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Efficiency of Indian ADRs and their underlying stocks: An Adaptive Market Perspective from Nonlinear Models

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Abstract: This paper is aimed at examining the efficiency of Level II/III Indian ADRs and their underlying stocks trading in Mumbai from a nonlinear univariate perspective. For this purpose, we consider the ADRs and the underlying stocks pertaining to Dr. Reddy's Laboratories, HDFC Bank, ICICI Bank, Infosys, Wipro, Tata Motors, and Sterlite Industries. We employ the windowed as well as the rolling hinich bicorrelation test procedures in an attempt to seek answers to hitherto-unanswered questions pertaining to Indian ADRs. Findings indicate that the degree of efficiency of all US/Indian scrips considered for this study is heterogeneous in nature and thereby warrant a ranking approach in each trading location. At a granular level, in the case of US, Infosys ADR and Sterlite Industries ADR were found to be more efficient than the overall US stock market (S&P 500). Similarly, in the case of India, Infosys, Wipro, Tata Motors scrips were found to be more efficient than the overall Indian stock market (Nifty). Further, the degree of efficiency of dually-listed stocks such as, and limited to, Dr. Reddy's Laboratories, HDFC Bank, Wipro, and Tata Motors, was found to be homogenous across trading locations, while the degree of efficiency of dually-listed stocks such as, and limited to, ICICI Bank, Infosys and Sterlite Industries, were found to lack homogeneity across trading locations. The collective take-away from this study is two-fold in nature. Firstly, the degree of market efficiency witnessed at the level of individual scrips differs considerably from the degree of efficiency of the broader stock market in which such scrips trade. Secondly, the degree of efficiency witnessed in certain (not all) dually-listed scrips considered for this study was found to be homogenous across trading locations. However, this does not happen to be the case for all other dually-listed scrips considered for this study.

Key Words: Bicorrelation, ADR, India

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Efficiency of Indian ADRs and their underlying stocks: An Adaptive Market Perspective from Nonlinear Models

1. Introduction & Literature Review

One of most widely researched area in the field of finance is market efficiency. Market efficiency can be broadly classified into three categories, namely weak form, semi-strong form and strong form efficiency. Should the asset prices exhibit weak form efficiency, then the past history of asset prices is immaterial when it comes to predicting future asset prices. Put differently, the past history of asset prices is already impounded in the current asset price, and the consequently, the best predictor of future price happens to be the current price of the asset. Earlier studies on market efficiency using conventional statistical tests such as unit root tests, runs test, and autocorrelation test supported the prevalence of weak form market efficiency. For a review of the early literature in support of market efficiency, refer to Fama, 1970. In due course of time, studies disputing market efficiency took shape. A major catalyst behind such studies was the realization that preliminary studies on market efficiency limited their focus on exploring linear relationships and in the process failed to explore the possibility of higher order dependence. In addition, the October 1987 crash forced both academicians and practitioners to revisit the presumption of market efficiency. The seminal work by Hinich & Paterson (1985), which showed that NYSE stock returns exhibit nonlinear dependence, was the tipping point that opened the gateway to subsequent scholarly excursions on market efficiency from nonlinear perspective. Other early studies that challenged the notion of market efficiency include Poterba & Summers, 1988; Fama & French, 1988; and Lo & MacKinlay, 1988.

Following Hinich & Patterson's seminal work, nonlinearity in developed markets was examined extensively in the literature.[2] The broader takeaways from the burgeoning literature on nonlinearity of asset prices are as follows. Firstly, of all the markets studied so far, US stock market happens to be the most efficient. Secondly, efficiency per se is no longer viewed as a static phenomenon. In other words, market efficiency is likely to evolve over time owing to a variety of factors such as, but not limited to, evolution of market microstructure, enhancement in investor base, changes in the nature and breadth of investment avenues, and establishment of regulatory institutions. This is in line with the Adaptive Market Hypothesis (AMH) put forth by Lo (2005). Grounded in evolutionary biology, AMH offers an overarching intellectual gateway that helps in reconciling conflicting perspectives held by the advocates and challengers of EMH. To be specific, markets are characterized by long periods of efficient behaviour, punctuated by short unexpected bursts of nonlinear dependence. Put

[2] See for example, Abhyankar et al., 1995; Hsieh, 1991; Kosefeld and Robe, 2001; Lima, 1998; Lim & Hooy, 2013; Opong et al., 1999; Scheinkman & LeBaron, 1989; Solibakke, 2005; and Willey, 1992. In addition, empirical examination of nonlinearity in emerging markets paved way for scholarly works such as, but not limited to, Afonso & Teixeria, 1998; Alagidede, 2011; Ammermann & Patterson, 2003; Cinko, 2002; Dorina & Simina, 2007; Hassan et al., 2003; Hiremath & Kamaiah, 2010; Lim & Brooks, 2009; Lim et al., (2008a and 2008b); Lim & Hinich, 2005; Mishra et al., 2011; Madhavan, 2014; Panagiotidis, 2005; Poshakwale, 2002; Romero-Meza et al., 2007; Scheicher, 1999; and Seddighi & Nian, 2004.

simply, long periods of tranquillity coupled with short bursts of turbulence happens to be a stylized fact that is witnessed in developed and emerging stock markets.

But for the studies by Hinich & Patterson (1985), Poshakwale (2002), Ammerman & Patterson (2003), and Madhavan (2014) an overwhelming portion of the above cited studies explore nonlinearity in national stock indices. The central intent behind such explorations is to garner insights on avenues for portfolio diversification at aggregate level for international investors. This paper breaks away from this aggregate trend and in the process examines the nature of nonlinearity in Level II / III American Depositary Receipts issued by Indian companies, and in the process searches for any discernable difference in the degree of efficiency exhibited by of Indian ADRs listed in NYSE/NASDAQ, their underlying Indian stocks listed in Mumbai, the broader US and Indian stock market indices, as indicated by discernable difference (if any) of the nature of nonlinearity exhibited by each of these time series.

American Depositary Receipts, which are negotiable instruments issued by non-US companies in US stock markets, serve as an avenue for international diversification for American investors. The different types of ADRs available in the market place are Rule 144A, Level I, Level II, and Level III ADRs. Rule 144a ADRs is traded only among qualified institutional buyers in PORTAL system, while Level I ADRs are traded in OTC market. Level II and III ADRs are listed in American stock exchanges such as NYSE, NASDAQ, and AMEX. Firms intent on issuing level II and/or level III ADRs are required to register with Securities and Exchange Commission (SEC) and meet all reporting requirements. Further firms that are intent on raising capital from American investors in US stock market would have to issue level III ADRs, since level II ADRs cannot be used as a conduit to do so.

Prominent strands of literature on ADRs include the following major strands:

a) the reasons behind the issuance of ADRs by foreign entities[3];
b) the search for evidence amidst ADRs and their underlying securities that support law of one price[4];
c) the stock price behaviour around the event date listing of ADRs in US markets[5];
d) the performance of ADRs as an investment instrument for portfolio diversification[6];
e) the effect of information content of ADR listing on global stock market integration or segmentation[7]; and
f) the adverse nonlinear impact of ADRs on the local index of the market wherein the originating firms reside.[8]

[3] Errunza & Miller, 2000; Baker et al., 2002; Pagano et al., 2002.
[4] Alaganar & Bhar, 2001; Kim et al., 2000; Ji, 2003; Kato et al., 1991; Maldonado & Saunders, 1983; Park & Tavakkol, 1994; Wahab et al., 1992; Chung et al., 1992; Chen et al., 2008
[5] Foerster & Karolyi, 1999, 2000; Jayaraman et al., 1993; Miller, 1999; Sundaram & Logue, 1996
[6] Choi & Kim, 2000; Jiang, 1998; Officer and Hoffmeister, 1987; & Wahab and Khandula, 1993
[7] Alexander et al., 1988; Domowitz et al., 1998; Webb et al., 1995; Fang & Loo, 2002
[8] Chen et al., 2011

A common phenomenon that underlines all of the above cited scholarly excursions is the employment of multiple time series at a time, such as, but not limited to the ADR, the underlying stock, the US stock market index, the foreign stock market index, the pertinent exchange rate, the pertinent industry and world indices at local and global levels so as to understand the return generating mechanisms of ADRs, the underlying dynamics behind all such time series considered, and the implications of such findings for portfolio diversification & market segmentation.

