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How Far is Mumbai from Luxemburg and London? : Price and Volatility Linkages between Indian GDRs and Their Underlying Domestic Shares

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Abstract: This paper tests for relationship between Indian GDRs traded in Luxembourg (London) and their underlying shares traded in Mumbai at two levels, viz., (a) between the stock prices at two exchanges; and (b) between the volatilities of the stock prices between the two exchanges. The relationship is studied between the GDR price and the domestic share price along with the appropriate exchange rates (INR-EUR/INR-GBP), the foreign stock market index (LuXX/FTSE100) and the NSE/BSE-listed national stock index (Nifty/Sensex) using Level VAR models and DCC-GARCH models. Our sample comprises of Luxembourg GDRs issued by Ambuja Cements, Indiabulls Financial Services, IndusInd Bank, Kotak Mahindra Bank, Sterling International Enterprises, Tata Motors, Tata Power, and United Spirits; and London GDRs issued by Larsen & Toubro, State Bank of India, Axis Bank and Tata Steel. The results indicate strong association between the GDR prices and their underlying stocks. To be specific, VAR outcomes indicate that there is quite a bit of similarity between the two prices of scrips considered for this study – one trading in Mumbai and the other trading in Luxembourg (London). Further, DCC-GARCH model outcomes indicate that, there is by and large, high dynamic correlation between Indian GDRs traded in Luxembourg (London) and their underlying stocks listed in Mumbai. Further, we found the price and volatility linkages between GDRs listed in London Stock Exchange (LSE) and their underlying scrips trading in NSE to be qualitatively similar to the findings obtained in connection with Luxembourg GDRs. Such similarity in findings, notwithstanding the difference in degree of information disclosure requirements at London and Luxembourg, reflects the stock-exchange-invariant nature of Law of One Price (LOOP), which in turn is indicative of a less significant impact of foreign stock exchange per se, when it comes to price dynamics of dually-listed Indian stocks.

Keywords: Stock Prices, Dual listing, GDR, India, Vector Autoregression, DCC-GARCH.

JEL Classification Codes: G15, C22

1. Introduction

How is the law of one price valid in a world fragmented by history, geography and economic and financial policies? This question seems to have haunted researchers for long. In particular, with the presumed efficiency and fast speed of flow of information in the financial market (i.e., no transport cost), one would expect prices of shares listed at two stock exchanges to be same with very limited arbitrage opportunities. Presence of home bias in financial market makes holes in this story whereby domestic investors tend to prefer domestic stock irrespective of their origin. But, even if the strong version of the law of one price is not valid, one can argue that there has to be some relationship between the domestically listed price of any stock and its foreign counterpart and any divergence between them could be traced in some institutional or economic factors. Factors like ease of listing and / or nature of exchange rate regime could play key roles in this regard. But law of one price is merely a relationship between the price levels (or the first moment, viz., the average). Should the volatilities of the stock prices be linked as well? Illustratively, would a volatile stock listed in the stock exchange, Mumbai mean volatility of its counterpart in London Stock exchange (say) as well? This issue seems to be primarily empirical in nature [1].

Thus, the issue of joint listing by companies has attracted research interest since long and a number of studies have looked into the behavior of cross listing by Indian companies in BSE / NSE and NYSE / NASDAQ. The present paper deviates from this literature from two standpoints. First, it attempts to look into the relationship of the share prices of a company listed in two different stock exchanges in terms of both levels as well as volatility. Second, it looks into the sensitivity of the results with respect to selection of the foreign stock exchange. In concrete terms, the paper delves into the cross listing behavior of Indian companies in NSE and Luxembourg (London) stock exchange at two levels: (a) between the share prices of listed in Mumbai and those listed in Luxembourg (London); and (b) between the volatilities of the share prices listed at the two exchanges. That is to say, we study the price and volatility linkages of Indian GDRs traded in Luxembourg (London) Stock Exchange with their respective underlying domestic shares traded in NSE/BSE. Interestingly, studying the relationship across different foreign stock exchange is expected to shed some light about the role and the consequent impact of foreign stock exchange with regard to the price and volatility relationships of dually-listed stocks (Floreani and Polato, 2014).

Thus, we examine the linkages between Indian GDRs listed in a foreign stock exchange and their underlying stocks listed in India. In doing so, we offer a juxtaposition of findings pertaining to price and volatility linkages obtained in connection with Indian GDRs listed at Luxembourg and London. We believe that this investigation is all the more pertinent in light of the many regulatory steps taken by Government of India since 2001 to mitigate arbitrage restrictions in

Indian depositary receipts landscape such as but not limited to enabling (hitherto prohibited) two-way fungibility. This is possibly the first study that deals with firm-level Indian GDRs listed at LuxSE and in the process offers a juxtaposition of findings pertaining to GDRs listed in LuxSE and LSE. Further, this paper contributes towards a prominent strand of literature on depositary receipts that deals with lead-lag relationship between domestic and foreign markets returns (volatility) of dually-listed stocks. Besides, since a priori listing in LuxSE is far less restrictive than listing in London, similarity of results between India and both the foreign stock exchanges (Luxembourg & London) could be indicative of a less significant impact of foreign stock exchange per se, when it comes to price dynamics of dually-listed Indian stocks.

The rest of the paper is organized as follows. Section two offers a brief background of the birth of depositary receipts, the different types of depositary receipts and the different institutional mechanisms in India that support different types of depositary receipts globally. Section three offers a relevant literature review, while section four details the data employed for the study. We lay out the methodology employed in the study in section five, while section six constitutes the findings of the study. We conclude in section seven.

2. Indian GDRs: A Synoptic Review

In recent times, India, with its vibrant economy and a share of around 5 percent in global GDP (at PPP) occupies a central place of attention in grouping like the BRICS or Developing Asia. The economic liberalization of 1991 paved the way for the Indian companies to raise capital from foreign investors by way of depositary receipts. Depositary receipts act as a conduit through which foreign investors could own stocks in companies belonging to foreign countries [2]. These depositary receipts can be broadly classified into two, namely American Depositary Receipts (ADRs) and Global Depositary Receipts (GDRs). ADRs, as the name indicates, are issued and traded in US, while GDRs trade in other parts of the globe. ADRs are issued by a Depositary Bank in US, after delivery and subsequent verification of underlying shares of an Indian Firm to the depositary bank's local branch in India. The depositary bank serves as a custodian of Indian securities and all payments such as, but not limited to dividends made by the concerned Indian firm to its shareholders are converted to equivalent US dollars by the depositary bank and distributed to ADR holders in US. This calls for the depositary bank to possess necessary stock transfer systems and requisite operating capabilities.

Not all depositary receipts are identical. Level I ADRs trade in OTC market in US. Companies that issue level I ADRs do not have to register with Securities and Exchange Commission, nor do they have an obligation to report their financial performance in-accordance with US Generally Accepted Accounting Principles (GAAP). Level II and Level III ADRs, which are listed in American stock exchanges, call for SEC registration and adherence to US GAAP. Foreign firms that are intent on raising capital in US through the public route would have to issue Level III ADRs, since Level II ADRs can be used only for listing in a US Stock Exchange and not for raising capital [3]. As an alternative to public route, foreign firms can raise capital by private placement of ADRs and the same can be traded amongst Qualified Institutional Buyers (QIBs) under the PORTAL system [4, 5]. Such offerings are governed by SEC Rule 12g3-2(b), which warrants only home country financial statements with English translation and no SEC registration.

In line with ADRs, Global Depositary Receipts (GDRs) act as a conduit for foreign companies to raise capital from non-US Investors. Level II/Level III GDRs are listed in foreign exchanges such as, but not limited to London Stock Exchange, Luxembourg Stock Exchange, and Frankfurt Stock Exchange through the Stock Exchange Automated Quotation System – International (SEAQ-I) platform. US Investors are prohibited from investing in such listed GDRs. However, in line with Rule 144A, Rule S enables depositary receipts issued to non-US Investors via private placement to be resold in US markets after a stipulated waiting period under "safe harbor" transactions. Trading in Reg S. securities takes place in DOSM framework [6].

3. A Brief Literature Snapshot

As issuance of depositary receipts gained traction amidst corporations, research efforts on this front underlined the many benefits behind such issuances. These benefits include enhanced shareholder base (Foerster and Karolyi, 1999; Karolyi, 1998), increased visibility of the company (Choi and Stonehill, 1982), enhanced ability to raise capital, access to a more liberal tax environment (Sarkissan & Schill, 2004), increased trading liquidity (Lins *et al.*, 2005; Mittoo, U.R., 1992), reduction in cost of capital (Errunza & Losq, 1985; Serra, 1999), and increase in investor protection (Coffee, 1999; Stulz, 1999; Reese & Weisbach, 2002; Doidge *et al.*, 2004).

From a signaling perspective, firms based in markets characterized by low disclosure requirements and investor protection would be able to signal high quality by listing in markets with stringent disclosure requirements and higher investor protection. Such foreign listings would consequently lead to reduction in information asymmetry, which in-turn would lead to reduction of firm's cost of capital and enhancement of firm valuation, as pointed out by prior research efforts based on information asymmetry models (Cantale, 1996; Fuerst, 1998; Moel, 2001)

Prior studies also touch-upon the stock movements in the domestic market around the day of international listing. Owing to increased liquidity and volume as a result of international listing, variance in domestic stock prices is expected to subside subsequent to an international listing. Empirical evidence in this regard is mixed. Jayaraman *et al.*, 1993 pinpoint that domestic volatility subsequent to ADR issuance is higher for stocks pertaining to developed economies. On the contrary, domestic volatility of Mexican stocks was found to be lower, subsequent to issuance of ADRs (Domowitz *et al.*, 1997). In case of India, domestic volatility of stocks subsequent to Rule 144A/Reg S issues is significantly lower during the time period 1990-1997. Further significant increase in liquidity is witnessed in home market stocks subsequent to issuance of Level III ADRs during the time period 1998-2001 (Kalimpalli & Ramchand, 2006). Also, GDR issuance by Indian firms is found to increase investor's recognition of underlying shares despite relatively less-stringed disclosure requirements as compared to US listings and lack of liquidity enhancement in domestic market owing to arbitrage restrictions (Pinegar & Ravichandran, 2002)

A prominent strand of literature on the depositary receipts front deals with lead-lag relationship between domestic and foreign markets returns (volatility) of dually-listed stocks. Prior studies on this front have touched upon dominant-satellite relationship between exchanges in terms of information creation and transmission (Garbade & Silber, 1979), reflection of domestic stock movements in foreign price volatility of cross-listed US stocks

(Neumark *et al.*, 1991), bidirectional informational flow between domestic and foreign markets in the case of Japanese and Hong Kong stocks (Lau and Diltz, 1994; Bae *et al.*, 1999), unidirectional information flow from the domestic market to the foreign market in the case of Israeli stocks (Hauser *et al.*, 1998; Lieberman *et al.*, 1999), the role of underlying share prices, the exchange rate and the US market in the pricing of ADRs and the speed of adjustment of ADRs to such factors (Kim *et al.*, 2000), the bi-directional volatility transmission and information flow between ADR and the underlying stock markets that tend to be unaffected by difference in synchronicity of trading period between US and other developed markets (Poshakwale & Aquino, 2008), sensitivity of depositary receipt returns (volatility) to shocks in the markets where they are cross-listed and the transmission of such shocks in the cross-listed market to the domestic stock returns (volatilities) (Jaiswal-Dale & Jithendranathan, 2009), and the prevalence of US market sentiment for UK ADRs whereby trading location influences pricing behavior (Chen *et al.*, 2009). The overarching economic antecedent behind these studies is the Law of One Price, which states that an asset trading at two different places should trade at the same price. Difference in pricing between the markets would pave way to arbitrage opportunities and the same would be exploited by arbitragers, provided arbitrage restrictions that preempt such actions are absent and transaction costs are minimal.

