milgrom (1985) considers a price manipulation model, in which a specialist taking into account the fact that the traders may be informed, sets the prices using Bayes rule to update his ex ante probability regarding the value of the stock.

Easley David and Maureen O’Hara (1985) reviews market microstructure and provides examples of strategic information based manipulation.

Easley David and Maureen O’Hara (1987) considers an informed trader who strategically chooses between small market orders and large block trades, to manipulate stock prices.

Vila Jean Luc (1989) has presented two examples of market manipulation as games in extensive form with asymmetric information and has derived the conditions for
equilibrium, treating the gains and losses as payoffs associated to the various strategies of the players.

Fishman Michael, J. and K. Hagerty (1991)\textsuperscript{8} propounds a model in which an uninformed trader takes advantage of the mandatory disclosure (or post-announcement) requirement for insiders as found in the Securities Exchange Act and the manipulator takes advantage of the market's inability to infer the information content of his disclosed trades. For example, although he has no information, he discloses his sale causing the stock price to drop because the market believes that he may be informed and then the manipulator buys his shares at the lower price. The authors have suggested two approaches to circumvent manipulation around disclosures - If disclosure is mandatory, then the 'short-swing profit' rule, which currently requires only corporate insiders to give up profits from short term trading profits, should be applied to all insiders who face disclosure requirements. Alternatively, mandatory disclosure requirement may be removed since voluntary disclosure is generally not forthcoming.

Utpal Bhattacharya and Matthew Spiegel (1991)\textsuperscript{9} examines the conditions that lead to a collapse of trade in a financial market. Based on a simple model constructed from the classical portfolio problem, it is concluded that if insider trading laws do not exist, the market may fail completely as a communication system and the uninformed may not have the confidence to trade with the insider at all.

Franklin Allen and Gary Gorton (1992)\textsuperscript{10} has relaxed the assumption made by Glosten and Milgrom and by Albert S. Kyle - treating liquidity traders as equally to be buyers as sellers and also treating them as equally likely to be informed - and have shown that the
asymmetry of price elasticity between buyers and sellers can create an opportunity for profitable price manipulation.

Robert A. Jarrow (1992) has examined the conditions under which a large trader, whose trades affect prices, can profit without risk, by implementing certain trading strategies like market corner and short squeeze, without any proprietary or inside information on the intrinsic value of the asset. For a market corner, the shares which the speculator brings by some time t must exceed the total supply. For the speculator’s position to exceed the total supply, short interest must be strictly positive i.e. some traders should have shorted the risky asset and effectively borrowed them from the speculator. A short squeeze occurs at time t when the speculator reduces his holdings by calling in the shorts i.e. by requiring to provide him with the delivery of all his outstanding shares. Although this process keeps his holdings greater than the total supply, the shorts, in order to return the borrowed shares, need to purchase them from him only, because of the corner and hence the speculator can arbitrarily determine the price. The speculator’s paper wealth is defined to be the value of his portfolio position when relative prices are evaluated using his current holdings and real wealth is defined to be the value of the speculator’s position when relative prices are evaluated as if his stock holdings were liquidated. The real wealth is strictly less than paper wealth iff the large trader’s risky asset position is non-zero. A market manipulation trading strategy is defined to be any zero initial wealth self-financing trading strategy such that the real wealth of the trading strategy at liquidation is non-negative for sure and strictly positive with positive probability. Thus a market manipulation trading strategy has a positive probability of generating positive real wealth with no losses from a zero initial investment.
Franklin Allen and Douglas Gale (1992)\textsuperscript{12} depicts a model in which an uninformed trader mimics an informed trader with positive information about the stock to raise the stock price and then sells his shares at a profit. The observation of the operation of trading pools during the great crash of 1929 i.e. a group of investors combining first to buy a stock, then to spread favourable rumours about the firm and finally to sell out at a profit, led to extensive provisions in the Securities Exchange Act of 1934 to eliminate manipulation. The kinds of manipulation that the Act effectively outlawed fall naturally into two categories – action based manipulation i.e. manipulation based on actions that change the actual or perceived value of the assets and information based manipulation i.e. manipulation based on releasing false information or spreading false rumours. The Act attempted to eradicate action based manipulation by, among other things, making it illegal for directors and officers to sell short of the securities of their own firm. To eliminate information based manipulation, firms were required to issue information to the public on a regular basis so that the spreading of rumours would be more difficult and it was made illegal for anybody to attempt to raise or depress stock prices by making statements which they knew to be false. However, there is a third category of manipulation that is much more difficult to be eradicated viz. trade based manipulation which occurs when a trader attempts to manipulate a stock simply by buying and then selling without taking any publicly observable actions to alter the value of the firm or releasing false information to change the price.

Craig W. Holden and Avanidhar Subrahmanyam (1992)\textsuperscript{13} considers a multi-period auction model in which multiple informed traders optimally exploit their long lived informational advantage. The basic finding is that in a unique linear equilibrium,
informed traders trade very aggressively and cause nearly all of their common private information to be incorporated into prices almost immediately. Thus they cause the depth of the market to become extremely large almost immediately, provided the number of auctions is reasonably large. Hence it is shown that a market with multiple informed traders approximates a strong form efficient market quite accurately at almost all times. In the Kyle’s model, a single privately informed trader with long-lived information optimally exploits his monopoly power over time and trades in a gradual manner so that his information is incorporated into prices at a slow, almost linear rate and when auctions are held continuously, the depth of the market is constant over time. The contrast in results between the case of a monopolistic informed trader and that of multiple informed traders is driven by aggressive competition among these traders. In the game in which private information lasts only one period with a linear pricing rule, the unique Nash equilibrium is an equilibrium in which imperfect competitors acting non-cooperatively choose larger quantities that a monopolist (or collusive agents) would choose. In the multi-period game with a linear pricing rule, the unique linear equilibrium consists of imperfect competitors trading aggressively in each period, in a manner analogous to their behaviour in a single period Nash equilibrium. This competition among informed traders causes prices to be more informationally efficient and alleviates information based manipulation. The model could be applied to explain intra-day phenomena such as the temporal variation in the adverse selection component of the bid – ask spread (measured by the adverse price impact of trades). For example, if long-lived information arrives during non-trading hours, then the model suggests that informed traders will concentrate
their trading at the opening of the market and therefore adverse selection problem will be most severe at the beginning of the day.