The central intent behind this paper is to step away from this multivariate approach that is methodologically grounded on law of one price, and in the process test for the nature of nonlinearity in ADRs and their underlying stocks, and identify discernable differences (if any) in the degree of efficiency exhibited by the individual ADRs, the underlying stock trading in Mumbai, the broader US market index and the broader Indian stock index, as evidenced by differences (if any) on the nature of nonlinearity exhibited by the different times series considered for this study, using the windowed as well as the rolling procedure of Hinich portmanteau bicorrelation test.

In light of the prevalence of law of one price amidst ADRs and their underlying stocks; and the perception of relative inefficiency of emerging markets, the findings of this paper could shed some light to the following questions:

a) Is there any discernable difference in the degree of efficiency exhibited by the firm-level ADRs and the broader US market?
b) Is there any discernable difference in the degree of efficiency exhibited by underlying stocks trading in Mumbai and the broader Indian stock market?
c) Is there any discernable difference in the degree of efficiency exhibited by the different ADRs considered for this study and their respective underlying stocks trading in Mumbai, notwithstanding discernable difference in the degree of efficiency exhibited by the broader US (S&P 500) and Indian (Nifty) stock markets?

The answers to these questions could help our understanding of the econometric manifestation of market efficiency at the level of individual scrips (ADRs in the case of US, and underlying stocks in the case of India) as opposed to the broader market index, and in the process bring to light, discernable differences (if any) when it comes to efficiency and evolving efficiency of the different time series considered for this study namely, the individual level II/III ADRs issued by Indian companies; the underlying stocks trading in Mumbai; and the broader US and Indian stock market indices.

2. Data

Daily closing prices pertaining to level II and level III ADRs issued by Indian companies, their underlying stocks trading in Mumbai, and the US national stock index (S&P 500) were downloaded from finance.yahoo.com, while daily closing prices pertaining to the Indian national stock index (Nifty) was downloaded from www.nseindia.com. A snapshot of the different ADRs considered for this study is made available in table 2.1. Missing values were imputed using linear interpolation. Table 2.2 contains detailed descriptive statistics pertaining to the different time series considered for this study. Each of the time series considered for this study was found to be I(1) at levels/logarithmic levels, while logarithmic returns of all the time series were found to be I(0). Figures 2.1 and 2.2 constitute the line plots of the different time series considered for this study.

[Insert Tables 2.1 and 2.2, and Figures 2.1 and 2.2 here]

3. Econometric Methodology

The windowed procedure of Hinich bicorrelation test has been employed by many researchers, such as, Brooks (1996), Brooks & Hinich (1998), Lim & Hinich (2005), Lim et al. (2005 & 2008a), and Bonilla et al. (2006 & 2008), so as to examine the nonlinear behaviour exhibited by a wide variety of assets classes such as ten daily sterling exchange rates, ten European exchange rates, fourteen Asian stock market indices, seven Latin American stock indices, and ten Latin American emerging market bonds. Further, the rolling procedure of hinich bircorrelation test has been applied by Lim (2007) and Lim et al. (2008b) so as to rank the market efficiency of global stock markets and to investigate the impact of the 1997 financial crisis on stock market efficiencies of eight Asian stock markets respectively.

We now describe the windowed procedure of Hinich bicorrelation test, otherwise called as H test in the literature. Let $\{x(t_k)\}$ denote the sampled data process, wherein time t is an integer. The test procedure employs non-overlapping time windows. If n is the length of each window, then kth window would be $\{x(t_k), x(t_k+1), x(t_k+2), x(t_k+3),\ldots., x(t_k+n-1)\}$ and the window after that would be $\{x(t_{k+1}), x(t_{k+1}+1), x(t_{k+1}+2), x(t_{k+1}+3),\ldots., x(t_{k+1}+n-1)\}$, where $t_{k+1} = t_{k+1} + n$. Let Z(t) denote the standardized observations obtained as follows

$$Z(t) = \frac{x(t) - m_x}{s_x}$$

for each t = 1,2,3,…, n, where m_x and s_x is sample mean and standard deviation respectively of each window.

The null hypothesis for each window is that x(t) are realizations of a stationary pure noise that has zero bicorrelation. Thus, under null hypothesis, the correlations $C_{zz}(r) = E[Z(t)Z(t+r)]=0$ for all $r \neq 0$ and the bicorrelations $C_{zzz}(r,s) = E[Z(t)Z(t+r)Z(t+s)]=0$ for all r,s except for r=s=0. The alternative hypothesis is that the underlying process in the window possesses nonzero correlations or bicorrelation for $0<r<s<L$ where L is the number of lags that define the window. Put differently, should there exist a second-order linear or third-order nonlinear dependence in the underlying data generating process, then $C_{zz}(r) \neq 0$ or $C_{zzz}(r,s) \neq 0$ for atleast one r or one pair of r and s values respectively. The r sample correlation coefficient is shown below.

$$C_{zz}(r) = (n-r)^{-1/2} \sum_{t=1}^{n-r} Z(t)Z(t+r)$$

The C statistic developed to test for existence of non-zero linear dependence within a window and its corresponding distribution is shown below.

$$C = \sum_{r=1}^{L} [C_{zz}(r)]^2 \sim \chi_L^2$$

The sample bicorrelation coefficient is defined as follows

$$C_{zzz}(r,s) = (n-s)^{-1} \sum_{t=1}^{n-s} Z(t)Z(t+r)Z(t+s) for\ 0 \leq r\ \leq s$$

The H statistic developed to test for existence of non-zero bicorrelation within each window and its corresponding distribution is as follows.

$$H = \sum_{s=2}^{L} \sum_{r=1}^{s-1} G^2(r,s) \sim \chi_{L(L-1)/2}^2$$

Where $G(r,s) = (n-s)^{1/2} C_{zzz}(r,s)$.

The number of lags L is specified as $L=n^b$ with $0<b<0.5$, wherein b is the parameter under choice by the user. Based on their outcomes pertaining to Monte Carlo simulations, Hinich & Patterson (2005) recommended the usage of b value of 0.4, as doing so would maximize the power of test, while ensuring a valid approximation of the asymptotic theory. Another input that needs to be decided by a researcher while employing the windowed procedure of hinich bicorrelation test is the length of the window. The larger the length of the window, the larger would be the number of lags employed, and consequently the greater would be the power of the test. Having said so, larger window length increases the uncertainty on the event time when serial dependence occurs. In short, the window length should be sufficiently long enough to validly apply bicorrelation statistic and yet short enough for the data generating process to remain roughly constant (Brooks & Hinich, 1998).

Rejection of null hypothesis of pure white noise, when subjecting a time series to hinich bicorrelation test, could be reflective of linear and/or nonlinear dependence exhibited by the time series. In order to remove the impact of linear dependence on hinich bicorrelation test outcomes, the time series is initially subjected to an AR filter. The AR-filtered residuals obtained from this prewhitening procedure is then subjected to windowed or rolling procedure of the hinich bicorrelation test. Further, it has to be noted that, unlike other popular nonlinearity tests such as the BDS test that calls for AR-GARCH filtering of the time series on hand so as to explore the possibility of non-multiplicative (additive) nonlinearity, the hinich bicorrelation test possesses proper asymptotic size in the event of the underlying time series exhibiting GARCH effects. This precludes the need for researchers to employ a GARCH filter before employing the hinich bicorrelation test.

Unlike the windowed hinich bicorrelation test procedure that calls for division of underlying time series into non-overlapping moving samples of equal length, the rolling hinich bicorrelation test procedure warrants fixed-length moving sample that moves one observation at a time.