Notable contributions towards this strand of literature in the context of Indian ADRs/GDRs reveal sensitivity of Indian GDR Index returns to domestic and international factors while the underlying Indian shares are impacted only by domestic variables (Jithendranathan *et al.*, 2000); bidirectional causality between price levels of ADRs and the underlying stocks listed in BSE/NSE despite prevalence of arbitrage restrictions such as one way fungibility (Hansda & Ray, 2003); sensitivity of Indian ADRs to movements in the US stock market rather than the capital market activities in India, despite the liquidity gains in Indian market subsequent to ADR issuance (Majumdar, 2007); sensitivity of GDR returns to the returns of underlying stocks in India and the significant but small impact that GDR returns have on the subsequent return of the underlying stocks (Kadapakkam & Misra, 2003); and Co-integration of London prices of GDRs and the Mumbai prices of the underlying Indian stocks, the equal contribution of each market towards price discovery, and the growing contribution of GDR market towards price discovery when accompanied with corresponding increase in foreign ownership of the firm and GDR issue size (Kadapakkam *et al.*, 2003)

This paper is an attempt to contribute towards this strand of literature. This paper tests for price and volatility linkages between Indian GDRs traded in Luxembourg (London) and the underlying domestic shares traded in Mumbai. Prior studies such as Jithendranathan *et al.* 2000 consider the SkiIndia GDR index, as a market proxy for performance of Indian GDRs, while Kadapakkam *et al.*, 2003 and Kadapakkam & Misra, 2003 consider only Indian GDRs that are traded on Stock Exchange Automation Quotation System – International (SEAQ-I) in London. This is possibly the first study that (a) deals with Indian GDRs traded in Luxembourg Stock Exchange, as the authors are yet to come across any prior study that does so; and (b) offers a juxtaposition of findings pertaining to price and volatility linkages, obtained in connection with Indian GDRs listed at Luxembourg and London. Also, we strongly feel that this study would be all the more pertinent, in light of the many regulatory actions taken by Government of India since 2001 on the depositary receipts front. Such actions include (a) Permission for Indian companies operating in Information Technology and Entertainment, Pharmaceuticals, and Biotechnology sectors to engage in overseas business acquisition through the ADR/GDR route; (b) Permission for Indian companies to use 100% of the ADR/GDR proceeds for overseas investments; (c) Permission for all Indian companies that have already issued ADR/GDR to acquire shares of foreign companies engaged in the same core activity, for up to $ 100 million or an amount equivalent to 10 times its export earnings in the preceding financial year, whichever is higher by way of swap of fresh shares of ADRs/GDRs on back to back basis, subject to compliance with certain conditions; (d) Permission for companies engaged in IT and ITeS sector to issue ADR/GDR linked stock options to permanent employees of subsidiary companies incorporated in India or outside; (e) Permission to re-convert underlying shares to ADRs/GDRs so as to ensure two-way fungibility of ADRs/GDRs to the extent of original conversion of ADR/GDR to underlying equity shares; (f) Permission for resident shareholders of Indian companies who offer their shares for conversion to ADRs/GDRs to receive the sales proceeds in foreign currency subject to the conditions that such conversion to ADRs/GDRs be approved by Foreign Investment Promotion Board; (g) Eligibility for resident turned non-residents to receive disinvestments proceeds that are receivable by residents through Foreign Currency Account abroad/Resident Foreign Currency Account in India/Rupee account in India; and (f) an amendment of Foreign Currency Convertible Bonds and Ordinary Shares Through Depositary Receipt Mechanism Scheme of 1993 in order to ensure that ADR/GDR guidelines are in line with the guidelines on domestic capital issues framed by SEBI.

4. Data and Stylized Facts

Daily closing prices pertaining to Indian GDRs listed at Luxembourg Stock Exchange (LuxSE) and London Stock Exchange (LSE), and their respective underlying stocks listed in NSE/BSE, were downloaded from a Bloomberg terminal. Our sample comprises of Luxembourg GDRs issued by Ambuja Cements (AC), Indiabulls Financial Services (IFS), IndusInd Bank (IB), Kotak Mahindra Bank (KM), Sterling International Enterprises (SIE), Tata Motors (TM), Tata Power (TP), and United Spirits (US); and London GDRs issued by Larsen & Toubro (LT), State Bank of India (SBI), Axis Bank (AB) and Tata Steel (TS).

Apart from the fact these are leading companies which floated GDRs in Luxembourg and London stock exchanges, it may be noted that all the Luxembourg GDRs considered for this study are constituents of Luxx India GDR Index listed at Luxembourg Stock Exchange, while all the London GDRs considered for this study are constituents of Bank of New York (BNY) Mellon Regional GDR Index for Asian region. Daily closing INR-USD, INR-GBP, and INR-EUR rates were downloaded from Reserve Bank of India archives, while daily closing prices for the S&P CNX Nifty Index, BSE Sensex Index, Luxembourg Stock Exchange National Index (Luxx), London Stock Exchange National Index (FTSE 100) were downloaded from www.nseindia.com, www.bseindia.com, www.bourse.lu and finance.yahoo.com respectively. Missing values were imputed using linear interpolation. A snapshot of the different time series considered for this study is made available in table 4.1, while tables 4.2 and 4.3 offer detailed descriptive statistics of different GDRs considered for this study and their respective underlying stocks. Further, the line plots pertaining to the different GDRs considered for this study and their respective underlying Indian stocks is made available as figures 4.1 to 4.13.

[Insert Tables 4.1, 4.2, and 4.3; and Figures 4.1 to 4.13 here]

5. Methodology

5.1. Studying the Relationship between share price listed at domestic and foreign stock exchange: VAR Models

As far discerning the relationship between the company specific GDRs and their stocks are concerned, there are two distinct methodologies that are followed in the literature: (i) cointegration analysis between the markets; and (i) non-cointegrated vector autoregression modelling between the variables under consideration. Between the competing paradigms of cointegration and VAR modelling, we used SVAR. The choice can be justified for two distinct considerations (Ray and Prabu, 2013).

First, analytically cointegration is a long run concept - and we felt the span of six years (2008 – 2012) is not sufficiently long to treat it for discerning a cointegrating relation. After all, having high frequency data is no substitute for the length of the period [7]. Furthermore the continuous time specification ensures that the discrete time model satisfied by the observed data is independent of the sampling frequency, a feature that is not always true in temporal aggregation of discrete time models (Chambers, 2011).

Second, it has been argued that co-integration among the markets essentially involves an error correction mechanism and implies that the cointegrated variables tend towards an equilibrium situation in the long-run, and for that to happen, the divergence between the co-integrated values keep on vanishing in the short-run. This adjustment by the market interest rates may lead to arbitrage opportunities and hence inefficiency in the market. Thus, cointegration and other standard measures of degree of market integration could actually show the linkage among the markets and that closer linkages do not necessarily imply higher financial market integration (Ayuso and Blanco, 2001).

The other dilemma we faced is whether to take the data in first differences or not. The arguments are present in each direction. For example, almost all works by Sims and his associates (like Sims, 1992) can be clubbed as a level VAR. The justification came from Sims *et al.* (1990) who had showed that notwithstanding the order of integration of the variables, coefficients could be consistently estimated in a level VAR. Furthermore, as Hamilton (1994) has pointed out, even if the true model is a VAR in differences, certain functions of the parameters and hypotheses tests based on VAR in levels have the same asymptotic distribution based on differenced data. Finally, as Sims and Uhlig (1991) has shown, one may give a Bayesian interpretation to the usual t or F distribution, even when the asymptotic theory for these statistics is non-standard. All these results show that VAR in difference form (if the variables are non-cointegrated) or in VECM form is by no means the only standard procedure; there is ample justification for running a VAR in levels. Afterall, a VAR in levels is more amenable to interpretation.

We thus, estimated a VAR model of the following form (1). The optimum lag structure of all VARs comprising of the Indian GDR trading in LuxSE/LSE, its underlying stock trading in NSE/BSE, pertinent national stock index of India (Nifty/Sensex), pertinent foreign stock market index (LuXX/FTSE 100), and the pertinent exchange rate (INR-EUR/INR-GBP) was arrived at based on SBC Criterion. Consequently we estimated a VAR of the following form:

$$\textbf{(1)} \qquad \begin{bmatrix} \boldsymbol{x\_G_t} \\ \boldsymbol{x\_S_t} \\ \boldsymbol{dom_t} \\ \boldsymbol{for_t} \\ \boldsymbol{er_t} \end{bmatrix} = \begin{bmatrix} a_{11}^{(1)} & a_{12}^{(1)} & a_{13}^{(1)} & a_{14}^{(1)} & a_{15}^{(1)} \\ a_{21}^{(1)} & a_{22}^{(1)} & a_{23}^{(1)} & a_{24}^{(1)} & a_{25}^{(1)} \\ a_{31}^{(1)} & a_{32}^{(1)} & a_{33}^{(1)} & a_{34}^{(1)} & a_{35}^{(1)} \\ a_{41}^{(1)} & a_{42}^{(1)} & a_{43}^{(1)} & a_{44}^{(1)} & a_{45}^{(1)} \\ a_{51}^{(1)} & a_{52}^{(1)} & a_{53}^{(1)} & a_{54}^{(1)} & a_{55}^{(1)} \end{bmatrix} \begin{bmatrix} \boldsymbol{x\_G_{t-1}} \\ \boldsymbol{x\_S_{t-1}} \\ \boldsymbol{dom_{t-1}} \\ \boldsymbol{for_{t-1}} \\ \boldsymbol{er_{t-1}} \end{bmatrix} + \ldots + \begin{bmatrix} a_{11}^{(2)} & a_{12}^{(2)} & a_{13}^{(2)} & a_{14}^{(2)} & a_{15}^{(2)} \\ a_{21}^{(2)} & a_{22}^{(2)} & a_{23}^{(2)} & a_{24}^{(2)} & a_{25}^{(2)} \\ a_{31}^{(2)} & a_{32}^{(2)} & a_{33}^{(2)} & a_{34}^{(2)} & a_{35}^{(2)} \\ a_{41}^{(2)} & a_{42}^{(2)} & a_{43}^{(2)} & a_{44}^{(2)} & a_{45}^{(2)} \\ a_{51}^{(2)} & a_{52}^{(2)} & a_{53}^{(2)} & a_{54}^{(2)} & a_{55}^{(2)} \end{bmatrix} \begin{bmatrix} \boldsymbol{x\_G_{t-i}} \\ \boldsymbol{x\_S_{t-i}} \\ \boldsymbol{dom_{t-i}} \\ \boldsymbol{for_{t-i}} \\ \boldsymbol{er_{t-i}} \end{bmatrix} + \begin{bmatrix} \boldsymbol{e1_t} \\ \boldsymbol{e2_t} \\ \boldsymbol{e3_t} \\ \boldsymbol{e4_t} \\ \boldsymbol{e5_t} \end{bmatrix}$$

where x_G and x_S are GDR price and domestic stock price of company x (x = AC, IB, IFS, KM, MM, US, TM, TP, and SI in the case of Luxembourg, while x = LT, SBI, AB and TS in the case of London); dom refers to the domestic share price index (i.e., nifty or sensex depending on where the domestic stock is listed); for refers to the foreign stock market index, which is the Luxembourg Stock Exchange National Index (LuXX) in the case of Luxembourg, while it is FTSE100 in the case of London; er refers to the pertinent exchange rate, which is INR-EUR in the case of Luxembourg and INR-GBP in the case of London; e's refer to the reduced form error terms; and i refers to the optimum number of VAR lags [8]. We, thus, ran twelve VAR models, one each for each of the twelve companies in the sample.

As far as discerning relationships are concerned, we employ the usual techniques of impulse response functions and variance decomposition. For this purpose we employ a recursive scheme of Choleski decomposition. The ordering of the variables are as follows: x_G. x_S, dom, for and er. Given the high correlation between x_G and x_S, we have experimented with interchanging their positions in the twelve VARs that we have run.