Kerry Back (1992)\textsuperscript{14} formalises and extends the continuous time version of the Kyle model. In the Kyle model, uniqueness of equilibrium has been established only within the linear class and for elliptical distributions and in contrast to the no expected trade theorem (which states that conditional on the total order, the market makers' expectation of the informed order is always zero in equilibrium), the expected informed order is proportional to the total order in equilibrium. The main result of the article is that there is a unique equilibrium in which the pricing rule of market makers is a strictly monotone function of the cumulative order and satisfies a certain finite variance condition.

Mark Bagnoli and Naveen Khanna (1992)\textsuperscript{15} uses a standard signaling model in which the manager of the firm possesses better information than the market and chooses an observable action by the firm such as issuing securities, repurchasing shares, announcing special dividends, going public or making a takeover attempt. The manager is permitted to voluntarily trade in the firm's stock after the competitive market makers and noise traders have observed the action. The manager will trade only when he expects to profit from doing so, causing a market maker to sell (buy) more shares when the manager believes that their value exceeds the offer price (is less than the bid price).

Benabou, R. and G. Laroque (1992)\textsuperscript{16} shows that many types of insiders have both the ability and the incentives to manipulate public information and asset prices through strategically distorted announcements or forecasts. There are three kinds of informed agents whose announcements influence prices - first is the journalist who writes a financial column and can trade directly or through namesakes; second is the guru who
issues forecasts or newsletters but is also in the business of trading for his own account or some investment firm and third is the corporate executive who owns or trades stock in his company and by the very nature of his job, periodically makes prospective reports to stockholders and financial analysts.

Gerard, B. and V. Nanda (1993)\textsuperscript{17} provides a model in which strategic informed traders short sell a firm's stock just prior to a seasoned equity offering in order to cause downward price pressures on the stock and then the manipulators will more than cover their positions by purchasing stocks in the offering at a reduced price.

Chatterjea Arkadev, Cherian Joseph A. and Jarrow Robert A. (1993)\textsuperscript{18} reviews the purposes for which a corporate manipulates its shares strategically viz. to maximise its share price and to prevent its shares from being manipulated by others.

Steve Thel (1994)\textsuperscript{19} has offered three reasons for why manipulation is a form of fraud - (a) rational informed traders have no interest in affecting the market price and would always try to buy at the lowest price available and sell for the highest (b) market participants should be able to look at reported prices as a reflection of transactions between players who trade stock for investment purposes i.e. buy at the lowest price possible and sell at the highest (c) bids placed for the purpose of raising (or depressing) the price of a stock, by buying (or selling) above (or below) the lowest (or highest) price possible mislead these price takers.

Cherian Joseph A. and Jarrow Robert A. (1995)\textsuperscript{20} has classified market manipulation trading strategies as follows. (a) \textit{Information based manipulation} - The prices of securities are manipulated by trading strategically based on inside information or after spreading false rumours. (b) \textit{Trade based manipulation} - The prices of securities are
manipulated by buying or selling stocks without taking any actions or possessing any special information. (c) *Action based manipulation* - The prices of securities are manipulated by actions that change the actual or perceived value of the stock price. The distinctions among the 3 different categories of manipulation are not always obvious but are nonetheless useful.

Mark Bagnoli and Barton L. Lipman (1996) presents a model in which a bid may be made in order to profit from the takeover announcement effect. A large trader announces a takeover bid to manipulate the target corporate’s shares and initiates a bidding by taking a substantial position in the stock, thereby causing an appreciation in share price as the market cannot identify if the bid is serious. The manipulator then sells his holdings at a profit and drops the bid. The effect depends crucially on the ex ante probability that the target is considered by a potential bidder. This may be referred to as the level of takeover activity and viewed as a measure of the number of agents who have both the capital to mount a takeover bid and the credibility to have the bid taken seriously relative to the number of targets.

Kose John and Ranga Narayanan (1997) studies the impact of the trade disclosure rule on the dynamic trading behaviour of corporate insiders and shows that the disclosure rule creates incentives for an informed insider to manipulate the stock market by sometimes trading in the wrong direction (i.e. buying when there is bad news or selling when there is good news about a firm). Insiders are defined by the Securities and Exchange Act 1934, as officers, directors and beneficial owners of more than 10% of any class of equity securities. Rule 10b-5 of the Act made insider trading and other schemes intended to defraud in connection with the purchase and sale of securities illegal. Section 16(a) of the
Act, called the trade disclosure rule, requires the insiders of a firm to report periodically any equity transactions they conduct to the regulator. Section 16(b), known as the short swing profit rule, requires insiders to return to the firm any profits made from a round trip transaction in the firm’s stock (a buy – sell or a sell – buy) within a six month period. Section 16(c) of the Act prohibits insiders from short selling their firm’s stock.

Gerald T. Garvey, Simon Grant and Stephen P. King (1998) considers a model which highlights the potential value of indexing an executive’s compensation to remove the influence of short-term stock price movements, but shows why this value may be illusory. The possibility of the manager having private information about the firm’s prospects is allowed and the case where the manager can simply announce her information to the market is considered. It is shown that indexation is impossible in this case because the manager will ‘talk down’ her firm – manipulate the short term share price and so artificially raise perceptions of her long-term value added. The manager will inform the truth in equilibrium, but only because her incentive contract will effectively ignore short-term stock price information.