4. Findings

4.1 Preliminary prewhitening procedure

To start with, we employ an AR filter so as to remove in any linear dependence in all the logarithmic returns of all time series considered for this study. The optimum number of lags for the AR filter were initially arrived at, based on Akaike Information Criterion (AIC). Subsequently, the C statistic pertaining to each of AR-filtered residuals is determined. Should any of the AR-filtered residuals exhibit residual linear dependence, as indicated by significant C statistic, efforts were undertaken by we to employ an higher order AR filter based on Ljung Box test so as to remove all residual linear dependence in the AR-filtered residuals.

4.2 Windowed hinich bicorrelation test outcomes

AR-filtered residuals obtained from the above prewhitening procedure were then subjected to windowed hinich bicorrelation test wherein each of the prewhitened time series were divided into equal but non-overlapping moving time windows of 35 observations each. Subsequently, the H statistic pertaining to each of the windows pertaining to all prewhitened time series is determined. Prevalence of a significant H statistic in few of the many non-overlapping moving windows is reflective of episodic nonlinearity in asset prices. The windowed bicorrelation test outcomes pertaining to the different US (Indian) scrips considered for this study is shown in table 4.1 (4.2).

[Insert Tables 4.1 and 4.2 here]

Test outcomes made available in tables 4.1 and 4.2 reveal the heterogeneous nature of nonlinearity exhibited by the different US and Indian scrips considered for this study. To be more specific, the degree of nonlinearity, as evidenced in the percentage of non-overlapping equally-sized windows with significant H statistic, that is exhibited by the individual US/Indian scrips is not quite the same as the degree of nonlinearity exhibited by the broader stock market index (S&P 500/Nifty). Further, windowed hinich bicorrelation test outcomes reveal that certain scrips, such as Sterlite Industries ADR and Infosys ADR in the case of US and Tata Motors and Infosys stocks in the case of India, are far more efficient than their respective national stock market index (S&P500 / Nifty).

4.3 Rolling bicorrelation test outcomes

Having examined the heterogeneous nature of nonlinearity exhibited by scrips trading in US and India, we then employed the rolling bicorrelation test procedure. Unlike the windowed bicorrelation test procedure, which warrants splitting the prewhitened time series into equally spaced, non-overlapping moving windows; the rolling hinich bicorrelation test accommodates for the possibility of evolving efficiency in much shorter horizons. Put differently, the rolling bicorrelation test procedure calls for a fixed-length moving sample approach that moves one observation at a time. Subjecting a moving sample to hinich bicorrelation test, reveals the evolving efficiency of the underlying prewhitened time series as evidenced by the time-varying trajectory of the H statistic at each point of time.

We computed the time-varying H statistic in a rolling window of 35 observations. In line with precedence in literature (Lim, 2007), the H statistics generated at different points of time were transformed into a percentile, which is 1 – p value. For instance, should the H statistic of a window be found to be significant at 5 % level, then the p value is bound to be lower than 0.05. Consequently the transformed H statistic will be above 0.95. As a result, a transformed H statistic value that is higher than 0.95 and much closer to one would indicate acute nonlinear serial dependence of the underlying time series.

Annexures one to four constitute the line plots of the transformed H statistic obtained for each of the time series considered in this study. These line plots, which reveal the time-varying tendency of the H statistic, pinpoint to the inadequacy of studies that characterize market efficiency as a static phenomenon that remains unchanged over time. In order to garner a better idea of the distribution of thousands of scrip-wise H statistics generated over time, detailed scrip-wise descriptive statistics of transformed H statistics is made available in table 4.3.

[Insert Table 4.3 here; Also View Annexures one to four at this juncture]

4.4 Ranking US and Indian scrips in the order of efficiency

As seen in table 4.3, all scrip-wise H statistics generated over time indicate skewness towards right, coupled with a kurtosis value that is less than three. In other words, the distribution of scrip-wise H statistics generated over time, as rightly pointed out by the Jarque-Berra test outcomes, is non-normal in nature. In light of the non-normal nature of scrip-wise H statistics generated over time, we follow the approach undertaken by Lim (2007), and consequently rank the different US and Indian scrips considered for this study, from highly efficient one to the least efficient one, using the median of scrip-wise H statistics generated. Tables 4.4 and 4.5 show the ranking of the different US and Indian scrips considered for this study, based on the median of rolling H statistics.

[Insert tables 4.4 and 4.5 here]

In the case of US, Infosys ADR and Sterlite Industries ADR are more efficient than the overall US stock market (S&P 500). Similarly, in the case of India, Infosys, Wipro, and Tata Motors scrips are more efficient than the overall Indian stock market (Nifty). Further, of all the different time series considered for this study, Infosys scrip happens to be the most efficient both in US and in India. Having said so, this seemingly-universal attribute of Infosys scrip on the efficiency front is not generalizable. To be specific, while Sterlite Industries ADR happens to be more efficient than the broader US market (S&P 500), the Sterlite Industries stock trading in Mumbai is the most inefficient of all scrips considered in this study. Finally, a broader take-away from tables 4.4 and 4.5, is the higher efficiency of US stock market as a whole (S&P 500) in comparison to its Indian counterpart (Nifty).

A notable criticism with respect to ranking markets/scrips on the efficiency front based on median of time-varying H statistics, is that the median per se, is not a true reflection of the thousands of scrip-wise time-varying H statistics generated as part of the rolling procedure. Further, ranking different markets/scrips based on such a singular measure would offer a biased perspective of the relative state of efficiency of different markets, which in turn, would run counter to the fundamental objective of rolling hinich bicorrelation procedure. Consequently, Lim (2007) offered a meaningful alternative measure aimed at ranking the different markets/scrips on the efficiency front, which is the percentage of significant H windows measure. The proportion of significant H windows for a highly efficient market would be far less than that of an inefficient market, which is likely to be punctuated with frequent nonlinear episodes.

Tables 4.6 and 4.7 show the ranking of the different US and Indian scrips considered for this study, based on the percentage of significant H windows measure. These findings are more or less in the same lines as the earlier scrip-wise findings based on median H statistic measure that were made available in tables 4.4 and 4.5.

[Insert Tables 4.6 and 4.7 here]

4.5 Testing for homogeneity of scrip-wise efficiency within a trading location

In light of the non-normality of scrip-wise H statistics generated over time, non-parametric tests for equality of median H statistic were employed so as to examine the homogeneity of the efficiency exhibited by the US and Indian scrips. Test outcomes made available in table 4.8 rejects the null hypothesis of equality of median H statistics amidst the different US scrips considered for this study. Similarly, test outcomes made available in table 4.9 rejects the null hypothesis of equality of median H statistic amidst the different Indian scrips considered for this study. Put differently tables 4.8 and 4.9 show that the scrip-wise efficiency rankings based on median H statistic is meaningful in nature. Further, the degree of efficiency of all US/Indian scrips considered for this study is heterogeneous in nature and thereby warrants a ranking approach in each trading location.

[Insert tables 4.8 and 4.9 here]

4.5 Testing for homogeneity of efficiency of dually-listed stocks

Finally efforts were undertaken by we to test for any discernable difference in the degree of efficiency exhibited by the different ADRs considered for this study and their respective underlying stocks trading in Mumbai, notwithstanding discernable difference in the degree of efficiency exhibited by the broader US (S&P 500) and Indian (Nifty) stock markets. Findings obtained in this regard are made available in table 4.10.

[Insert table 4.10 here]

It is interesting to note that the nonparametric test outcomes indicate equality of median H statistic for ADR-Underlying Stock pairs pertaining to (a) Dr. Reddy's laboratories and HDFC Bank scrips at 5% significance level and (b) Wipro and Tata Motors scrips at 1% significance level. In other words, the degree of efficiency of dually-listed stocks such as, and limited to, Dr. Reddy's Laboratories, HDFC Bank, Wipro, and Tata Motors, as captured by the median H statistic, is found to be homogenous across trading locations. However, this attribute is not generalizable across all the dually-listed scrips considered for this study. To be specific, test outcomes made available in table 4.10 reveal inequality of median H statistic for ADR-Underlying Stock pairs pertaining to ICICI Bank, Infosys and Sterlite Industries. In other words, the degree of efficiency of dually-listed stocks such as, and limited to, ICICI

Bank, Infosys and Sterlite Industries, as captured by the median H statistic, is found to lack homogeneity.