5.3: Studying the Relationship between volatilities of share price listed at domestic and foreign stock exchange: DCC-GARCH Models

Further, the time varying correlation between each Indian GDR considered for this study, its underlying shares traded in NSE/BSE, the National Stock Index of India (Nifty/Sensex), the foreign stock market index (Luxx/FTSE100) and the pertinent exchange rate (INR-EUR/INR-GBP) is examined using a Dynamic Conditional Correlation specification of the multivariate GARCH model developed by Engle (2002). The primary reason behind employing dynamic conditional correlation model is the progressive removal of impediments by Indian policymakers when it comes to foreign investments in Indian ADRs/GDRs. Such progressive steps undertaken by policy makers so as to remove investment impediments has found to be one of the primary reasons as to why correlations between concerned markets is not constant over time (Longin & Solnik, 1995). Other prominent reasons that necessitate the need for a dynamic conditional correlation model as opposed to a constant correlation framework, as pointed out by Longin & Solnik (1995), are the possibility of a time trend, asymmetry in asset price movements, and the possibility of common factors that impact multiple stock markets at the same time. The following DCC-GARCH model for a five dimensional vector comprising of different time series considered for this study is employed.

$$(2) \qquad y_t = E(y_t/I_{t-1}) + r_t$$

Where y_t is a k x 5 vector comprising of five time series of equal length k, namely LuxSE /LSE listed GDR returns, NSE/BSE listed underlying stock returns, returns of pertinent national stock index of India (Nifty/Sensex), returns of pertinent foreign stock market index (LuXX/FTSE100), and the daily returns of pertinent exchange rate (INR-EUR/INR-GBP); I_{t-1} is the information set at time t-1.

As part of the DCC-GARCH model, each of the five time series is modelled as a univariate GARCH(1,1) process at time t based on information set available at time t-1, as shown below.

$$(3) \qquad h_{i,t} = \eta_{i0} + \eta_{i1} r_{i,t-1}^2 + \tau_{i,1} h_{i,t-1}$$

wherein $r_{i,t}=h^{1/2}\varepsilon_{i,t}$ and conditional variance $E(r_{i,t}^2) = h_{i,t}$

Subsequently the conditional correlations are allowed to be time-varying by following the GARCH (1,1) model given below.

$$(4) \qquad q_{i,j,t} = (1-\eta-\tau)\overline{\rho_{i,j}} + \eta\varepsilon_{i,t-1} + \tau q_{i,j,t-1}$$

where $q_{i,j,t}$ is time varying co-variance of $\varepsilon_{i,t}$, $\overline{\rho_{i,j}}$ is the unconditional variance of $\varepsilon_{i,t}$ and η and τ are non-negative scalars.

6. Findings

6.1: Relationship between the Stock Prices

To begin with, one may note that the share prices at the NSE and Luxembourg (London) stock exchange are highly correlated, as seen in tables 6.1 and 6.2.

[Insert Table 6.1 and 6.2 here]

While this establishes some *a priori* basis of the close linkages between GDR prices and their domestic counterpart in a company, this also creates some sensitivity to the ordering of the variables in the VAR model that is discussed below.

How does a change in GDR price of a company influence its domestic share price or the other way? Towards finding answers to such questions, the Impulse Response Functions (IRF) of the VARs are generated – these relate to, eight Indian companies whose scrips are trading in LuxSE, and four Indian companies whose scrips are trading in LSE. These IRFs are generated with standard error bands that are indicative of the reliability of the impulse responses [9]. As evidenced in figures 6.1 to 6.12, the impulse response of (a) X_G to X_S and X_S to X_G in the case of Luxembourg and (b) X_LG to X_S and X_S to X_LG in the case of London, showed almost instantaneous sharp reaction on the first day, which could be indicative of smooth informational flows between Indian and Luxembourg (London) stock exchanges. This conclusion remains unaltered, despite an interchange of order of GDR price and the domestic stock price in the VAR frameworks.

[Insert Figures 6.1 to 6.12 here]

A more interesting way will be to look into the variance decomposition of the structural errors as implied in the impulse responses. Instead of reporting the full output, tables 6.3 and 6.4 reports the proportion of error variance of GDR price that is explained by underlying domestic stock price and the proportion of error variance of underlying domestic stock price that is explained by GDR price. Interestingly, the variance decompositions of domestic prices of all stocks are to a considerable extent explained by their respective GDR. And, this happens to be the case for GDRs trading in Luxembourg (LuXSE) as well as for GDRs trading in London (LSE).

[Insert Tables 6.3 and 6.4 here]

Some Robustness Checks

This result could be entirely sensitive to the ordering of the variables – hence we have considered an alternative ordering of x_S followed by x_G (x_LG) and found out the forecast error variance decomposition (tables 6.5 and 6.6). Given the high correlation between x_S and x_G (X_LG), it is no wonder that the results are quite different from what are reported in tables 6.3 and 6.4. But taken together, it shows that, there is quite a bit of similarity between the two prices of the scrips – one in Mumbai and the other in Luxembourg (London).

[Insert Tables 6.5 and 6.6 here]

6.2: Relationship between Stock Price Volatilities

Having discussed the price linkages between Luxembourg (London) GDRs and their respective underlying shares, we now turn to the volatility linkages between Luxembourg (London) GDR returns, the returns of underlying stocks, domestic share market returns (Nifty/Sensex returns), returns of the foreign stock markets wherein the Indian GDRs are listed (LuXX index returns in the case of Luxembourg and FTSE100 index returns in the case of London), and daily returns of pertinent exchange rate (INR-EUR in the case of Luxembourg and INR-GBP in the case of London). As stated in the methodology section, efforts were undertaken by us to model this behavior using a DCC-GARCH(1,1) model while imposing the constraints such as, and limited to, (a) all variance equation coefficients are positive and (b) sum of all coefficients of the variance equation is less than one.

Should the DCC-GARCH(1,1) model outcomes yield variance equation estimates whose sum exceed one for one or more of the five time series considered for multivariate modeling, then we executed a DCC-IGARCH(1,1) model with the imposition of constraints such as, and limited to, (a) all variance equation coefficients are positive and (b) sum of all coefficients of the variance equation is equal to one. Further should the DCC-GARCH(1,1) model outcomes that involves all five time series, yield outcomes wherein one or more of the variance equation coefficients is negative for one or more of the five time series considered, then efforts were undertaken by authors to execute DCC-GARCH models that involved all but the time series which yield negative ARCH and/or GARCH coefficients.

As seen in annexures 1 to 5, DCC-GARCH models pertaining to Tata Motors (TM), Tata Power (TP), and Sterling International Enterprises (SI), which are trading in Luxembourg, involved all but the INR-EUR time series. This is because the variance equation coefficient estimates of INR-EUR time series, which formed part of the original DCC-GARCH model that involved all five time series (GDR, underlying stock, Nifty/Sensex, LuXX, INR-EUR) violated non-negativity constraint imposed by us [10]. But for TM, TP, and SI, DCC-GARCH (DCC-IGARCH) model outcomes of all other LuxSE-listed (LSE-listed) Indian GDRs yielded variance equation coefficients that are positive and significant, and whose sum is closer to (or equal to) unity [11].

[See Annexures 1 to 5 at this juncture]

The broader theme that emerged from DCC-GARCH (DCC-IGARCH) test outcomes is the significance of all ARCH and GARCH coefficients at 1% levels. Further, the sum of variance equation coefficients ($\eta + \tau$) is close to (equal to) unity, which in-turn indicates high volatility persistence. It is notable that the estimated coefficients of persistence of the time-varying correlation ($q_{i,j,t-1}$) and the coefficients of the most recent co-movements ($\varepsilon_{i,t-1}\varepsilon_{j,t-1}$) are jointly significant and similar for 6 out of the 8 models in the case of Luxembourg and for all 4 models in the case of London.

Based on DCC-GARCH test results, the Dynamic Conditional Correlation of each Indian GDR trading in Luxembourg (London) with respect to its underlying stock trading in Mumbai is made available as figure 6.13 (6.14). A common theme that emerges from the figures 6.13 and 6.14, is that, all LuxSE-listed Indian GDRs and all LSE-listed Indian GDRs considered for this study exhibit, by and large, high dynamic correlation with its underlying stock listed in Mumbai.

[Insert Figures 6.13 and 6.14 here]

The collective take-away from this study is two-fold in nature. First, level VAR and DCC-GARCH (1,1) model outcomes highlight significant price and volatility linkages between Indian GDRs trading in Luxembourg/London and their underlying stocks trading in Mumbai. Secondly, it is interesting to note that, the study's findings on aspects such as and limited to (a) the preliminary correlation examinations between Indian GDRs considered for this study and their underlying stocks trading in Mumbai; and (b) the price and volatility linkages between Indian GDRs and their respective underlying stocks trading in Mumbai, were qualitatively similar regardless of the location of trading of Indian GDRs. Put simply, the stock exchange per se

(LuxSE or LSE), in which Indian GDRs are listed, has no discernable impact on the price and volatility linkages between Indian GDRs and their underlying domestic stocks.

To summarize, the stock prices between the stock exchanges are strongly related both in their levels as well as volatilities and this is invariant to the stock exchange chosen, viz., London or Luxemburg.

7. Concluding Observations

The purpose of this paper was to examine the price and volatility linkages (if any) between Indian GDRs listed in Luxemburg Stock Exchange and London Stock Exchange and their respective underlying stocks traded in Mumbai. We have employed a level VAR so as to understand the price linkages between GDRs and their underlying stocks. Further multivariate DCC-GARCH models were employed by us to explore the dynamic conditional correlations between GDRs, their respective underlying stocks, the pertinent national and foreign stock market indices (LuXX/ FTSE100), and the pertinent exchange rate (INR-EUR/INR-GBP).

At the outset, we found high correlation between the eight LuxSE-listed Indian GDRs considered for this study and their respective underlying stocks being traded in Mumbai. Further, Level VAR test outcomes indicate that, the variance decompositions of domestic prices of all other stocks are to a considerable extent explained by their respective GDRs. However, we find the variance decomposition results to be sensitive to the order of variables in the level VAR framework. Having said so, all things considered, the study's findings indicate that there is quite a bit of similarity between the two prices of scrips considered for this study – one in Mumbai and the other in Luxembourg.

When it comes to volatility linkages between LuxSE-listed Indian GDRs and their respective underlying stocks traded in Mumbai, the broader them that emerges from the different DCC-GARCH (DCC-IGARCH) model outcomes, is (a) the significance of all variance equation coefficients, (b) the prevalence of high volatility persistence in all DCC-GARCH models, and (c) by and large, high dynamic correlation between LuxSE listed Indian GDRs and their respective underlying stocks listed in Mumbai.

Subsequent efforts undertaken by us to explore the price and volatility linkages between LSE-listed Indian GDRs and their underlying scrips trading in Mumbai yielded results that are qualitatively similar to the ones obtained in the case of LuxSE-listed Indian GDRs. In light of the difference in degree of information disclosure called-for at Luxembourg and London, such qualitatively similar findings are surprising in nature. To be more specific, such qualitatively similar findings not only reflect the prevalence of Law of One Price (LOOP) amidst Indian scrips trading in different geographies, but also reflect the stock-exchange-invariant nature of LOOP. To be more specific, the stock exchange per se, wherein the Indian GDRs are listed, has no discernable impact on the price and volatility linkages between Indian GDRs and their underlying stocks.

Finally, prevalence of high levels of price and volatility linkages between Indian GDRs traded in Luxembourg (London) and their corresponding underlying stocks traded in Mumbai as indicated by the study's findings, coupled with the reality of progressive policy actions undertaken by the Indian policy makers so as to reduce impediments to foreign investments on Indian scrips, further limits the opportunity for arbitrage trades aimed at exploiting market inefficiencies.

End Notes

1. Prior work on volatility of dually-listed stocks include (a) contributions made by authors such as Jayaraman et al., (1993), Domowitz et al. (1997), Kalimpalli & Ramchand (2006), and Pinegar & Ravichandran (2002), which examine domestic stock price volatility of a firm subsequent to the date of international listing; and (b) contributions made by authors such as Neumark et al. (1991), Poshakwale & Aquino (2008), and Jaiswa-Dale& Jithendranathan (2009), which are centered on the location-of-trade effect on scrips listed in foreign locations, its consequent impact on volatility of such scrips, and the volatility transmission that happens between such scrips listed in foreign locations and their underlying stock trading in the domestic market.
2. Another mechanism whereby foreign investors could directly invest in Indian stock market is by registering as a Foreign Institutional Investor (FII) with Securities and Exchange Board of India (SEBI). However, should foreign investors exercise this option; they would be exposed to a brokerages, custody fees, poor regulatory mechanism and low liquidity. Also, FIIs are permitted to own not more than 10% of an Indian firm, and aggregate FII investment is limited to 30% in a firm. Despite such limitations, a large number of foreign investors who trade in depositary receipts are also registered with SEBI as FIIs.
3. Level II and Level III ADRs are listed in NYSE, NASDAQ, and AMEX.
4. QIBs are a) institutional investors who possess a securities portfolio of at least $100 million, b) banks that hold at least $25 million of net assets in addition to the $100 million portfolio requirement, and c) securities dealers who hold a portfolio of at least $10 million.
5. PORTAL stands for Private Offering, Resales & Trading through Automated Linkages. Trades in PORTAL are cleared through Depositary Trust Corporation.
6. DOSM stands for Designated Offshore Securities Markets. These include markets such as London International, Amsterdam, Brussels, Frankfurt, Luxembourg, Milan, Paris, Stockholm, Zurich, Johannesburg, Hong Kong, Tokyo, Toronto, Vancouver, Montreal and Australia. Trade Settlements pertaining to DOSMs happen through European Clearing Agencies CEDEL or EUROCLEAR.