Cherian Joseph A. and Kuriyan Vikram J. (1998) investigates the possibility of information-less market manipulation by way of large trading volumes and in the presence of an intermediary akin to the market makers of U.S. capital markets and presents a model with positive feedback traders (who submit trades in the direction of current price movements) in which the price process responds to the entire order flow processed by the market maker, in consistence with a number of models of equilibrium market microstructure, as opposed to just the manipulator’s trades.
Archishman Chakraborty and Bilge Yilmaz (1999)\textsuperscript{25} considers a model of strategic trading by an insider called the dynamic trader who may have long lived private information about the expected future returns of the asset being traded or may be uninformed. Further, the market makers or price-setters also do not know if the insider has traded at all i.e. if the insider exists. There are a number of other traders in the market, called followers who have superior information when compared to the market makers in that they know if the insider has traded, although they do not know if the insider has any information and what the nature of his information is. Due to this informational advantage over the market makers, the followers will find it profitable to mimic the trades of the insider.

Archishman Chakraborty and Bilge Yilmaz (1999)\textsuperscript{26} shows that in Kyle type of models with one insider trading repeatedly, if the number of periods is large enough, then the equilibrium will involve a non-linear manipulative trading strategy of the insider since, unlike in Kyle’s model, the market faces uncertainty about the existence of the insider and noise trading is bounded. Due to bounded noise trading, some of his trades will be revealed in the long run and if he is trading non-manipulatively, this will also reveal his information and reduce his profits. This leads the insider to manipulate to try and signal that he is not trading on any information, provided there is uncertainty about his existence in the market place.

Fabrice Rousseau (1999)\textsuperscript{27} considers a two-period model and the market is organised as a dealership market where the dealer or market maker sets the prices before the traders’ order submissions. There exist a non-myopic trader with private information of the future asset value (informed trader) and many myopic liquidity traders. The quantity submitted
by the liquidity traders is exogenously fixed and the market maker when facing a trader does not know the trader's identity. This paper determines the market conditions leading to the use of the bluffing strategy (establishing a trend or a bubble with some trades and then trading against this trend) in equilibrium.

Rajesh K. Aggarwal and Guojun Wu (2003) examines various forms of stock market manipulation and their implications for stock market efficiency. Using a unique data set, it has been proved that more illiquid stocks are more likely to be manipulated and manipulation increases stock volatility and also shown that stock prices rise throughout the manipulation period and then fall in the post-manipulation period. Further, prices and liquidity are higher when the manipulator sells than when the manipulator buys. In addition, at the time the manipulator sells, prices are higher when liquidity is greater, consistent with returns to manipulation being higher when there are more information seekers in the market. Also, at the time the manipulator sells, prices are higher when volatility is greater, consistent with returns to manipulation being higher when there is greater dispersion in the market's estimate of the value of the stock. These results suggest that stock price manipulation may have important impacts on market efficiency.

Fang Cai (2003) uses a detailed audit trail transactions dataset to investigate whether market makers in the treasury bond futures market of Chicago Board of Trade, who might have had superior knowledge of customer order flow, exploited such informational advantage in their trading and profited from the weakness of Long Term Capital Management when it had faced binding margin constraints. The term "front running" refers to a situation in which a trader, knowing that an order is about to come in, trades in the same direction before the anticipated order is executed. The front runner plans to
unwind her position afterwards and hopes to profit through the price impact of the expected order. While front running by a trader against his own customers violates the rules of the Commodity Futures Trading Commission, front running based on signals observable in the trading pit about other incoming customer orders is legal.

Asim Ijaz Khwaja and Atif Mian (2003) analyses a unique data set containing all daily trades of each broker in every stock trading on the Karachi Stock Exchange, the main stock exchange in Pakistan. The high level of dis-aggregation in the data has provided compelling evidence to isolate a particular price manipulation mechanism through which brokers cheat the naïve outside investor – when prices are low, colluding brokers trade amongst themselves to artificially raise prices and attract naïve positive feed-back traders; once prices have risen, the former exit leaving the latter to suffer the ensuing price fall. It is found that the principal brokers, who trade primarily on their own or for a few investors in a given stock, earn significantly higher returns than those who act as intermediaries in that stock. The difference in returns is both statistically and economically highly significant and the annualised return on trades done by the principal brokers in a stock is 4% to 8% higher.

Thus, most of the publications portray stock price manipulation in market maker model of the American stock market. Further, almost all the papers analyse the conditions for equilibrium of the market with price manipulation as a characteristic. Stock price manipulation has been studied under various situations like continuous auction, insider trading, asymmetric information, corners, short squeezes, imperfect competition, financial signaling, equity offerings, takeover bids, ‘talking down’ the firm, no
information, nested information, bluffing and front running. A seminal article, Vila Jean Luc (1989) uses game theoretic model to study market manipulation. Although manipulators of the stock market use special strategies, like the players in a game, not many papers have used game theoretic concepts to study market manipulation. In spite of the vast literature on the subject, there is still a lot of scope for in-depth study of manipulation of prices in the stock market, using the concepts of stochastic calculus, game theory and information theory.

(B) PRICE DISCOVERY IN SECURITIES MARKET
Examination of price discovery and hedging efficiency of futures market is as old as the futures market itself. Starting from the late 1970’s, there has been a lot of research on the price discovery efficiency of commodity futures market, currency futures market and equity futures market in various developed and developing economies and hence there has been a large number of research articles on the subject. In view of the same, a review of such publications in respect of the Indian markets is in order.

Thiripalraju et al (1999)31 studies price transmission from futures to spot market for the Indian pepper and castor markets, using Garbade - Silber model with a dataset from 1991 to 1996 and concludes that the futures market plays an important role in price discovery.
Singh (2001)32 investigates the price discovery efficiency of commodity futures market in India and finds strong lead lag relationship between the futures and the spot prices.
Thomas and Karande (2002)33 analyses price discovery between spot and futures contracts in India’s castor seed markets at Ahmedabad and Mumbai, using Garbade
Silber model with daily data for the period May 1985 to December 1999. It is found that in the Mumbai market, futures market prices dominate spot market prices in all contracts except one, whereas in the Ahmedabad market neither the futures market nor the spot market dominates in price discovery.