5. Conclusion

The central intent behind this study was to examine the efficiency of Level II/III Indian ADRs and their underlying stocks trading in Mumbai from a nonlinear univariate perspective. Prior research works that employed time-varying non-linear serial dependence measures were centered on ranking the efficiency of the global stock markets based on degree of nonlinearity exhibited by the different national stock indices. Outcomes pertaining to such studies indicate the heightened level of efficiency of US stock market coupled with relative inefficiency of emerging markets such as India. We of this study break away from this aggregate trend and examine the evolving efficiency of Indian DRs that are listed in most efficient trading location, namely the US. In doing so, we seek to answer the following hitherto-unanswered questions. Firstly, is there any discernable difference in the degree of efficiency exhibited by the firm-level ADRs and the broader US market? Secondly, is there any discernable difference in the degree of efficiency exhibited by underlying stocks trading in Mumbai and the broader Indian stock market? Finally, is there any discernable difference in the degree of efficiency exhibited by the different ADRs considered for this study and their respective underlying stocks trading in Mumbai, notwithstanding discernable difference in the degree of efficiency exhibited by the broader US (S&P 500) and Indian (Nifty) stock markets?

The study's findings indicate that the degree of efficiency of all US/Indian scrips considered for this study is heterogeneous in nature and thereby warrant a ranking approach in each trading location. At a granular level, in the case of US, Infosys ADR and Sterlite Industries ADR were found to be more efficient than the overall US stock market (S&P 500). Similarly, in the case of India, Infosys, Wipro, Tata Motors scrips were found to be more efficient than the overall Indian stock market (Nifty). Further, of all the different time series considered for this study, Infosys scrip happens to be the most efficient both in US and in India. Having said so, this seemingly-universal attribute of Infosys scrip on the efficiency front is not generalizable across all other scrips. To be specific, while Sterlite Industries ADR happens to be more efficient than the broader US market (S&P 500), the Sterlite Industries stock trading in Mumbai is the most inefficient of all scrips considered in this study.

Also, efforts undertaken by us to test for any discernable difference in the degree of efficiency exhibited by the different ADRs considered for this study and their respective underlying stocks trading in Mumbai, notwithstanding discernable difference in the degree of efficiency exhibited by the broader US (S&P 500) and Indian (Nifty) stock markets, yielded nuanced results. To be specific, the degree of efficiency of dually-listed stocks such as, and limited to, Dr. Reddy's Laboratories, HDFC Bank, Wipro, and Tata Motors, was found to be homogenous across trading locations (US and India), while the degree of efficiency of dually-listed stocks such as, and limited to, ICICI Bank, Infosys and Sterlite Industries, were found to lack homogeneity across trading locations.

Apart from addressing certain hitherto-unanswered questions we started with, the study’s findings also throws light on the long road ahead for researchers, who are intent on garnering a deeper perspective of market efficiency. This is because; the study’s findings indicate that the degree of market efficiency witnessed at the level of individual scrips differs considerably from the degree of efficiency of the broader stock market in which such scrips trade. Further, degree of efficiency witnessed in certain (not all) dually-listed scrips considered for this study was found to be homogenous across trading locations. However, this does not happen to be the case for all dually-listed scrips considered for this study. For instance, notwithstanding the heightened efficiency of Infosys scrip in comparison to all other scrips considered for this study in US as well as in Indian market place, the degree of efficiency exhibited by Infosys ADR and its underlying Indian share trading in Mumbai fail to exhibit homogeneity. The above-stated findings bring to light the need for granular, disaggregated, firm-level market efficiency studies aimed at (a) examining firm-level market efficiency at different trading locations and (b) identifying the antecedents behind divergences/similarities in firm-level market efficiency across different trading locations.

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Table 2.1: A snapshot of the different ADRs considered for this study

S. No.	DR Issue	Capital Raised	DR: Shares Ratio	Industry	Effective Date	Time period considered for this study
1	Dr. Reddy's Laboratories	Yes	1:1	Pharmaceuticals & Biotechnology	Apr 24,2001	1/2/2002 to 10/31/2013
2	HDFC Bank	Yes	1:3	Banks	Jul 25,2001	1/2/2002 to 10/31/2013
3	ICICI Bank	Yes	1:2	Banks	Mar 31,2000	1/2/2002 to 10/31/2013
4	Infosys	Yes	1:1	Software & Computer Services	Mar 16,1999	1/2/2002 to 10/31/2013
5	Sterlite Industries	Yes	1:4	Industrial Metals & Mining	Jun 22,2007	6/22/2007 to 10/31/2013
6	Wipro	Yes	1:1	Software & Computer Services	Oct 24,2000	1/2/2002 to 10/31/2013
7	Tata Motors	No	1:5	Industrial Engineering	Sep 27,2004	9/27/2004 to 10/31/2013

Table 2.2: Descriptive statistics of daily logarithmic returns

		Number of Observations	Mean	Median	Maximum	Minimum	Standard Deviation	Skewness	Excess Kurtosis	Jarque-Berra (JB) Statistic	JB Sig. Level
Dr. Reddy's Laboratories	ADR	3086	0.0002	0.0005	0.1399	-0.6944	0.0242	-7.8106	222.4075	6391766.4726	0.0000
	Underlying Stock	3086	0.0003	0.0000	0.1195	-0.7029	0.0228	-9.6973	296.4543	11348934.4065	0.0000
HDFC Bank	ADR	3086	0.0003	0.0005	0.2104	-1.6044	0.0397	-21.2594	861.9320	95760454.3991	0.0000
	Underlying Stock	3086	0.0009	0.0000	0.2189	-0.2310	0.0204	0.2333	13.3414	22914.9643	0.0000
ICICI Bank	ADR	3086	0.0007	0.0004	0.2621	-0.2253	0.0331	0.2385	6.3973	5291.5784	0.0000
	Underlying Stock	3086	0.0008	0.0000	0.2261	-0.2196	0.0271	0.0485	5.9755	4592.5528	0.0000
Infosys	ADR	3086	0.0000	0.0009	0.2104	-0.7388	0.0317	-7.7841	167.9789	3659389.2977	0.0000
	Underlying Stock	3086	0.0006	0.0000	0.1562	-0.3117	0.0218	-1.2433	22.4331	65504.1022	0.0000
Sterlite Industries	ADR	1659	-0.0001	0.0000	0.5207	-0.1881	0.0374	1.5118	26.1171	47782.3234	0.0000
	Underlying Stock	1659	0.0005	0.0000	0.1911	-0.1827	0.0325	0.2316	3.6776	949.7508	0.0000
Wipro	ADR	3086	-0.0004	0.0000	0.3341	-1.0953	0.0372	-10.7790	290.2310	10890848.0731	0.0000
	Underlying Stock	3086	-0.0002	0.0000	0.2015	-1.0908	0.0332	-14.3783	436.4824	24603624.6279	0.0000
Tata Motors	ADR	2373	0.0005	0.0003	0.3195	-0.1934	0.0299	0.5340	9.2014	8484.1373	0.0000
	Underlying Stock	2373	0.0006	0.0000	0.1746	-0.1942	0.0286	-0.0435	4.2503	1786.9058	0.0000
Nifty		3086	0.0006	0.0013	0.1633	-0.1305	0.0152	-0.2706	10.2183	13463.5609	0.0000
S&P 500		3086	0.0001	0.0007	0.1096	-0.0947	0.0128	-0.1924	9.5635	11779.4473	0.0000