7. Illustratively, using Monte Carlo methods, Zhou (2001) showed the potential benefits of using high frequency data series and that when the studies are restricted by relatively short time spans, increasing data frequency may yield considerable power gain and less size distortion.

8. But for LSE-listed GDRs issued by L&T and Tata Steel, the optimum number of VAR lags for all other GDRs considered for this study was found to be two. The optimum number of VAR lags for L&T and Tata Steel was found to be three and one respectively.

9. The standard error bands of IRFs were arrived at based on 10,000 Monte Carlo iterations using inbuilt RATS procedures.

10. In the interest of brevity, these preliminary DCC-GARCH (1,1) results pertaining to TM, TP and SI are not made available here. Interested readers may contact us to obtain a copy of these preliminary results pertaining to TM, TP, and SI.

11. It may be noted that we have initially employed the BFGS algorithm due to Broyden, Fletcher, Goldfarb, and Shanno for all DCC-GARCH models. In the absence of convergence, the BHHH optimization algorithm due to Berndt, Hall, Hall, and Hausman was subsequently employed by us.

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Table 4.1: A Snapshot of the different GDRs considered for this study

S. No.	GDR Issue	CUSIP	Capital Issuance	Exchange	Industry	DR: Shares Ratio	Date of Inception	Time Period Considered for this study
1	Ambuja Cements - Reg. S	02336R200	No	Luxembourg Stock Exchange	Construction & Materials	1:1	May 03,1994	1/2/2008 to 12/31/2012
2	Indiabulls Financial Services - Reg. S	45409R102	Yes	Luxembourg Stock Exchange	Financial Services	1:1	Mar 03,2005	1/2/2008 to 12/31/2012
3	IndusInd Bank - Reg. S	455786103	Yes	Luxembourg Stock Exchange -Euro MTF	Banks	1:1	Mar 30,2007	1/2/2008 to 12/31/2012
4	Kotak Mahindra Bank - Reg. S	50071Q200	Yes	Luxembourg Stock Exchange -Euro MTF	Banks	1:1	Apr 27,2006	1/2/2008 to 12/31/2012
5	Mahindra & Mahindra - Reg. S	Y54164119	No	Luxembourg Stock Exchange -Euro MTF	Industrial Engineering	1:1	Dec 14,1993	1/2/2008 to 12/31/2012
5	Sterling International Enterprises - Reg. S	85935N100	Yes	Luxembourg Stock Exchange -Euro MTF	Technology Hardware & Equipment	1:4	Dec 15,2009	12/16/2009 to 12/31/2012
6	Tata Motors - Reg. S	876568601	Yes	Luxembourg Stock Exchange	Industrial Engineering	1:1	Oct 15,2009	10/16/2009 to 12/31/2012
7	Tata Power - Reg. S	876566407	Yes	Luxembourg Stock Exchange -Euro MTF	Electricity	1:10	Jul 27,2009	7/28/2009 to 12/31/2012
8	United Spirits - Reg. S	91152Q206	Yes	Luxembourg Stock Exchange	Beverages	2:1	Mar 30,2006	1/2/2008 to 12/31/2012
9	Larsen & Toubro - Reg. S	Y5217N118	Yes	London Stock Exchange	Construction & Materials	1:1	Nov 28,1994	1/2/2008 to 12/31/2012
10	State Bank of India - Reg. S	856552203	No	London Stock Exchange	Banks	1:2	Oct 03,1996	1/2/2008 to 12/31/2012
11	Axis Bank - Reg. S	05462W109	Yes	London Stock Exchange	Banks	1:1	Mar 16,2005	1/2/2008 to 12/31/2012
12	Tata Steel - Reg. S	87656Y406	Yes	London Stock Exchange	Industrial Metals & Mining	1:1	Feb 24,1994	7/22/2009 to 12/31/2012

Table 4.2: Summary Statistics of Eight LuxSE-listed GDRs and their Underlying Stocks

		Obs.	Mean	Max.	Min.	Std. Dev.	Skewness	Excess Kurtosis	JB Statistic	JB Sig. Level
Ambuja Cements (AC)	GDR	1304	2.59	4.20	0.90	0.70	-0.29	-0.73	46.79	0.00
	Underlying Stock	1304	118.15	215.60	40.56	39.28	0.39	-0.45	43.74	0.00
IndiaBulls Financial Services (IFS)	GDR	1304	4.45	22.93	1.55	3.32	3.21	11.05	8877.73	0.00
	Underlying Stock	1304	173.65	738.44	64.83	102.19	2.68	8.72	5695.76	0.00
IndusInd Bank (IB)	GDR	1304	3.92	7.94	0.53	2.08	-0.17	-1.39	111.88	0.00
	Underlying Stock	1304	186.87	433.75	26.23	108.43	0.08	-1.22	82.44	0.00
Kotak Mahindra Bank (KM)	GDR	1304	8.59	17.82	2.08	2.55	-0.50	0.75	85.23	0.00
	Underlying Stock	1304	320.80	673.60	53.65	183.86	0.26	-1.46	130.28	0.00
Sterling International (SI)	GDR	794	11.80	31.66	0.17	8.36	-0.33	-1.43	82.62	0.00
	Underlying Stock	794	135.91	354.70	2.33	94.72	-0.38	-1.44	88.11	0.00
Tata Motors (TM)	GDR	837	21.68	30.68	11.36	4.74	-0.09	-1.19	50.15	0.00
	Underlying Stock	837	210.58	319.25	105.86	50.17	-0.03	-1.07	39.98	0.00
Tata Power (TP)	GDR	895	24.84	32.78	15.46	4.84	-0.37	-1.40	93.89	0.00
	Underlying Stock	895	118.68	148.98	81	16.01	-0.32	-1.33	80.70	0.00
United Spirits (US)	GDR	1304	11.87	26.97	4.60	4.45	0.53	-0.25	63.49	0.00
	Underlying Stock	1304	1095.32	2074.97	474.47	353.92	0.41	-0.54	53.27	0.00

Table 4.3: Summary Statistics of four LSE-listed GDRs and their Underlying Stocks

		Obs.	Mean	Max.	Min.	Std. Dev.	Skewness	Excess Kurtosis	JB Statistic	JB Sig. Level
Larsen & Toubro (LT)	GDR	1304	36.53	111.04	11.01	17.60	1.58	2.94	1011.93	0.00
	Underlying Stock	1304	1680.21	4342.75	562.05	655.71	1.27	2.35	651.11	0.00
State Bank of India (SBI)	GDR	1304	87.79	157.81	34.04	24.94	0.23	-0.37	18.62	0.00
	Underlying Stock	1304	2029.09	3489.95	895.30	521.32	0.03	-0.28	4.38	0.11
Axis Bank (AB)	GDR	1304	21.53	36.01	5.26	6.57	-0.28	-0.41	25.54	0.00
	Underlying Stock	1304	1012.13	1588.75	281.40	287.96	-0.51	-0.40	66.16	0.00
Tata Steel (TS)	GDR	899	10.81	15.76	6.35	2.65	0.02	-1.37	70.75	0.00
	Underlying Stock	899	512.86	704.05	335.35	92.86	0.10	-1.29	63.60	0.00

Line Plots: GDRs vs. Underlying Shares

Figure 4.1 : Ambuja Cements

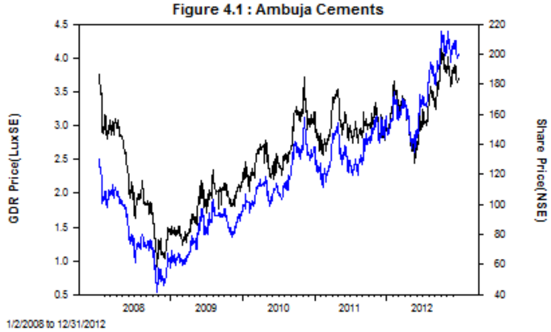


Figure 4.3 : IndusInd Bank

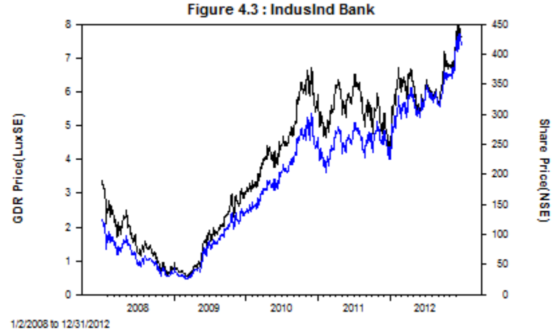


Figure 4.5 : United Spirits

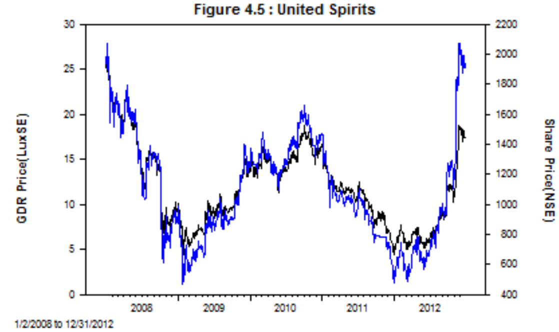


Figure 4.2 : Indiabulls Financial Services

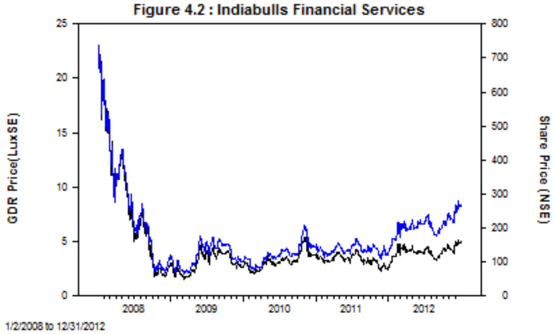


Figure 4.4 : Kotak Mahindra Bank

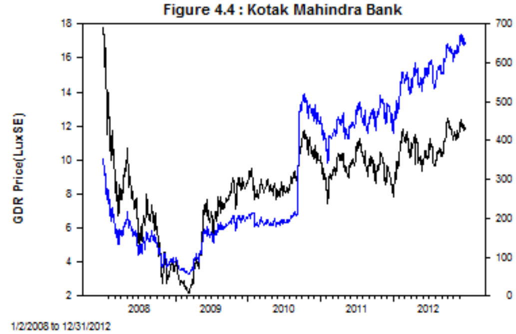
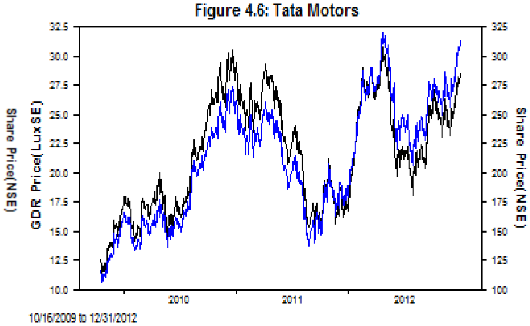


Figure 4.6: Tata Motors



Line Plots: Indian GDRs vs. Underlying Shares

Figure 4.7 : Tata Power

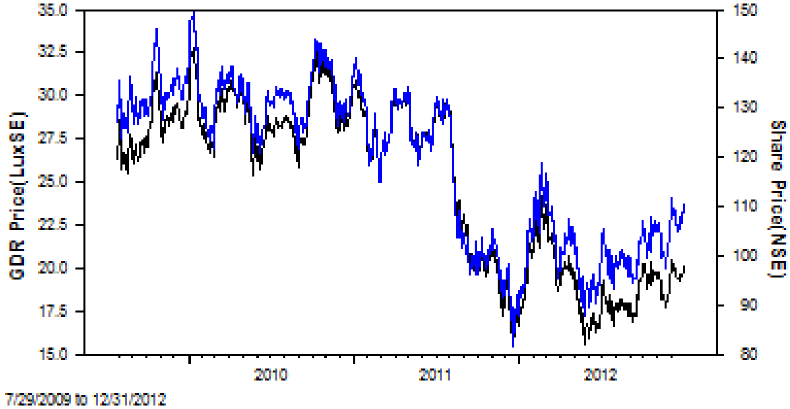


Figure 4.8 : Sterling International Enterprises Ltd.