Sahadevan (2002) evaluates the efficiency of Indian agricultural commodities futures markets in price discovery and finds that the futures markets are not efficient since the futures prices are not an unbiased predictor of the future ready rates and that the futures exchanges fail to provide an efficient hedge against the risk emerging from the volatile prices of many farm products on which they carry on futures trading.

Vipul (2005) has observed that futures contracts are under-priced which may result into misleading information regarding the prospective moves in the cash market, which in turn may damage the interest of the traders. It has also been observed that due to existence of co-integration, both the markets may be in dis-equilibrium in the short-run but such deviations are corrected through arbitrage process.

Praveen D.G. and Sudhakar A. (2006) highlights how the commodity futures market influences the spot market and facilitates better price discovery, in India. It has been found that the spot and / or futures market dominates the price discovery, but it appears that a better price discovery occurs when there is a mature futures market for the commodity. Using Granger causality test on the Indian stock and commodity markets, a comparison is drawn for price discovery between the grown stock market and the growing commodity market.

Kapil and Balwinder (January 2006) investigates the hypothesis that the market for futures contracts on Nifty equity index of National Stock Exchange of India Limited
(NSEIL) effectively serves the price discovery function in the underlying spot market. Johansen's co-integration, Vector error correction model and Generalized impulse response analysis are applied to test the hypothesis on daily data from NSEIL. Bilateral causality is observed between Nifty index and Nifty futures. The evidence supports the hypothesis, suggesting that the futures market in India is a useful price discovery vehicle. Kakati and Kakati (2006) examines price dynamics between spot and futures prices and also informational content of the basis (whether information revealed by the basis has a signaling role in determining the direction of change in spot and futures prices), using daily prices of futures contracts on Nifty index, CNX IT index and ten individual stocks traded on National Stock Exchange of India Limited. No evidence has been found to assert that futures prices lead spot prices on a day-to-day basis. It appears that information is mostly aggregated in the spot market and then transmitted to the futures market. For longer lag periods, bi-directional causality with moderate feedback has been noticed. It is found that the basis reveals the direction of changes in futures prices and to a much less extent, that of spot prices.

Sah and Kumar (2006) observes that futures contracts on the equity index Nifty significantly leads the price movement in cash market of National Stock Exchange of India Limited (NSEIL), which may play key role in the risk transfer process from cash market to futures market.

Kapil and Balwinder (December 2006) investigates the price discovery and hedging efficiency of the futures contracts on the equity index Nifty and some individual stocks traded on NSEIL for the period November 2001 to June 2006, using Vector Auto-Regression and finds significant evidence that futures market leads cash market, which
implies that futures market is an efficient price discovery vehicle. Further, hedge ratio has been estimated using EGARCH (1,1) model.

M.T. Raju and Kiran Karande (2003)41, applying error correction model to daily closing values of the equity index Nifty in the cash market and the futures contract on Nifty, in National Stock Exchange of India (NSEIL) over the period June 2000 — October 2002, concludes that information gets reflected first in the derivatives market segment.

Thus, many of the publications pertain to the commodities markets in India and analysis has been made using Garbade – Silber model or error correction method, in almost all the articles. Both the approaches involve construction of simultaneous linear equations relating the price levels in the spot and the futures markets and thus study only linear relationships between the two markets whereas financial time series are known to have non-linear characteristics also.

(C) INTERACTIONS BETWEEN STOCK AND OTHER MARKETS

The study about co-movement of the general price level in the stock market and the exchange rate of the currency of a country has gained considerable interest among financial economists since the mid-1990’s and there has been many publications on the topic after the financial crisis of the east Asian countries during 1997 – 98. Some important articles on the interactions between stock and forex markets of various economies are given below.
Golaka C. Nath and G. P. Samanta (2003) has used Granger causality test in Vector Auto Regression framework and Geweke’s feedback measures on daily data of the exchange rate of Indian Rupee vis-à-vis USA Dollar and Nifty, the stock price index of NSE (National Stock Exchange of India) for the period from April 1993 to March 2003 and found that Granger causality test did not point much impressive causal relationship between returns in the two markets though there was evidence of strong causal relationship in some specific financial years, whereas Geweke’s feedback measures detected strong bi-directional and contemporaneous causal relationship between returns in these markets.

Huzaimi Hussain and Venus Khim-Sen Liew (2004) has used Granger causality test, Sim causality test and Geweke causality test on daily data of Kuala Lumpur Stock Exchange Composite Index and Stock Exchange of Thailand Index and exchange rates of Malaysian Ringitt and Thai Baht vis-à-vis US dollar for the period July 1997 – August 1998 and found that

- there was uni-directional causality from exchange rate to stock prices in Thailand
- there was feedback relationship between exchange rate and stock prices in Malaysia
- the fall in Thailand currency had been transmitted to Malaysian currency via the close ties between the stock markets of the two countries, during the 1997 currency crisis.

Rizwan Tahir and Ahmed Abdul Ghani (2004) has used Granger causality test on monthly data of stock price index of Bahrain stock market and exchange rates of Bahraini Dinar vis-à-vis Great Britain Pound, Deutsche Mark and Japanese Yen (since Bahraini Dinar is pegged to US dollar) and found no relationship between stock prices and
exchange rate vis-à-vis Deutsche Mark and also uni-directional causality from stock prices and exchange rate vis-à-vis Great Britain Pound and Japanese Yen.