Table 4.1: Windowed bicorrelation test results for US scrips

Rank	Scrips	Fitted AR(p) model	Total Number of Non-overlapping Windows	Windows with significant H statistics	Percentage of windows with significant H statistics	Dates of nonlinearities
1	Sterlite Industries ADR	AR(9)	47	1	2.13%	7/15/2011 - 9/1/2011
2	Infosys ADR	AR(6)	88	3	3.41%	2/20/2002 - 2/6/2003; 8/8/2008 – 9/25/2008; 11/14/2008 – 1/1/2009
3	ICICI Bank ADR	AR(13)	87	3	3.45%	12/31/2002 – 2/17/2003; 5/4/2004 – 6/21/2004; 2/5/2008 – 3/24/2008
4	Dr. Reddy's Laboratories ADR	AR(4)	89	6	6.74%	7/24/2002 – 9/10/2002; 11/3/2004 – 12/21/2004; 2/14/2007 – 4/3/2007; 1/23/2008 – 3/11/2008; 11/17/2010 – 1/4/2011; 7/20/2011 – 9/6/2011
5	HDFC Bank ADR	AR(1)	88	6	6.82%	2/22/2002 – 4/11/2002; 4/12/2002 – 5/30/2002; 3/21/2003 – 5/8/2003; 6/27/2003 – 8/14/2003; 4/16/2004 – 6/3/2004; 3/7/2008 – 4/24/2008
6	Wipro ADR	AR(2)	88	6	6.82%	1/12/2004 – 2/27/2004; 1/16/2006 – 3/3/2006; 1/25/2010 – 3/12/2010; 9/5/2011 – 10/21/2011; 2/25/2013 – 4/12/2013; 6/3/2013 – 7/19/2013
7	Tata Motors ADR	AR(13)	67	5	7.46%	12/30/2005 – 2/16/2006; 4/7/2006 – 5/25/2006; 6/22/2007 – 8/9/2007; 3/29/2013 – 5/16/2013; 7/5/2013 – 8/22/2013
8	S&P 500	AR(13)	87	7	8.04%	10/24/2005 – 12/9/2005; 3/29/2010 – 5/14/2010; 8/23/2010 – 10/8/2010; 8/1/2011 – 9/16/2011; 1/21/2013 – 3/8/2013; 3/11/2013 – 4/26/2013; 6/17/2013 – 8/2/2013

Table 4.2: Windowed bicorrelation test results for Indian scrips

Rank	Scrips	Fitted AR(p) model	Total Number of Non-overlapping Windows	Windows with significant H statistics	Percentage of windows with significant H statistics	Dates of nonlinearities
1	Tata Motors	AR(12)	67	3	4.48%	4/6/2006 – 5/24/2006; 6/30/2011 – 8/17/2011; 6/7/2012 – 7/25/2012
2	Infosys	AR(9)	87	5	5.75%	6/12/2002 – 7/30/2002; 3/19/2008 – 5/6/2008; 1/7/2009 – 2/24/2009; 12/16/2009 – 2/2/2010; 2/3/2010 – 3/23/2010
3	HDFC Bank	AR(7)	87	5	5.75%	11/4/2002 – 12/20/2002; 8/2/2004 – 9/17/2004; 4/4/2005 – 5/20/2005; 6/28/2010 – 8/13/2010; 11/26/2012 – 1/11/2013
4	Dr. Reddy's Laboratories	AR(0)	88	6	6.82%	2/21/2002 – 4/10/2002; 1/30/2003 – 3/19/2003; 10/28/2004 – 12/15/2004; 12/21/2006 – 2/7/2007 11/11/2010 – 12/29/2010; 7/14/2011 – 8/31/2011
5	Nifty	AR(13)	87	6	6.90%	11/12/2002 – 12/30/2002; 12/09/2003 – 1/26/2004; 5/4/2004 – 6/21/2004; 7/24/2007 – 9/10/2007; 9/11/2007 – 10/29/2007; 12/18/2007 – 2/4/2008
6	Wipro	AR(1)	88	8	9.09%	2/22/2002 – 4/11/2002; 12/17/2004 – 2/3/2005; 2/4/2005 – 3/24/2005; 4/21/2006 – 6/8/2006; 9/15/2006 – 11/02/2006; 2/9/2007 – 3/29/2007; 4/3/2009 – 5/21/2009; 1/22/2010 – 3/11/2010
7	ICICI Bank	AR(11)	87	9	10.34%	1/18/2002 – 3/7/2002; 6/14/2002 – 8/1/2002; 11/08/2002 – 12/26/2002; 12/05/2003 – 1/22/2004; 3/12/2004 – 4/29/2004; 4/8/2005 – 5/26/2005; 9/7/2007 - 10/25/2007; 1/18/2013 – 3/7/2013; 3/8/2013 – 4/25/2013
8	Sterlite Industries	AR(0)	47	7	14.89%	10/1/2007 – 11/16/2007; 1/7/2008 – 2/22/2008; 2/25/2008 – 4/11/2008; 1/11/2010 – 2/26/2010; 11/1/2010 – 12/17/2010; 4/1/2013 – 5/17/2013; 7/8/2013 – 8/23/2013

Table 4.3: Descriptive statistics of Rolling H statistics

		Number of Observations	Mean	Median	Maximum	Minimum	Standard Deviation	Skewness	Excess Kurtosis	Jarque-Berra (JB) Statistic	JB Significance Level
Dr. Reddy's Laboratories	ADR	3048	0.4196	0.3642	0.9999	0.0000	0.3263	0.3026	-1.2777	253.8490	0.0000
	Underlying Stock	3052	0.4211	0.3745	1.0000	0.0000	0.3103	0.3447	-1.1368	224.7910	0.0000
HDFC Bank	ADR	3051	0.4362	0.3909	1.0000	0.0000	0.3197	0.2626	-1.2728	240.9995	0.0000
	Underlying Stock	3045	0.4409	0.3872	1.0000	0.0000	0.3130	0.3221	-1.1660	225.1581	0.0000
ICICI Bank	ADR	3039	0.3695	0.2892	1.0000	0.0002	0.2987	0.6405	-0.7699	282.8640	0.0000
	Underlying Stock	3041	0.4258	0.3757	1.0000	0.0000	0.3179	0.3308	-1.2229	244.9611	0.0000
Infosys	ADR	3046	0.3189	0.2337	1.0000	0.0000	0.2989	0.7961	-0.5343	358.0057	0.0000
	Underlying Stock	3043	0.3939	0.3118	1.0000	0.0000	0.3221	0.4866	-1.1352	283.4989	0.0000
Sterlite Industries	ADR	1616	0.3537	0.2748	1.0000	0.0000	0.2949	0.5740	-0.9114	144.6869	0.0000
	Underlying Stock	1625	0.5097	0.5058	1.0000	0.0000	0.3320	0.0119	-1.3791	128.8048	0.0000
Wipro	ADR	3050	0.3970	0.3399	1.0000	0.0000	0.3217	0.4072	-1.1957	265.9917	0.0000
	Underlying Stock	3051	0.4073	0.3472	1.0000	0.0000	0.3216	0.3935	-1.1722	253.4025	0.0000
Tata Motors	ADR	2326	0.3845	0.3283	1.0000	0.0001	0.3096	0.4951	-0.9998	191.8961	0.0000
	Underlying Stock	2327	0.3982	0.3550	1.0000	0.0002	0.2937	0.3841	-1.0932	173.1003	0.0000
Rediff.com	ADR	3039	0.4573	0.4116	1.0000	0.0001	0.3309	0.2584	-1.2837	242.4868	0.0000
Sify	ADR	3036	0.3991	0.3585	0.9998	0.0000	0.3144	0.4376	-1.0676	241.0841	0.0000
WNS Holdings	ADR	1858	0.4644	0.4255	1.0000	0.0000	0.3301	0.2275	-1.3029	147.4472	0.0000
Nifty		3039	0.4332	0.3708	1.0000	0.0000	0.3236	0.3886	-1.1767	251.7934	0.0000
S&P 500		3040	0.3733	0.2877	1.0000	0.0001	0.3080	0.5488	-0.9600	269.3132	0.0000