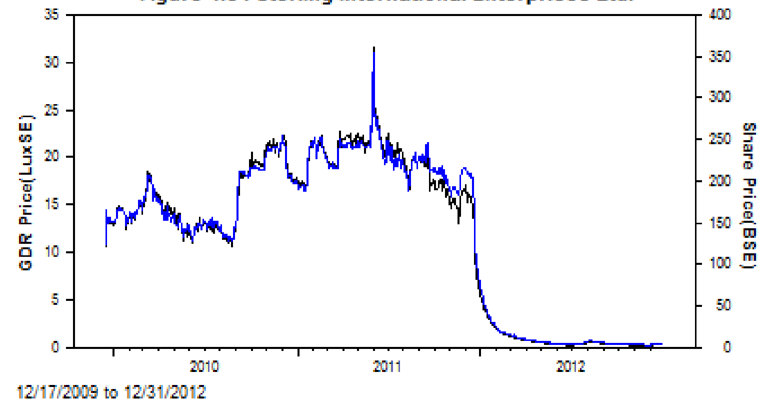


Figure 4.9 : Larsen & Toubro

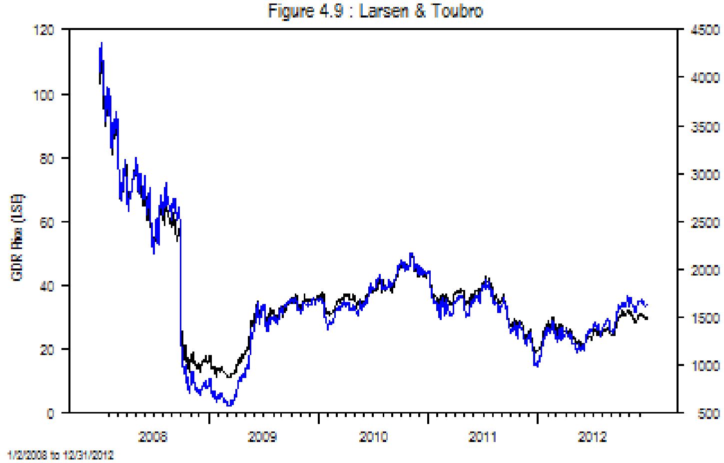
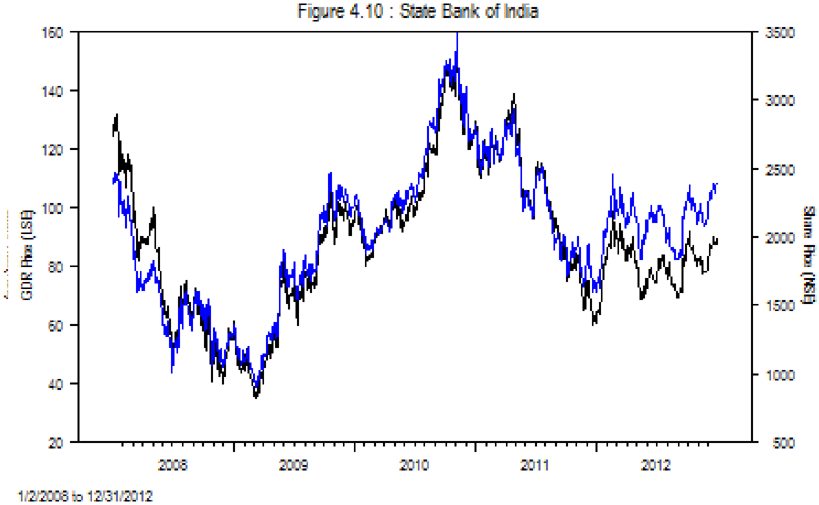
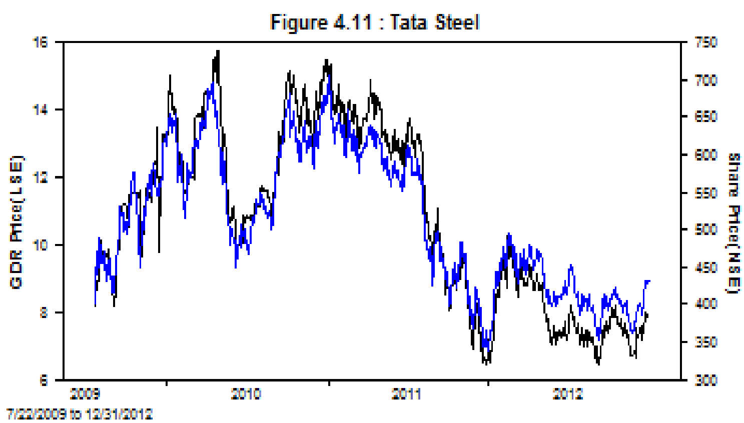


Figure 4.10 : State Bank of India



Line Plots: Indian GDRs vs. Underlying Shares



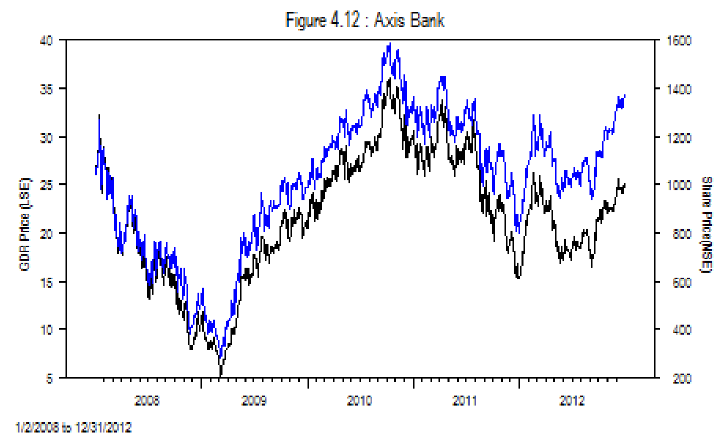


Table 6.1: Correlation Structure of LuxSE-listed firm specific GDR Price and Price of their Domestic Counterpart

	AC_G	AC_S	IB_G	IB_S	IFS_G	IFS_S	KM_G	KM_S	US_G	US_S	TM_G	TM_S	TP_G	TP_S	SI_G	SI_S
AC_G	1.00															
AC_S	0.993	1.00														
IB_G			1.00													
IB_S			0.995	1.00												
IFS_G					1.00											
IFS_S					0.985	1.00										
KM_G							1.00									
KM_S							0.942	1.00								
US_G									1.00							
US_S									0.995	1.00						
TM_G											1.00					
TM_S											0.997	1.00				
TP_G													1.00			
TP_S													0.998	1.00		
SI_G															1.00	
SI_S															.999	1.00

Please Note: X_G refers to LuxSE-listed GDR of Company X, while X_S refers to the underlying stock of the company X listed in NSE/BSE.

Table 6.2: Correlation Structure of LSE-listed firm specific GDR Price and Price of their Domestic Counterpart

	LT_LG	LT_S	SBI_LG	SBI_S	AB_LG	AB_S	TS_LG	TS_S
LT_LG	1.00							
LT_S	0.996	1.00						
SBI_LG			1.00					
SBI_S			0.996	1.00				
GI_LG								
GI_S								
AB_LG					1.00			
AB_S					0.996	1.00		
TS_LG							1.00	
TS_S							0.997	1.00

Please Note: X_LG refers to LSE-listed GDR of Company X, while X_S refers to the underlying stock of the company X listed in NSE.

Table 6.3: LuxSE vs. NSE/BSE: Variance Decomposition (in percentage) of x_G explained by x_S and x_S explained by x_G (Order of the Variables: x_G followed by x_S)

	Period	VAR 1 (AC)	VAR 2 (IB)	VAR 3 (IFS)	VAR 4 (KM)	VAR 5 (SIE)	VAR 6 (TM)	VAR 7 (TP)	VAR 8 (US)
Variance Decomposition of X_G explained by X_S		**AC_S**	**IB_S**	**IFS_S**	**KM_S**	**SIE_S**	**TM_S**	**TP_S**	**US_S**
	1	0.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	5	3.172	0.617	3.332	2.202	10.656	0.960	0.236	3.291
	10	4.592	0.830	4.054	2.879	12.048	1.224	0.558	5.486
	15	6.138	1.050	4.798	3.538	12.843	1.504	0.852	7.878
	20	7.784	1.284	5.566	4.206	13.415	1.810	1.072	10.338
	25	9.485	1.530	6.347	4.880	13.848	2.144	1.203	12.766
	30	11.204	1.788	7.135	5.551	14.185	2.506	1.253	15.100
Variance Decomposition of X_S explained by X_G		**AC_G**	**IB_G**	**IFS_G**	**KM_G**	**SIE_G**	**TM_G**	**TP_G**	**US_G**
	1	53.142	85.613	68.571	36.285	68.520	90.468	86.637	67.307
	5	54.720	85.244	62.741	33.690	67.506	88.004	91.472	64.707
	10	52.856	84.420	60.578	31.662	69.494	86.956	90.921	62.051
	15	50.929	83.629	58.768	29.849	71.107	85.979	88.920	59.672
	20	49.106	82.853	57.111	28.224	72.298	85.005	86.124	57.543
	25	47.408	82.092	55.565	26.767	73.125	84.024	82.921	55.642
	30	45.833	81.347	54.115	25.460	73.650	83.035	79.583	53.942

Table 6.4: LSE vs. NSE: Variance Decomposition (in percentage) of x_LG explained by x_S and x_S explained by x_LG (Order of the Variables: x_LG followed by x_S)

	Period	VAR 1 (LT)	VAR 2 (SBI)	VAR 3 (AB)	VAR 4 (TS)
Variance Decomposition of X_LG explained by X_S		**LT_S**	**SBI_S**	**AB_S**	**TS_S**
	1	0.000	0.000	0.000	0.000
	5	1.830	3.332	5.030	21.721
	10	1.436	4.681	6.439	44.709
	15	1.120	5.954	7.792	55.373
	20	0.896	7.264	9.179	60.845
	25	0.746	8.616	10.602	64.061
	30	0.652	10.000	12.052	66.155
Variance Decomposition of X_S explained by X_LG		**LT_LG**	**SBI_LG**	**AB_LG**	**TS_LG**
	1	77.850	61.994	58.323	23.737
	5	82.795	63.282	57.224	23.143
	10	84.711	61.953	55.039	22.803
	15	86.002	60.543	52.788	22.640
	20	86.932	59.128	50.569	22.549
	25	87.589	57.724	48.431	22.492
	30	88.032	56.339	46.402	22.453

Table 6.5: LuxSE vs. NSE/BSE: Variance Decomposition (in percentage) of x_G explained by x_S and x_S explained by x_G (Order of the Variables: x_S followed by x_G)