- during the pre-Euro period, that stock prices uni-directionally Granger caused exchange rate in Hungary and that mutually reinforcing interactions between exchange rates and stock prices existed in the Czech Republic and Poland
- during the Euro period, that exchange rates uni-directionally Granger caused stock prices in all the three nations

Naeem Muhammad and Abdul Rasheed (2004) has used Granger causality test on monthly data of stock price indices and exchange rates for 4 Asian nations viz. Pakistan, India, Bangladesh and Sri Lanka and found no evidence of short run association between these variables in any of the 4 nations but found bi-directional long run relationship in Bangladesh and Sri Lanka.

Daniel Stavarek (2004) has used vector error correction modeling and standard Granger causality test on monthly data of effective exchange rates and standard national indices of Morgan Stanley Capital International, pertaining to USA and eight European Union member countries and found predominantly uni-directional causality from stock prices to exchange rates in countries with developed capital and foreign exchange markets (old European Union member countries and USA), which was stronger than in the new European Union member countries.
Tahir M.F. and Wong Wing Keung (2006) has used Granger causality test on monthly data of exchange rate of Pakistan Rupee vis-a-vis USA dollar and the main and sectoral indices of Karachi Stock Exchange and found evidence in favour of portfolio balance model i.e. uni-directional causation of stock prices to exchange rate.

W.N.W.Azman-Saini, M.S.Habibullah, Siong Hook Law and A.M.Dayang-Afizzah (2006) has used Granger non-causality test, proposed by Toda and Yamamoto (1995), on daily data of Kuala Lumpur Stock Exchange Composite Index and exchange rate of Malaysian Ringitt vis-a-vis USA dollar for the period January 1993 – August 1998 and found that both stock and forex markets were not efficient since there was feedback relationship during the pre-crisis period and that there was uni-directional causality from exchange rate to stock prices during the crisis period.

Benjamin M.Tabak (2006) has used Granger causality test and impulse response functions on daily data of Sao Paulo Stock Exchange Index and the exchange rate of Brazilian Real vis-a-vis US dollar and found evidence supporting the portfolio balance approach after devaluation of the domestic currency, however using non-linear causality test it has been found that changes in exchange rate cause stock price changes.

Hooi Hooi Lean, Paresh Narayan and Russell Smyth (2006) has used Granger causality test in a panel data framework on weekly data of stock price indices and nominal exchange rates for 8 Asian nations and found no evidence of a long run equilibrium relationship between the exchange rate and the stock prices.

Sangeeta Chakravarty (2006) has used Granger non-causality test proposed by Toda and Yamamoto (1995), on monthly data of 5 macro-economic variables pertaining to
India and stock price index of Bombay Stock Exchange for the period from April 1991 to December 2005 and found no causal relation between stock prices and exchange rate.

Paresh Kumar Narayan (2007) has used several variants of EGARCH model on daily data of exchange rate of Indian Rupee vis-à-vis USA Dollar and stock price index of BSE (Bombay Stock Exchange) for the period January 1992 to September 2006 and found that over the entire period depreciation had reduced mean returns and an appreciation of the rupee during 2002 – 2006 had increased mean returns and reduced volatility.

Thus, most of the publications have used Granger causality analysis which studies only linear relationships between any two variables.

Apparently, not many studies have analysed the dynamical relationship between the stock and the commodities markets in India. V.Shanmugam and D.G.Prasad (2007) has analysed 2 years data of crude oil prices in the Multi-Commodity Exchange of India (MCX) and the 30 stock index Sensex of Bombay Stock Exchange (BSE), India using regression analysis and found that an increase in crude oil price has led to a fall in the Sensex. In this article, it has also been reported that the equity prices of a few base metal companies and the associated metal futures prices in MCX are highly correlated.

**IMPORTANCE OF THE STUDY**

(a) The Indian stock market has undergone a sea change over the last ten years. The rapid expansion of electronic trading, the almost complete dematerialisation of securities, the
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smooth shift to rolling settlements, the implementation of a tighter settlement cycle (aimed at T + 1 settlement) and the formation of settlement guarantee fund have tilted the market system in favour of investors. The challenge now towards systemic improvement is to clamp down on price manipulation and trading based on inside information.

Securities and Exchange Board of India (SEBI), the market regulator has framed code of conduct for stock brokers vide SEBI (Stock brokers and sub-brokers) Regulations 1992 which stipulates, inter alia, that a stock broker shall not indulge in manipulative, fraudulent or deceptive transactions or schemes or spread rumours with a view to distort market equilibrium or make personal gains. SEBI has also put in place regulations like SEBI (Prohibition of insider trading) Regulations 1992, SEBI (Substantial acquisition of shares and takeovers) Regulations 1997 and SEBI (Prohibition of fraudulent and unfair trade practices relating to securities market) Regulations 2003, to prevent manipulation of the stock market. Further, stock exchanges have framed rules prescribing strict disciplinary action against brokers who are found to have indulged in market manipulation and price rigging. Therefore there is an imminent need for effective tools to filter potential manipulation cases. In this context, testing the suitability of entropy in this area will serve a great purpose towards ensuring market integrity.

(b) Identification of causal relationships between the equities and the derivatives segments of the stock market furthers the understanding of the market's internal dynamics and has a lot of implications, for all the participants of the market. In case causal relationship exists between the two market segments, unexpected changes in
equities and derivatives prices will be more correlated. This will improve risk transfer function of derivatives market and reduce arbitrage opportunities and further, the direction of causality serves as a guide to choose the dynamic relationship model between equities and futures prices. In case there is no causal relationship between the two markets, hedging results in non-trivial risk exposure to hedgers, however market players may diversify their portfolios across markets. Existing studies using linear models, have generally observed that price innovations appear first in the derivatives market and are then transmitted to the equities market. Hence analysis of such relationship using non-linear measures like entropy is expected to enhance our understanding of the price dynamics in the two segments.