Table 4.4: Ranking of US Scrips using median of Rolling H Statistics

Rank	US Scrips	Median of H Statistics
1	Infosys ADR	0.2337
2	Sterlite Industries ADR	0.2748
3	S&P500	0.2877
4	ICICI Bank ADR	0.2892
5	Tata Motors ADR	0.3283
6	Wipro ADR	0.3399
7	Dr. Reddy's Laboratories ADR	0.3642
8	HDFC Bank ADR	0.3909

Table 4.5: Ranking of Indian Scrips using median of Rolling H Statistics

Rank	Indian Scrips	Median of H Statistics
1	Infosys	0.3118
2	Wipro	0.3472
3	Tata Motors	0.3550
4	Nifty	0.3708
5	Dr. Reddy's Laboratories	0.3745
6	ICICI Bank	0.3757
7	HDFC Bank	0.3872
8	Sterlite Industries	0.5058

Table 4.6: Ranking of US Scrips using Percentage of significant H windows

Rank	Scrips	Total Number of Rolling Windows	Total Number of windows with significant H statistics	Percentage of significant H windows
1	Sterlite Industries ADR	1616	53	3.28%
2	Infosys ADR	3046	117	3.84%
3	S&P 500	3040	173	5.69%
4	ICICI Bank ADR	3039	173	5.69%
5	Wipro ADR	3050	174	5.70%
6	Tata Motors ADR	2326	139	5.98%
7	Dr. Reddy's Laboratories ADR	3048	212	6.96%
8	HDFC Bank ADR	3051	230	7.54%

Table 4.7: Ranking of Indian Scrips using Percentage of significant H windows

Rank	Scrips	Total Number of Rolling Windows	Total Number of windows with significant H statistics	Percentage of significant H windows
1	Tata Motors	2327	62	2.66%
2	Dr. Reddy's Laboratories	3052	185	6.06%
3	Infosys	3043	204	6.70%
4	Wipro	3051	213	6.98%
5	ICICI Bank	3041	214	7.04%
6	HDFC Bank	3045	224	7.36%
7	Nifty	3039	308	10.13%
8	Sterlite Industries	1625	224	13.78%

Table 4.8: Nonparametric tests for equality of median H Statistic amidst US scrips

Method	Degrees of freedom	Value	Probability
Med. Chi-square	7	207.8615	0.0000
Adj. Med. Chi-square	7	206.5546	0.0000
Kruskal-Wallis	7	286.9682	0.0000
Kruskal-Wallis (tie-adj.)	7	286.9685	0.0000
van der Waerden	7	294.2186	0.0000

Table 4.9: Nonparametric tests for equality of median H Statistic amidst Indian scrips

Method	Degrees of freedom	Value	Probability
Med. Chi-square	7	101.6595	0.0000
Adj. Med. Chi-square	7	100.814	0.0000
Kruskal-Wallis	7	181.6864	0.0000
Kruskal-Wallis (tie-adj.)	7	181.6864	0.0000
van der Waerden	7	213.2089	0.0000

Table 4.10: Nonparametric tests for equality of median H Statistic for all ADR - Underlying stock pairs

		Med. Chi-square	Adj. Med. Chi-square	Kruskal-Wallis	Kruskal-Wallis (tie-adj.)	van der Waerden
	Degrees of freedom	1	1	1	1	1
Dr. Reddy's Laboratories ADR-Stock Pair	Value	0.6715	0.6302	0.7354	0.7354	1.5148
	Probability	0.4125	0.4273	0.3912	0.3911	0.2184
HDFC Bank ADR-Stock Pair	Value	0.1476	0.1286	1.0774	1.0774	2.8413
	Probability	0.7008	0.7199	0.2993	0.2993	0.0919
ICICI Bank ADR-Stock Pair	Value	38.8480	38.5290	41.0958	41.0958	29.9593
	Probability	0.0000	0.0000	0.0000	0.0000	0.0000
Infosys ADR-Stock Pair	Value	33.9998	33.7015	97.2170	97.2170	116.0453
	Probability	0.0000	0.0000	0.0000	0.0000	0.0000
Sterling Industries ADR-Stock Pair	Value	115.1889	114.4361	184.4489	184.4490	193.6957
	Probability	0.0000	0.0000	0.0000	0.0000	0.0000
Tata Motors ADR-Stock Pair	Value	3.9168	3.8016	5.8192	5.8192	4.9296
	Probability	0.0478	0.0512	0.0159	0.0159	0.0264
Wipro ADR-Stock Pair	Value	0.4263	0.3935	2.4591	2.4591	5.4543
	Probability	0.5138	0.5304	0.1168	0.1168	0.0195