	Period	VAR 1 (AC)	VAR 2 (IB)	VAR 3 (IFS)	VAR 4 (KM)	VAR 5 (SIE)	VAR 6 (TM)	VAR 7 (TP)	VAR 8 (US)
Variance Decomposition of X_G explained by X_S		**AC_S**	**IB_S**	**IFS_S**	**KM_S**	**SIE_S**	**TM_S**	**TP_S**	**US_S**
	1	53.142	85.613	68.571	36.285	68.520	90.468	86.637	67.307
	5	67.097	87.782	78.505	47.384	90.296	92.601	82.309	77.702
	10	70.735	88.137	80.159	49.389	92.392	92.797	78.512	81.107
	15	73.185	88.339	81.252	50.555	93.032	92.837	74.689	83.434
	20	75.072	88.458	82.119	51.345	93.186	92.800	70.919	85.102
	25	76.554	88.520	82.832	51.868	93.062	92.703	67.344	86.286
	30	77.716	88.542	83.424	52.178	92.743	92.555	64.047	87.109
Variance Decomposition of X_S explained by X_G		**AC_G**	**IB_G**	**IFS_G**	**KM_G**	**SIE_G**	**TM_G**	**TP_G**	**US_G**
	1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	5	0.059	0.040	0.201	0.087	0.025	0.039	1.268	0.030
	10	0.057	0.022	0.422	0.278	0.080	0.114	1.745	0.221
	15	0.156	0.026	0.717	0.547	0.222	0.230	2.057	0.535
	20	0.330	0.051	1.072	0.864	0.391	0.388	2.250	0.923
	25	0.558	0.095	1.474	1.207	0.555	0.584	2.340	1.350
	30	0.825	0.155	1.914	1.561	0.700	0.818	2.348	1.791

Table 6.6: LSE vs. NSE: Variance Decomposition (in percentage) of x_LG explained by x_S and x_S explained by x_LG

(Order of the Variables: x_S followed by x_LG)

	Period	VAR 1 (LT)	VAR 2 (SBI)	VAR 3 (AB)	VAR 4 (TS)
Variance Decomposition of X_LG explained by X_S		**LT_S**	**SBI_S**	**AB_S**	**TS_S**
	1	77.850	61.994	58.323	23.737
	5	85.124	76.953	75.931	61.561
	10	84.160	80.203	78.810	80.535
	15	82.864	82.383	80.238	87.284
	20	81.558	84.169	81.084	90.471
	25	80.309	85.694	81.578	92.299
	30	79.138	87.010	81.833	93.481
Variance Decomposition of X_S explained by X_LG		**LT_LG**	**SBI_LG**	**AB_LG**	**TS_LG**
	1	0.000	0.000	0.000	0.000
	5	0.753	0.034	0.018	0.007
	10	1.466	0.029	0.129	0.015
	15	2.235	0.085	0.332	0.019
	20	3.047	0.194	0.612	0.022
	25	3.870	0.352	0.953	0.024
	30	4.678	0.553	1.341	0.025

Figure 6.1: Impulse Responses of Ambuja Cements (AC)

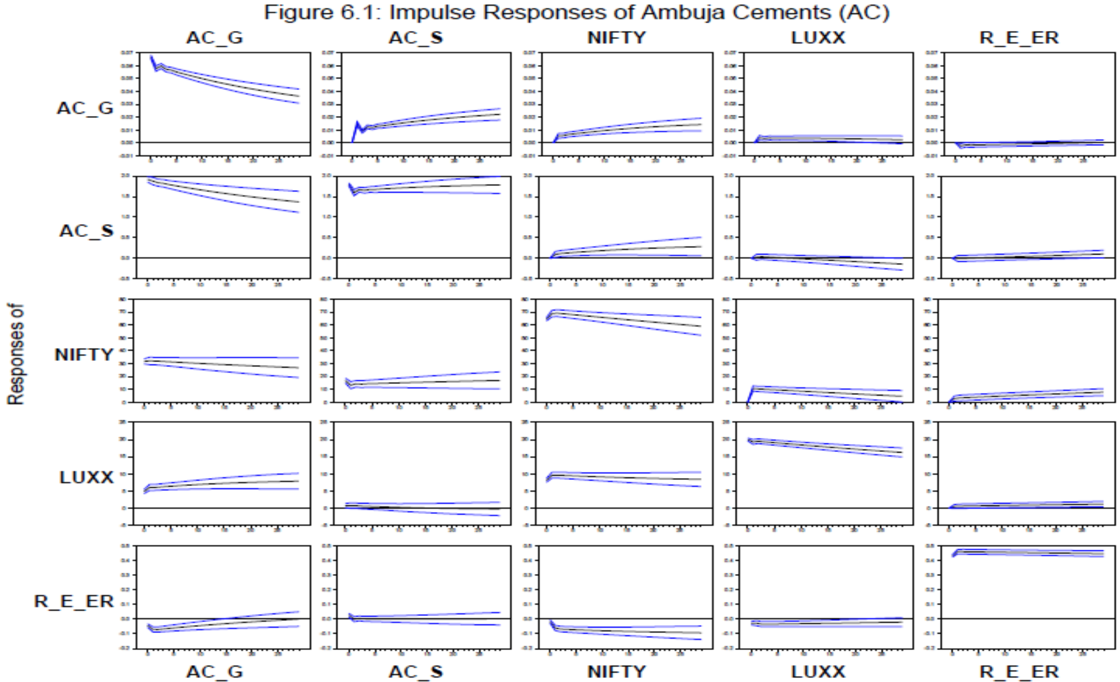


Figure 6.2: Impulse Responses of IndusInd Bank (IB)

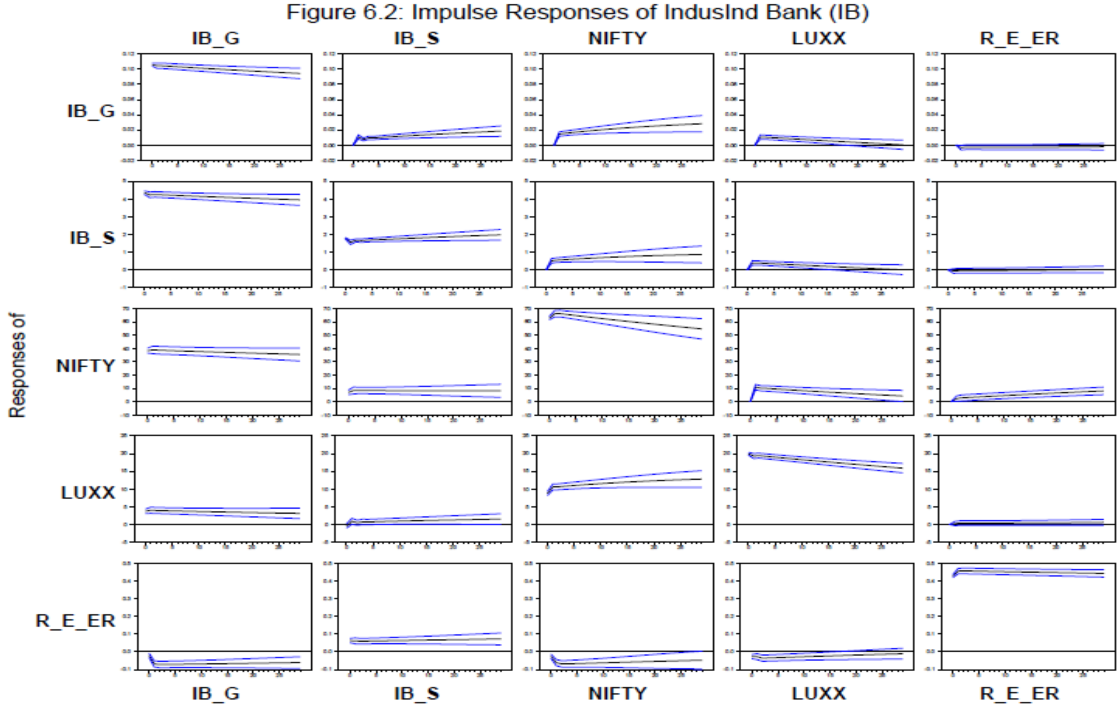


Figure 6.3: Impulse Responses of Indiabulls Financial Services (IFS)

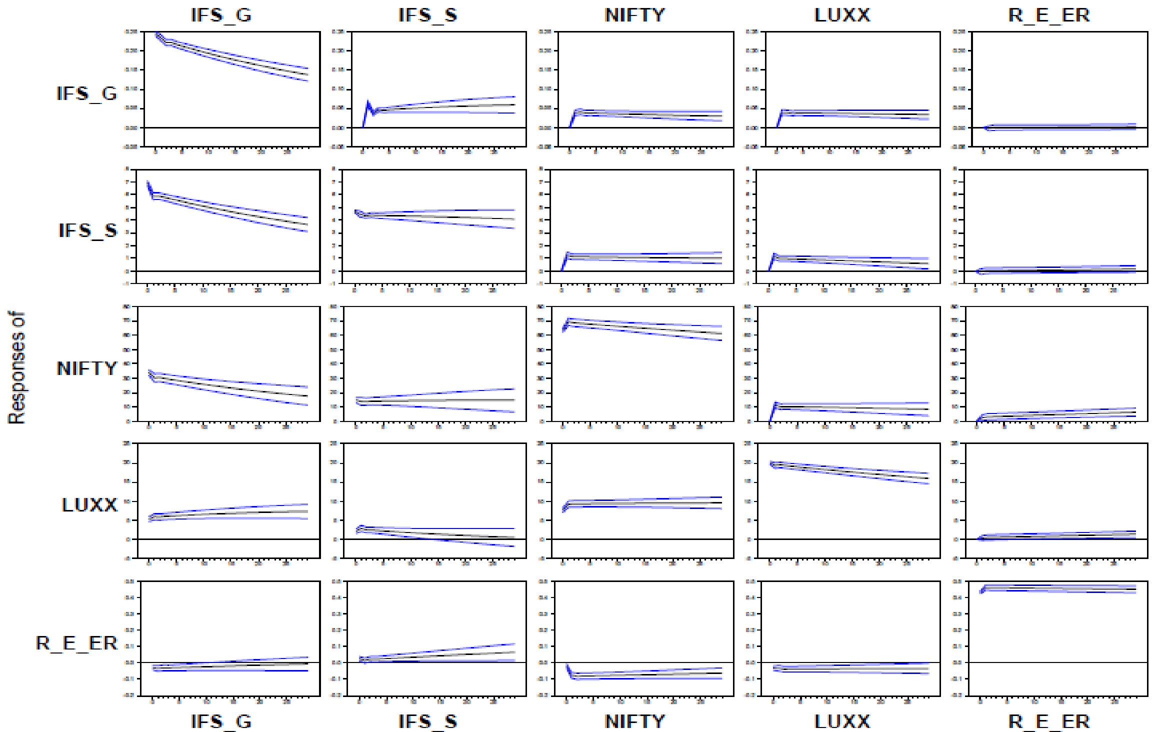


Figure 6.4: Impulse Responses of Kotak Mahindra Bank (KM)

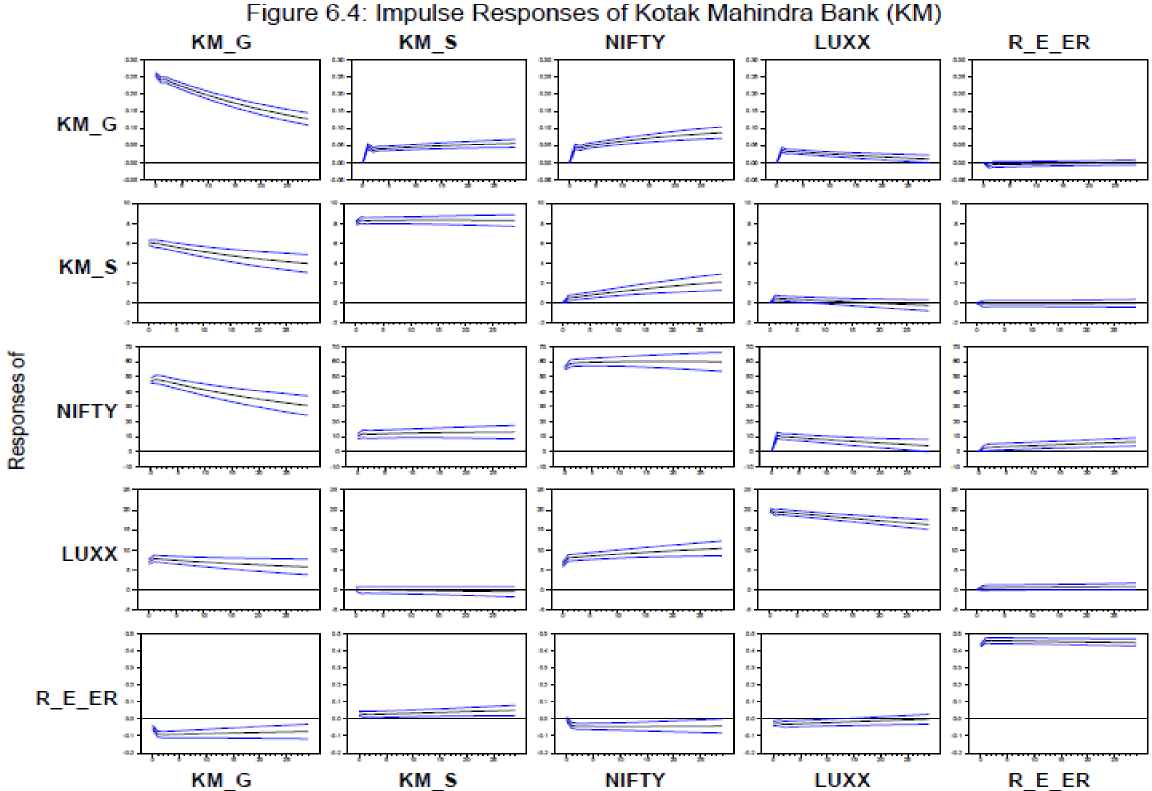


Figure 6.5: Impulse Responses of United Spirits (US)