(c) Interactions between the stock and the forex markets of a country have many implications for not only the domestic participants of the markets but also foreign investors. If exchange rate leads stock prices, then crisis in stock market can be prevented by controlling the exchange rate. Moreover, developing nations may exploit such interaction to attract foreign portfolio investment in their nations. If stock prices lead exchange rate, then policy makers can focus on domestic economic policies to stabilise the stock market. If there is feedback in both the directions, then investors may predict the behaviour of one market using information on the other market. If the markets are not related, investors may reduce risk exposure by diversifying their portfolios across the markets. Existing studies using linear models have arrived at mixed results such as stock market leading forex market or the other way and also, no relationship between the two markets. Non-linear analysis of the lead – lag relationship between the two markets in
India is likely to throw more light which may facilitate decision making regarding the policy requirements in order to attract more foreign investment for sustaining the growth of the Indian economy.

Interactions between the stock and the commodities markets of a country have many implications for not only the participants of the markets but also for the policy makers and the producers of the commodities and, in the case of developing nations, for the economy as a whole. If price discovery in commodities derivatives market is caused by the stock market, agricultural policy may be designed using such causal relationship. Similarly, pro-active steps may be taken to face any shortages or gluts in a commodity which are revealed in futures market in advance. Absence of relationship may be used to diversify investment portfolios across markets. There are not many studies regarding the relationship between the stock and the commodities markets of India and the existing studies have used only linear methods to analyse the relationship. Hence the dynamics of information transfer between the stock and the commodities markets in India may be studied using entropy, which captures non-linear dynamic relationship also, in order to facilitate better understanding of the relationship between these markets.

**OBJECTIVES**

The objectives of the study are as follows.

(A) To verify the suitability of entropy as a tool for studying price manipulation in the Indian stock market
(B) To study price discovery mechanism between the equities and the derivatives segments of the Indian securities market using the non-linear invariant entropy

(C) To analyse interactions between the stock market and other markets like foreign exchange market and commodities derivatives market of India, using entropy.

METHODOLOGY

(A) PRICE MANIPULATION IN INDIAN STOCK MARKET

For the study of manipulation in stock prices, generally, variation in the price quoted for purchase or sale of a security by the market participants, from the mean price levels is considered. For investigating into potential manipulation cases, stock exchanges maintain surveillance systems which monitor trading activities of the participants in the various securities and throw alerts based on intra-day price movements and abnormal trade quantities. For this purpose, the following measures of variation are used generally.

(a) Price variation in a security = \( \frac{(LTP - CP) \times 100}{CP} \)

where LTP = last trade price of the security

CP = previous closing price defined as the weighted average price of all the trades in the security during the last ½ hour of the previous trading day.

(b) High-low variation in a security = \( \frac{(HP - LP) \times 100}{CP} \)

where HP = highest price at which the security is traded during a day

LP = lowest price at which the security is traded during a day

CP = previous closing price of the security
(c) Consecutive trade price variation in a security = \( \frac{(LTP - PTP) \times 100}{PTP} \)

where LTP = last traded price of the security

PTP = price of the trade immediately preceding the last trade

(d) Quantity variation in a security = \( \frac{(TQ - AQ) \times 100}{AQ} \)

where TQ = total traded quantity in the security during a day

AQ = average traded quantity in the security during the last n days

It may be noted that although a trading pattern which crosses the limits stipulated for such variations may be identified on-line, there may be many manipulative trading patterns well within the stipulated limits which will go undetected. Further, these measures of variation identify only linear relationships. Hence advanced techniques are required to detect complex manipulative strategies involving non-linear relationships also. In this context, the non-linear invariant of entropy appears to be a suitable tool to study manipulation of stock prices since entropy is concerned about the irregularity or disorder in a system.

The matter may be approached also through the recent developments in game theory. It has been already observed that Vila Jean Luc (1989) has used game theoretic concepts to study the equilibrium of a stock market subject to price manipulation. Further, Ronald B.Shelton (1997)\(^5\) has portrayed the stock market as a game and studied about pay-offs resulting from the strategies chosen by the players, based on the risks involved in the
strategies. Before examining as to how the concepts applied in studying games may be used in the analysis of stock price manipulation, let us assess the stock market as a game.

There is a finite set of players in a game. Every player has a set of strategies and a real valued payoff function depending on the strategies chosen by the players. A game may be a one-stage game, a finitely repeated game or an infinitely repeated game. If the players know all past actions of all the players and the outcomes of all the past actions, then the game is said to be of perfect information. The action space of a player consists of his pure strategies. The more complex entity that chooses among the pure strategies at random in various proportions is called a mixed strategy. It is assumed that when a player uses mixed strategies, he is interested in his average return and does not care about his maximum possible gain or loss. The justification for this is the basic premise of utility theory, which states that one should evaluate a payoff by its utility to the player rather than its numerical monetary value.

The stock market may be considered as a finitely repeated game with many players. A stock exchange maintains an electronic order book that receives all orders placed by the market participants (players) for buying / selling securities. The orders may be placed at various prices for various quantities of any security. These orders result into trades as per pre-specified matching algorithms. Every player has pure strategies in the form of placing a buy order or sell order for a quantity of a security at market price or limit price, as considered justifiable by the player. Further, mixed strategies like placing successive orders quoting a range of prices / quantities and placing both buy and sell orders, may be
used by the players. As long as the players place their orders spontaneously based on their information, near equilibrium prices will prevail depending on demand and supply factors apart from the fundamental features of the securities.

However, a player or a group of players may choose strategies which are correlated and may result in creating artificial demand / supply thereby leading to skewed prices. For the players to generate the correlation, the game may have to pass through many stages. Those opponents with so less information as not to observe such correlation, will find the skewed prices much to their disadvantage in terms of utility value of their payoff. The strategies are so distributed as to conceal the correlation from the weak opponents. For example, a group of players may place orders for buying and selling small quantities of a security successively at monotonically increasing prices although there is no natural demand / supply in respect of the security and thus create an artificially high price for the security. Those who do not have perfect information so as to recognise the correlation in the strategies will be lured to choose buy strategy, in successive stages at skewed prices disadvantageous to them. After the group of players sell all their store of the security in a few stages, there will not be any supply of the security and then the weak players against whom concealment of correlation was orchestrated, will be laden with large quantities of the security for which there will not be any demand in the market.