Figure 2.1: Line plots of time series considered for this study

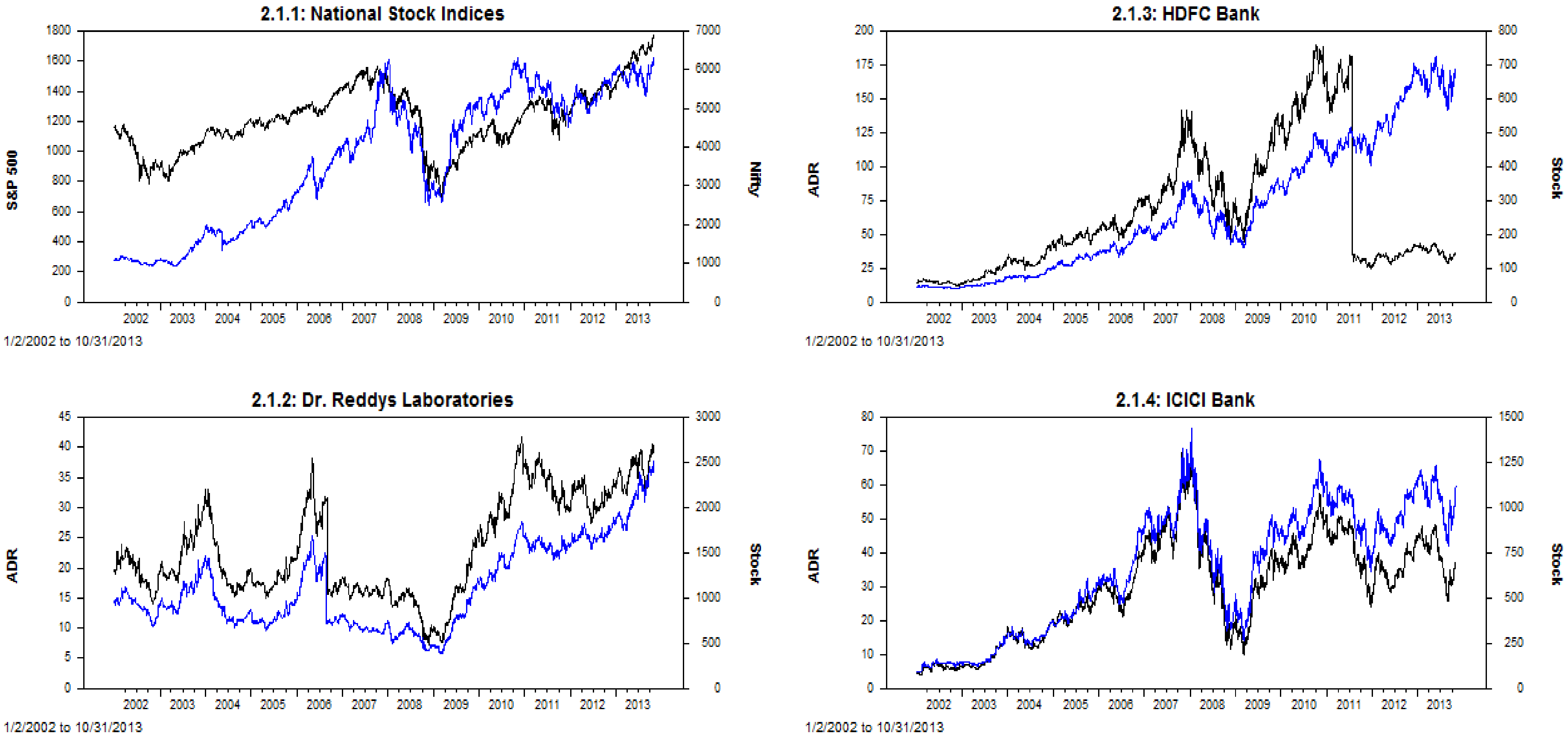
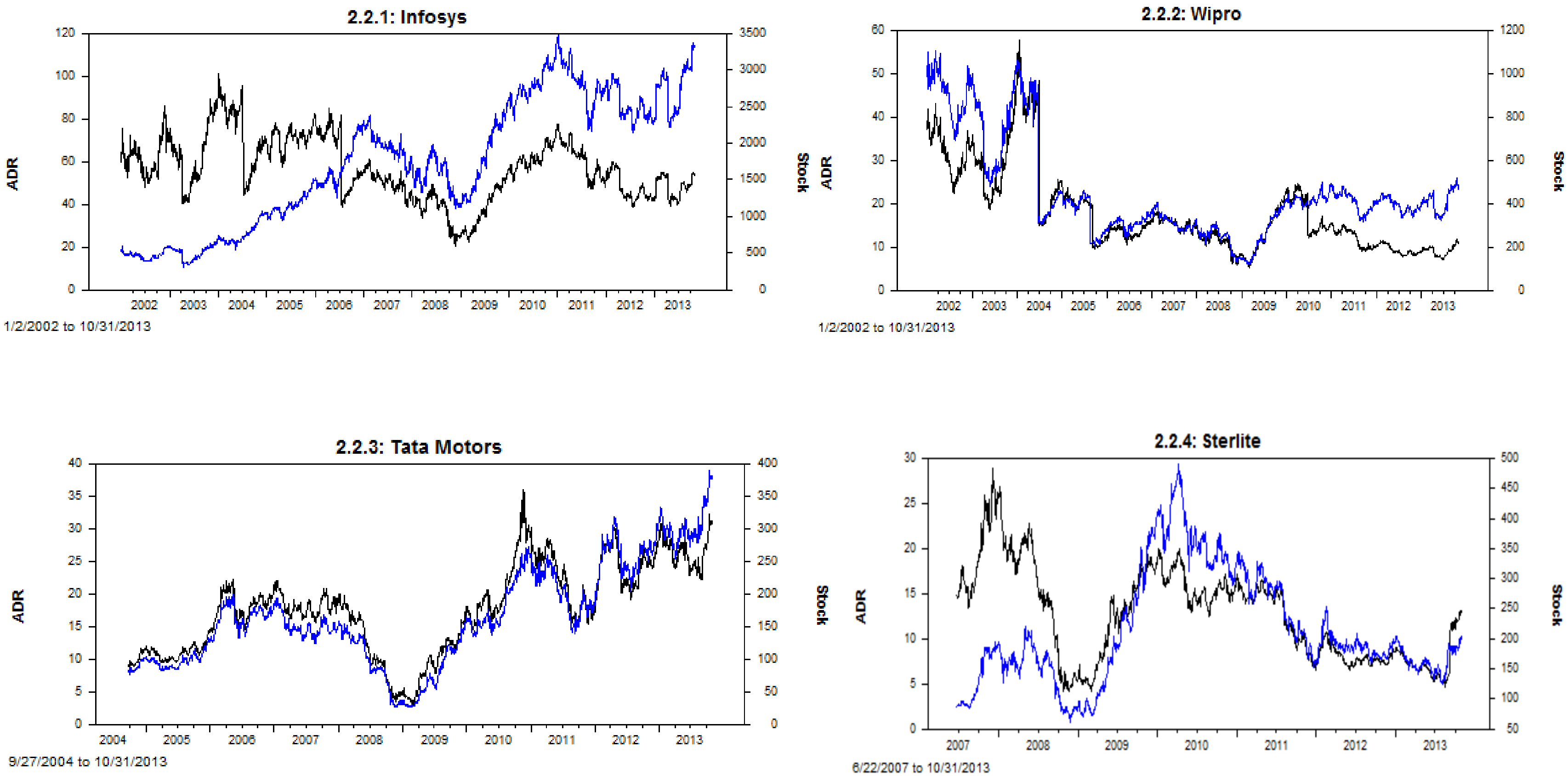
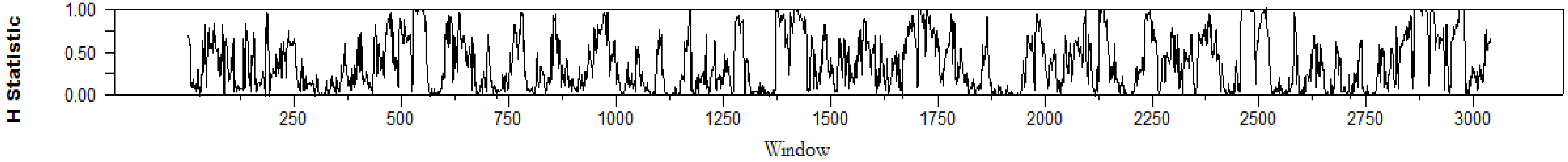