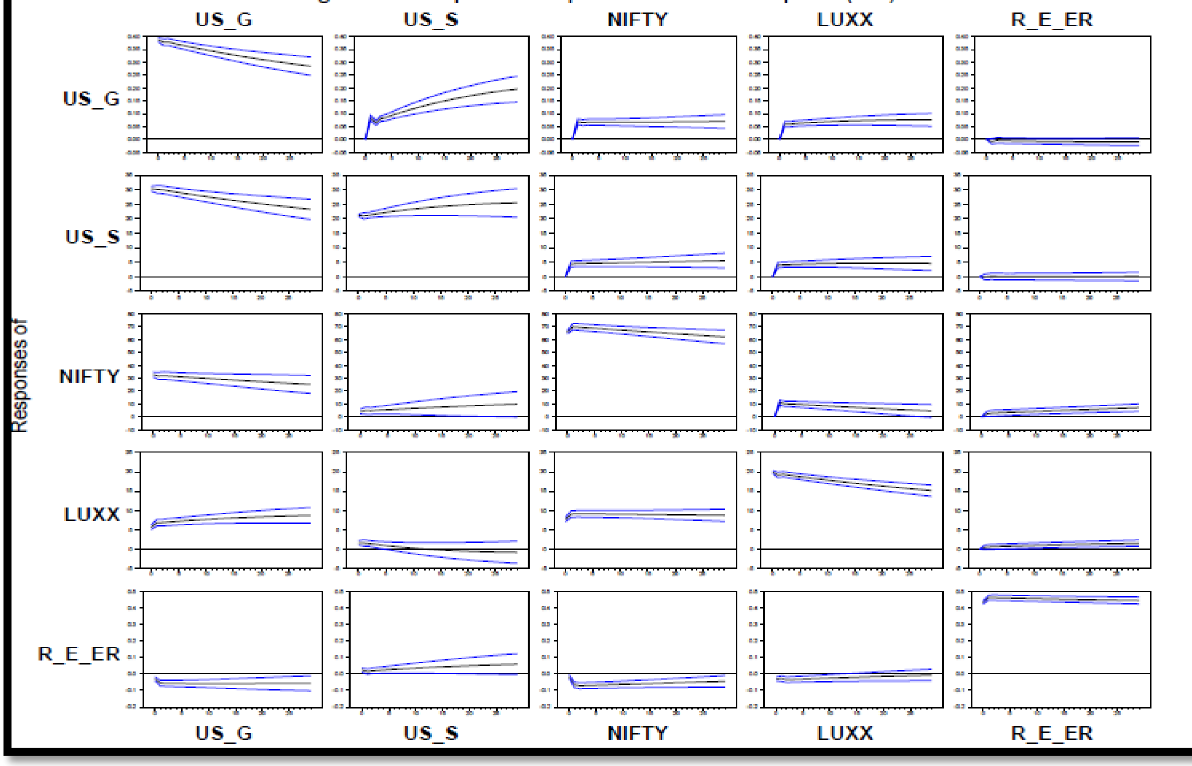


Figure 6.6: Impulse Responses of Tata Motors (TM)

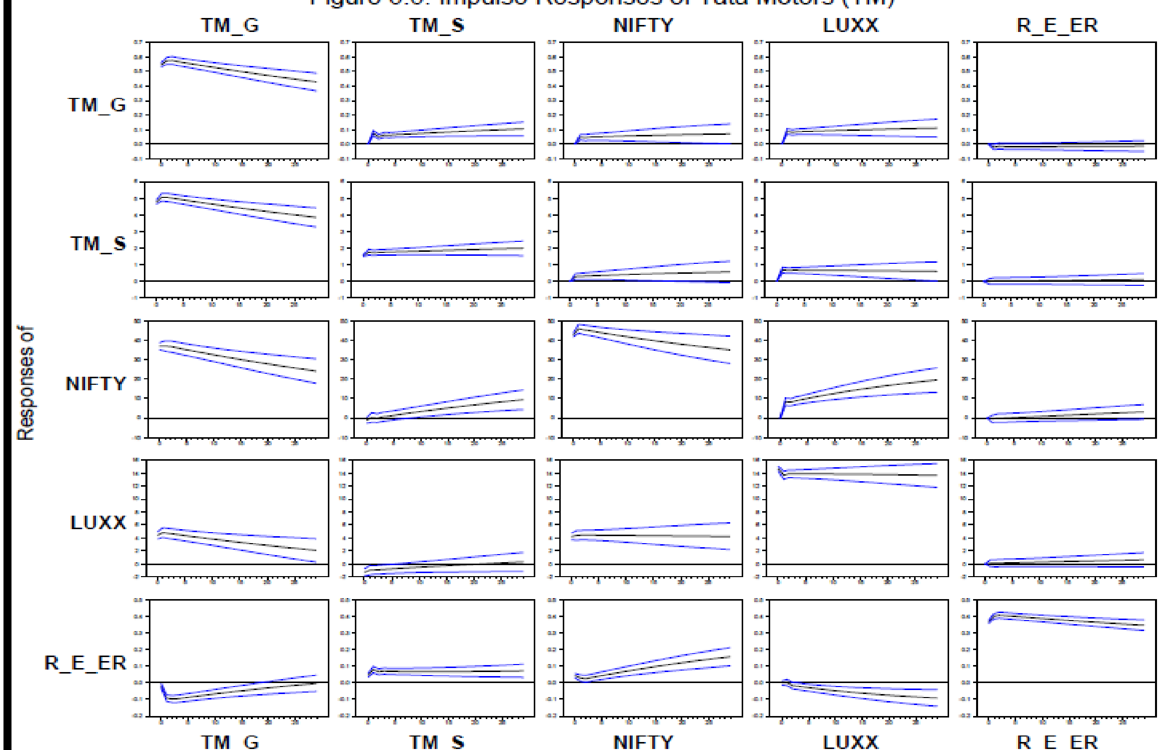


Figure 6.7: Impulse Responses of Tata Power (TP)

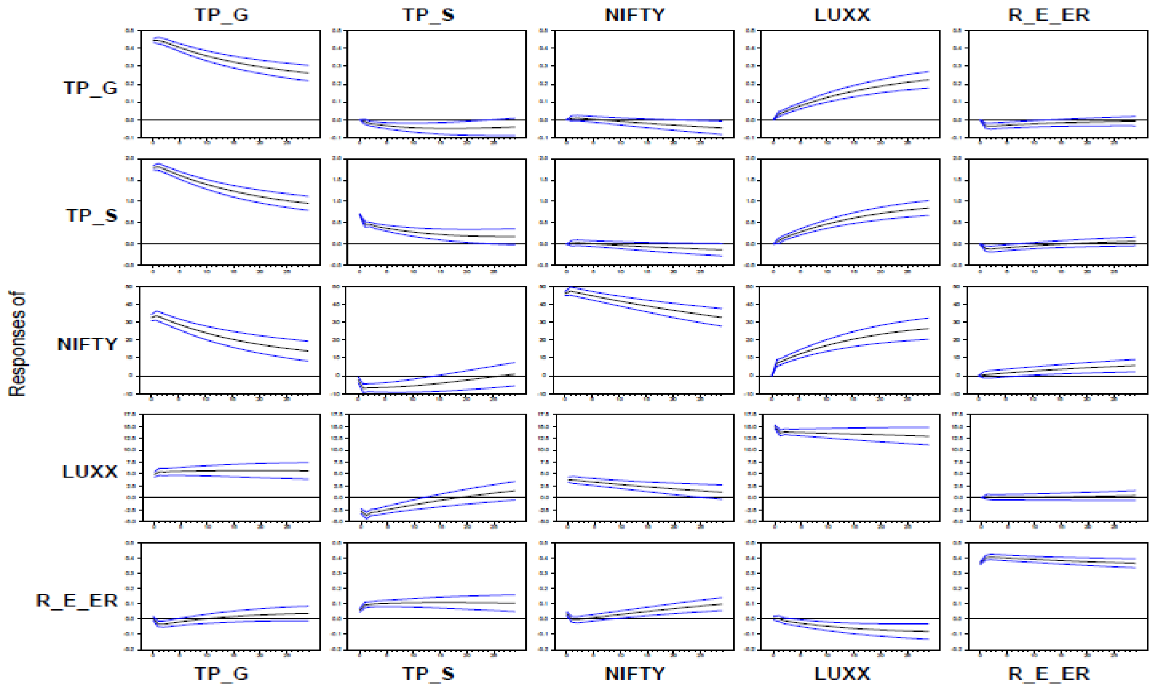


Figure 6.8: Impulse Responses of Sterling International Enterprises (SI)

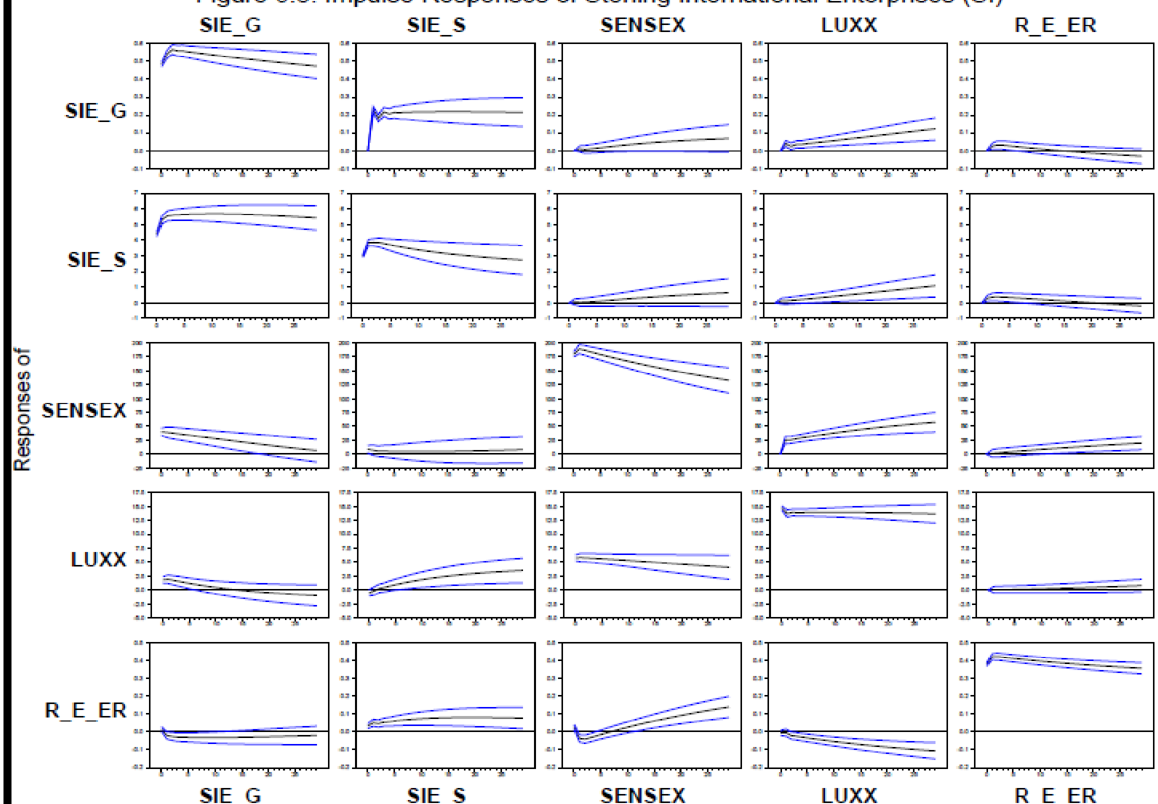


Figure 6.9: Impulse Responses of Larsen & Toubro (LT)