The presence of online correlation in the strategies of a few players of a game, which is concealed from the other players, has been studied by a few researchers, in the context of laboratory games. A path-breaking article, Gilad Bavly and Abraham Neyman (2003)
presents the feasibility of online correlation in the strategies adopted by a group of players in a repeated game, which is concealed from a player with less information. It has been shown that the best response of a player to the concealed and correlated actions of his opponents is not guaranteed to yield an expected payoff as large as his individually rational payoff. Further, the notion of strategic concealment is defined using information theoretic terminology and the conditions for the existence of such concealment have been stated in terms of entropy of the strategies adopted by the players. It may be noted that entropy is defined for the probability mass or density function of a random variable and that a mixed strategy being a probability distribution on the set of all pure strategies available to a player, entropy of the mixed strategies of the players in a game is defined naturally.

However, these studies have not covered the presence of online correlation in the trading strategies of the players in a stock market game. Those who are involved in price manipulation in the stock market may act in collusion with a few other players or may act in seclusion. They distribute their trading strategies in the successive stages in such a way that they appear random to the other players. However a concealed correlation is orchestrated in the distribution of the successive strategies. The entropy of such a distribution will be different from that of the distributions which do not have such correlation built-in by the players. Hence the concept of entropy is a prospective technique to study potential manipulation in stock prices.
Thus considering the stock market either as a non-linear dynamical system or as a game, we find entropy as an appropriate method to identify possible manipulation in stock prices. In the electronic stock trading system, as market participants place orders for buying or selling a security at different prices and for various quantities, trades are effected by matching these orders according to price – time priority. A security’s price is expected to change from time to time based on the fundamental factors of the security, its past history and the demand for the security. The prices at which, the times at which and the quantities for which, orders are placed by a participant, are expected to be in accordance with the prevalent market conditions and towards investment / speculative purpose. As the information related to and the perception on the price of a security change with time, a participant assigns values to the variables – price, time and quantity - with some probabilities, while placing orders. Hence order price, time and quantity in respect of a security may be construed as random variables with probability distributions.

Since the computation of entropy of a random variable requires its probability mass function, we may compute the entropy of the random variables of order price, order time and order quantity in respect of a security for every participant, if only we can fit a probability distribution for each of these variables. For any security, the only publicly available information are trade price, trade time and trade quantity, for all trades on any day and without the identity of the participants who are parties to the trades. Hence fitting probability mass or density function for the order placement strategies adopted by each of the participants is not possible. However, considering trade price, trade time and trade quantity, for all trades in a security on any day as variables, we have time series of these
variables for any trading day. Different versions of entropy like sample entropy, are available to compute the entropy of such time series and we may compute the sample entropy of these time series for successive trading days. So long as a participant places orders in the normal course of business, the entropy values of these variables will be in some ranges. Just as volatility of price differs from security to security and from time to time, entropy also will vary from security to security, depending on the trading activity.

However, when a market participant repeatedly places orders for buying / selling a security according to some pattern in the price or time or quantity, with a motive of manipulating the price of the security, the probability distributions of these variables undergo changes which will get reflected in the corresponding entropy values. Further, such orders placed for manipulating the stock market will induce more regularity or persistence in the distributions and consequently entropy is likely to decrease. Large decrease in the entropy value from usual ranges may lead to potential evidence of price manipulation by a participant. Of course, regularity of such nature may occur by chance rarely. However, repeated drops in the entropy values of the variables of a security in a span of a few trading days point to likely manipulation in the price of the security.

In this study, 3 securities which were reported to have been subject to manipulation are considered, sample entropy of the time series of the prices of all trades in each security for every trading day during the period of manipulation is computed and the values are analysed to identify any indication of price manipulation.
The temporal relationship between the equities and the derivatives segments of the securities market in various countries has been studied by identifying lead – lag relationship between the value of a representative index of the equities market and the price of a corresponding index futures contract in the derivatives market. Various methods have been proposed for the analysis of the set of simultaneously recorded variables - stock index value and index futures price - over a period of time and it has been generally observed that price innovations appear first in the derivatives market and are then transmitted to the equities market. Early studies of such price discovery have generally used cross-correlation and cross-spectrum, with time delay in the observations pertaining to one market segment, in order to facilitate identification of the direction of information flow. Garbade and Silber model and Granger's causality model have been introduced subsequently and have been used in a number of studies examining the source of price discovery. These two approaches involve estimation of simultaneous linear equations in a pair of variables with time lags.

Since relationship between financial variables include non-linear characteristics also, it is required to estimate the information exchange between financial time series, using non-linear methodology. An information theoretic measure called transfer entropy which quantifies the exchange of information between two non-linear dynamical systems, has been introduced recently. This has been used by researchers for studying the relationship between the US and German stock markets and also for studying information flow among groups of stocks traded in New York Stock Exchange. In this study, price discovery in
Indian securities market is analysed using transfer entropy, with high frequency data. Two time series – value of 50 stock index of the equities market of the National Stock Exchange of India Limited viz. Nifty and price of the near month Nifty index futures contract traded in the derivatives market of the exchange – with minute-wise data over the period October 2005 – September 2006 are formed since day-wise data may not be meaningful in the context of fast communication and information dissemination technology available now-a-days. Transfer entropy is computed between the two series in both the directions – from equities market to derivatives market and from derivatives market to equities market – and the computed values are interpreted using the notions of net information flow, normalised directionality index and relative explanation added.