Figure 2.2: Line plots of time series considered for this study

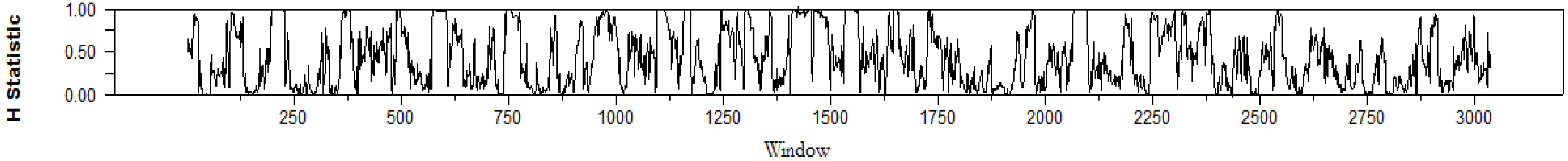


Annexure #1: Rolling H Statistic for S&P 500, Nifty and Dr. Reddy’s Laboratories

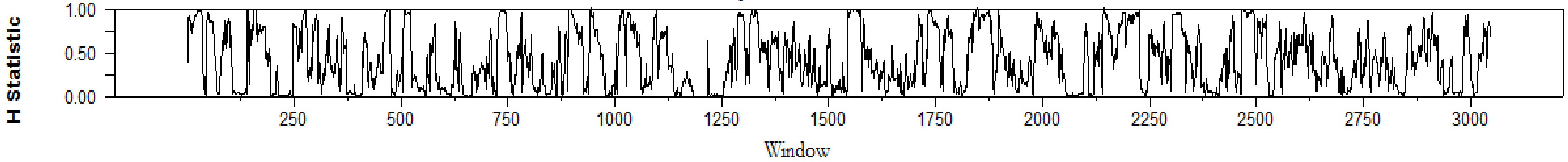
S&P 500



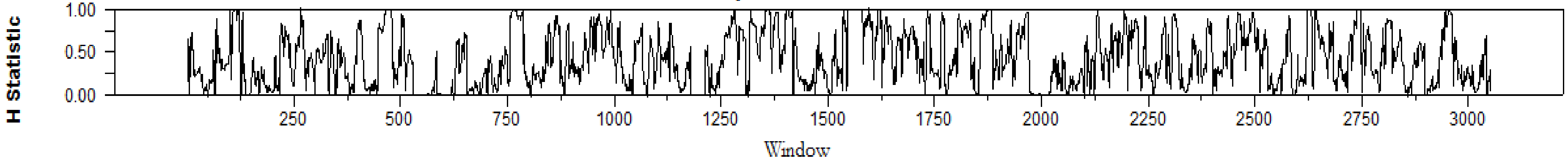
NIFTY



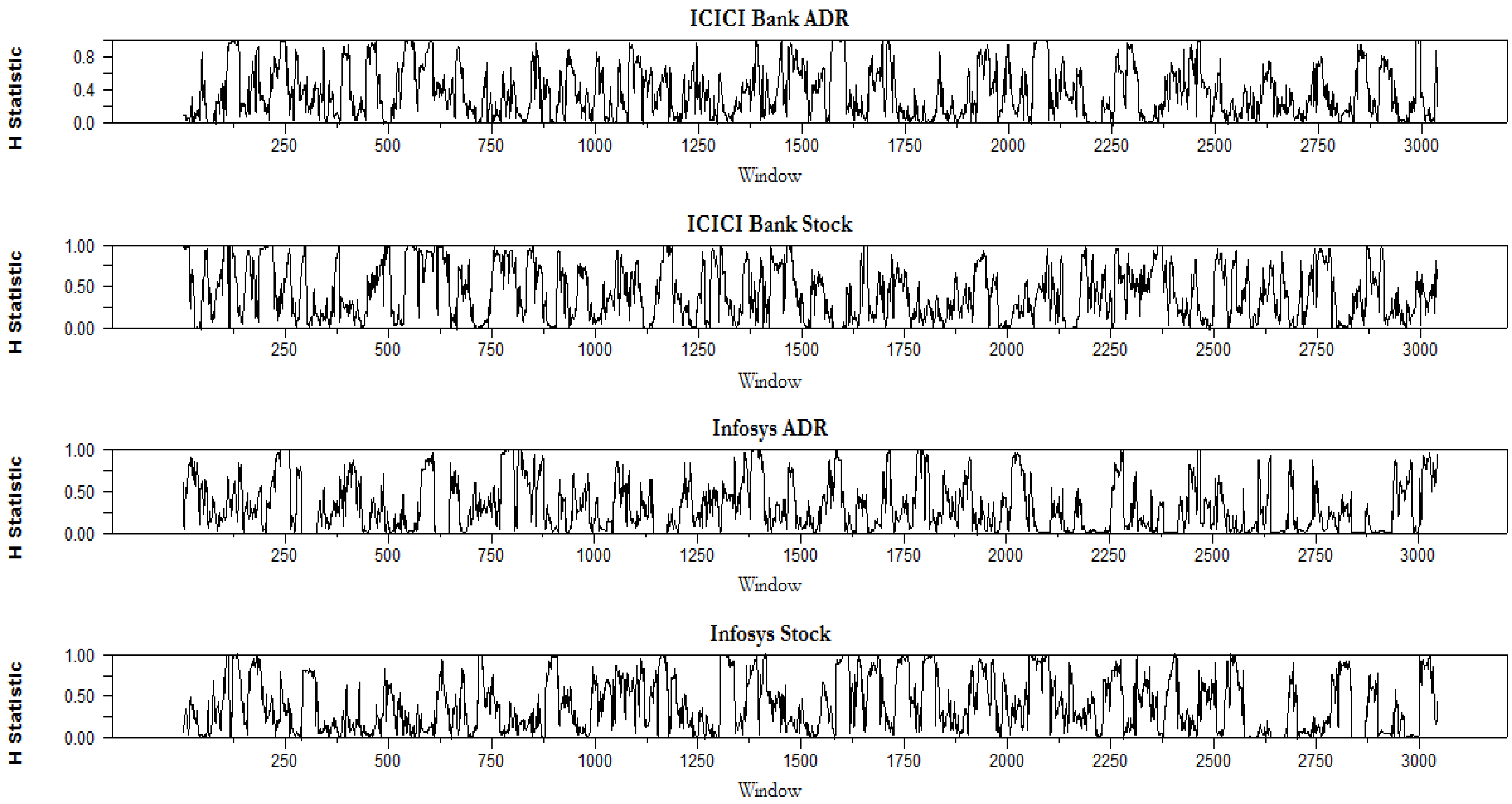
Dr. Reddy's Laboratories ADR



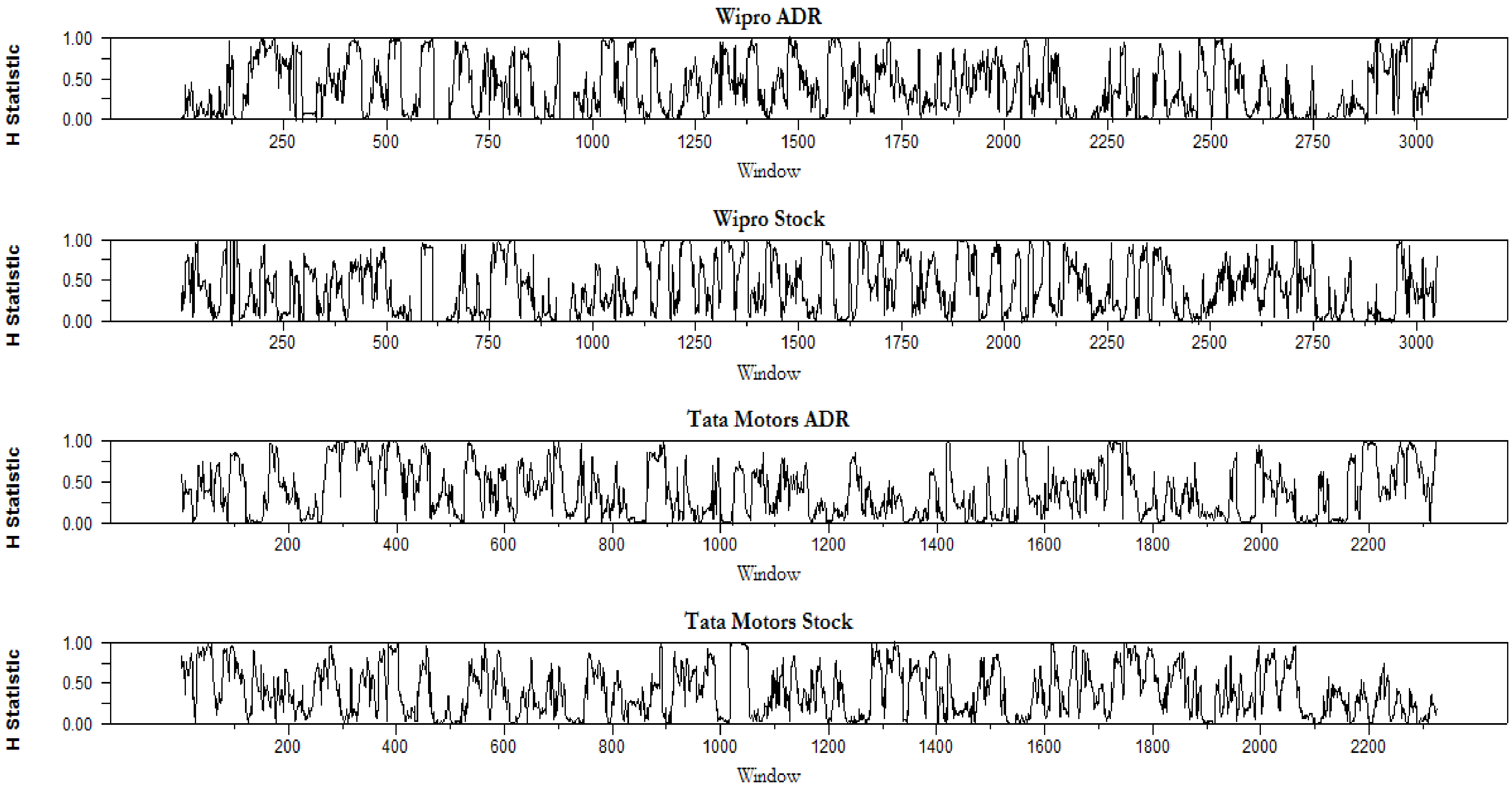
Dr. Reddy's Laboratories Stock



Annexure #2: Rolling H Statistic for ICICI and Infosys



Annexure #3: Rolling H Statistic for Wipro and Tata Motors



Annexure #4: Rolling H Statistic for Sterlite Industries