(C) INTERACTIONS BETWEEN STOCK AND OTHER MARKETS OF INDIA

(i) The interactions between the stock market and the foreign exchange market of developing and developed nations has been studied by identifying lead – lag relationship between the value of a representative index of the stock market and the exchange rate of the local currency vis-à-vis US dollar or the currency of a developed economy. Researchers have used various methods and mostly, the error correction model to study such relationship and arrived at mixed results such as stock market leading forex market or the other way and also, no relationship between the two markets. All these methods study only linear relationship and hence in this study, it is proposed to use transfer entropy to identify interaction, if any, between the stock market and the foreign exchange market of India.
The 50 stock index of the National Stock Exchange of India Limited viz. Nifty and the Reserve Bank of India (RBI) reference rate for the Indian Rupee vis-à-vis US Dollar are taken as representatives of the stock market and the forex market of India, for identifying causal relationship, if exists. The daily values of these two variables over the period from November 1995 to March 2007 are taken as two time series and transfer entropy between the two series is computed. Considering the important developments in the two markets, the period under study is divided into 3 sub-periods and transfer entropy is computed for each sub-period separately, to study the interactions between the two markets in view of the developments. Further, net information flow, normalised directionality index and relative explanation added are computed from the transfer entropy values, to gain more insight into the relationship between the two markets in India.

(ii) Linear regression has been used in existing studies to analyse the relationship between the stock and the commodity markets in India and hence it is proposed to use the non-linear measure of transfer entropy to identify causal relationship, if any, between the two markets in India. The 50 stock index of the National Stock Exchange of India Limited viz. Nifty, the near month futures contract on the Nifty index, the index of commodities spot prices NCDEXAGRI launched by the National Commodity & Derivatives Exchange Ltd. (NCDEX) and the index FUTEXAGRI constructed on the basis of online prices of the nearest month expiry futures contracts traded in NCDEX are taken as the representatives of the stock, the stock derivatives, the commodities spot and the commodities derivatives markets in India, for studying the relationship among these markets. The daily values of these variables over the period from June 2005 to September 2007 are taken as four time series. Transfer entropy is computed between these series,
taken two at a time and the computed values are interpreted using net information flow, normalised directionality index and relative explanation added.

LIMITATIONS

The value of sample entropy depends on 2 parameters - the template size m and the tolerance limit r - they are not to be assigned arbitrarily but m is to be chosen on the basis of minimum mutual information of the trade price time series so as to enhance the independence of the templates to a large extent and r is to be chosen on the basis of minimum relative error of sample entropy so as to reduce the variance of the entropy estimate to a large extent. The study of price manipulation in the stock market has been done using trade related data since order related data are not available publicly. It may be noted that all the orders placed by a potential manipulator may not result in trades and thus order related data will carry more information than trade related data. Hence entropic analysis of order related data (if available) will ensure more efficiency in filtering potential manipulation cases. Further, if there are too few trades on any day in a scrip i.e. if the time series pertaining to any day is too short, say, with less than 25 trades, then sample entropy may not be defined for that day.

It may be noted that in the study of causal relationship, entropic analysis does not provide a model revealing the relationship between the variables under study but estimates a value for the same. Further, the value of transfer entropy, as such does not convey much information and deduced measures like net information flow, directionality index and real
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It may be noted that in the study of causal relationship, entropic analysis does not provide a model revealing the relationship between the variables under study but estimates a value for the same. Further, the value of transfer entropy, as such does not convey much information and deduced measures like net information flow, directionality index and real
explanation added are required to interpret the results. Moreover, in the computation of transfer entropy, determination of the appropriate partition of the data series and the block length of the transferee time series, has to be done with utmost care. \( T_{Y \rightarrow X}(k,l) \) is a non-increasing function of the block length \( k \) of the series \( X \), since inclusion of more number of past observations in the variable \( X \) is likely to result in reduction of flow of information from \( Y \) in the estimation of the next value of \( X \). The parameter \( k \) is to be chosen as large as possible in order to find an invariant value for \( T_{Y \rightarrow X} \), however due to the finite size of real time series, it is required to find a reasonable compromise between unwanted finite sample effects and a high value for \( k \). Further, a very small value of \( k \) may lead to misinterpretation of information contained in past observations of actually both series as an information flow from \( Y \) to \( X \) and hence \( k \) may be chosen as large as possible. A good choice for \( k \) is such that contiguous templates of size \( k \) constructed from the time series are not within the neighbourhood of one another. Such a choice is provided by the value of \( k \) corresponding to which the mutual information of the time series with delay \( k \) viz. \( I(k) \) is small and consequently the contiguous templates are independent to a large extent. As \( k \) is increased, \( I(k) \) decreases and may rise again and hence the first minimum of \( I(k) \) may be considered to choose the value of \( k \).

**CHAPTERISATION**

The thesis is divided into six chapters.

- The INTRODUCTION chapter portrays the backdrop in which this study is made and points out the relevant importance this study carries. This chapter also spells out the
objectives of the study and reviews the existing literature on the subject. Further, this chapter includes a description of the methodology adopted in this study and the limitations of this study.

- The second chapter THEORETICAL FRAMEWORK OF ENTROPY explains the concept and the basics of entropy theory and also provides an account of the development of the theory.

- In the third chapter PRICE MANIPULATION IN INDIAN STOCK MARKET—CASE STUDIES, the suitability of sample entropy as a tool to filter potential manipulation cases is illustrated by way of 3 case studies.

- PRICE DISCOVERY IN INDIAN SECURITIES MARKET forms the fourth chapter in which lead – lag relationship between the equities and the derivatives segments of the Indian securities market is studied using transfer entropy.

- The fifth chapter INTERACTIONS BETWEEN STOCK AND OTHER MARKETS OF INDIA applies transfer entropy to study non-linear dynamical relationship between the stock market on the one side and the foreign exchange and the commodities markets on the other side.

- The concluding chapter SUMMARY OF FINDINGS AND SUGGESTIONS presents a brief summary of the findings of the study and a list of suggestions for policy making and also for the investing community. The scope for further research has been included in this chapter.
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