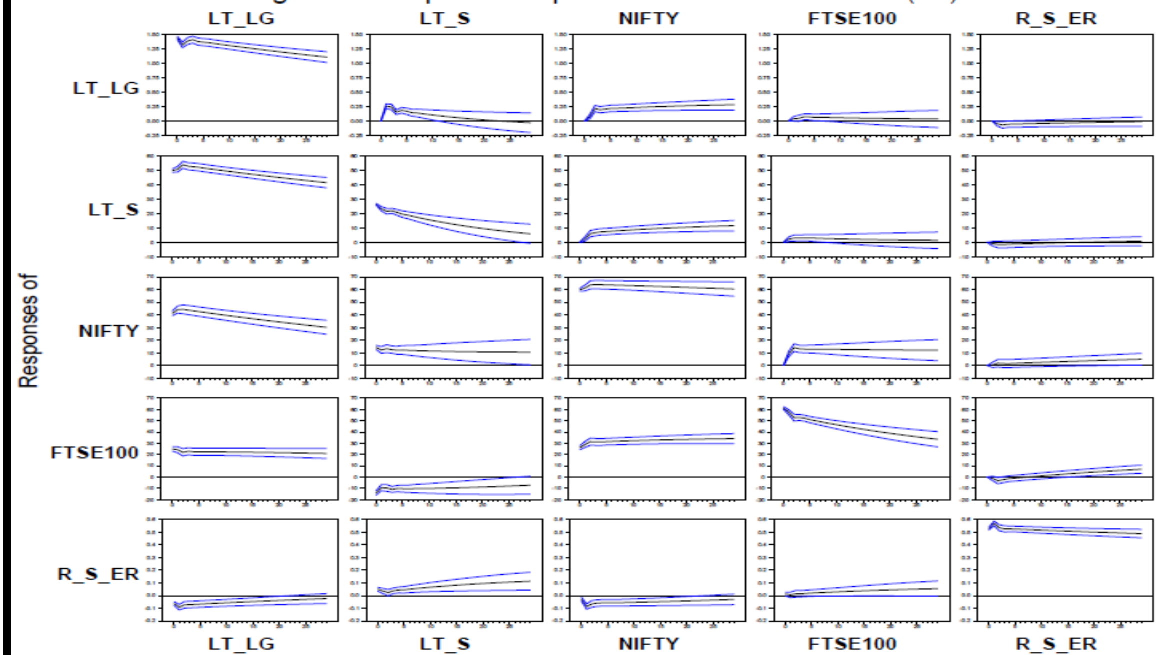


Figure 6.10: Impulse Responses of State Bank of India (SBI)

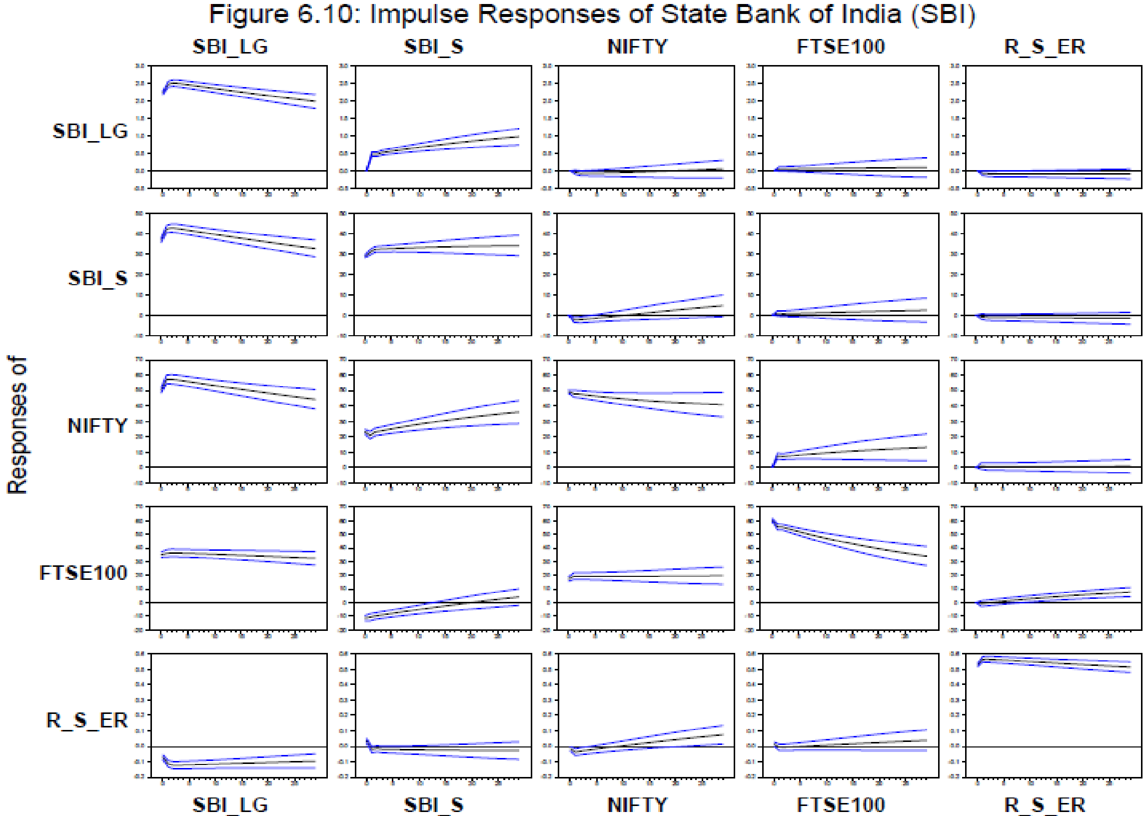


Figure 6.11: Impulse Responses of Axis Bank (AB)

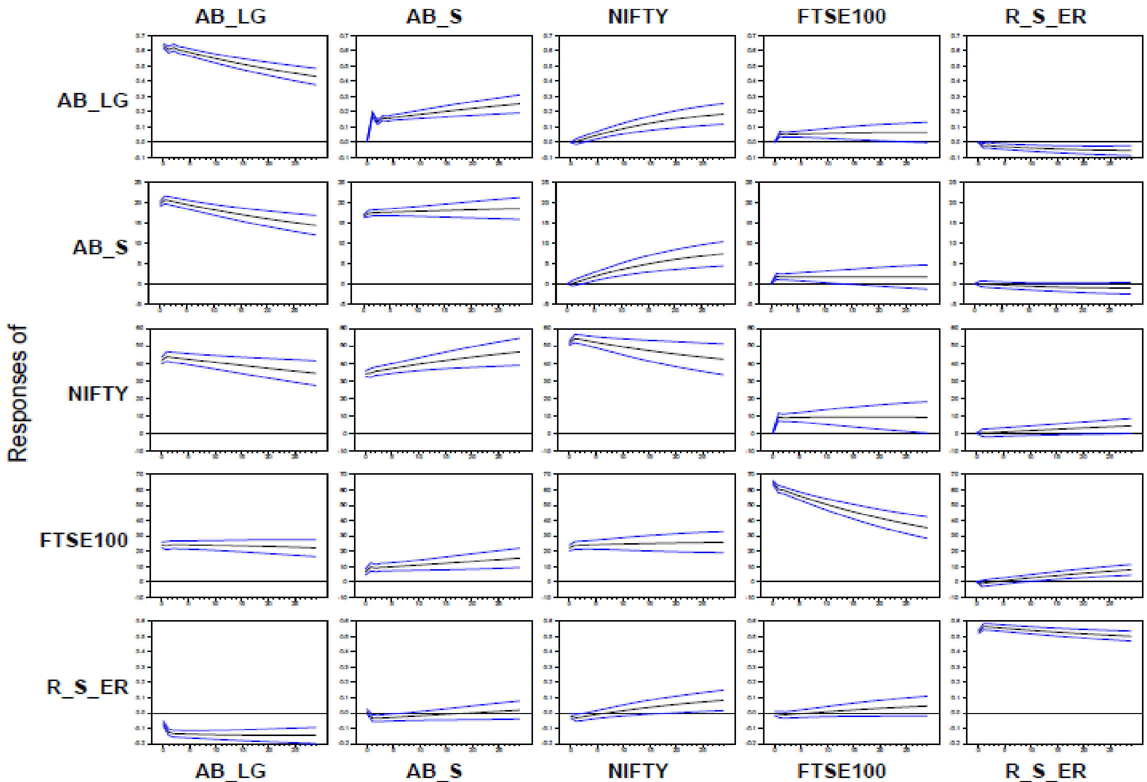


Figure 6.12: Impulse Responses of Tata Steel (TS)

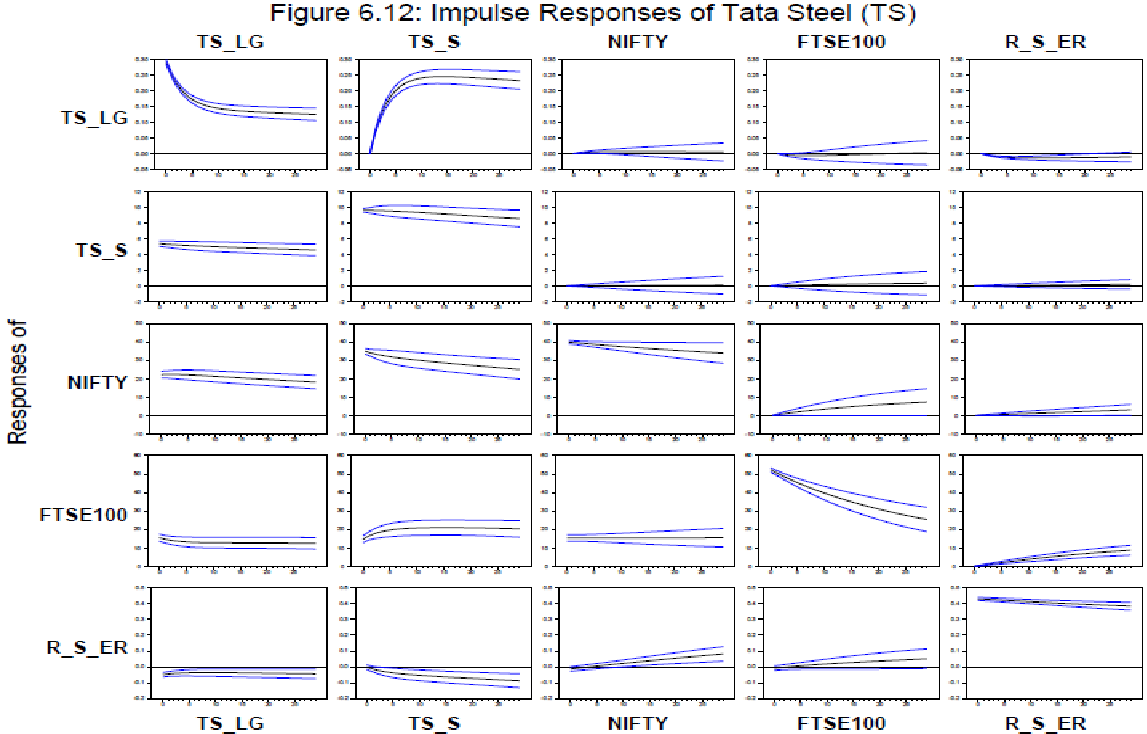


Figure 6.13: Dynamic Conditional Correlations of LuxSE-listed Indian GDRs with their underlying stocks listed in NSE/BSE

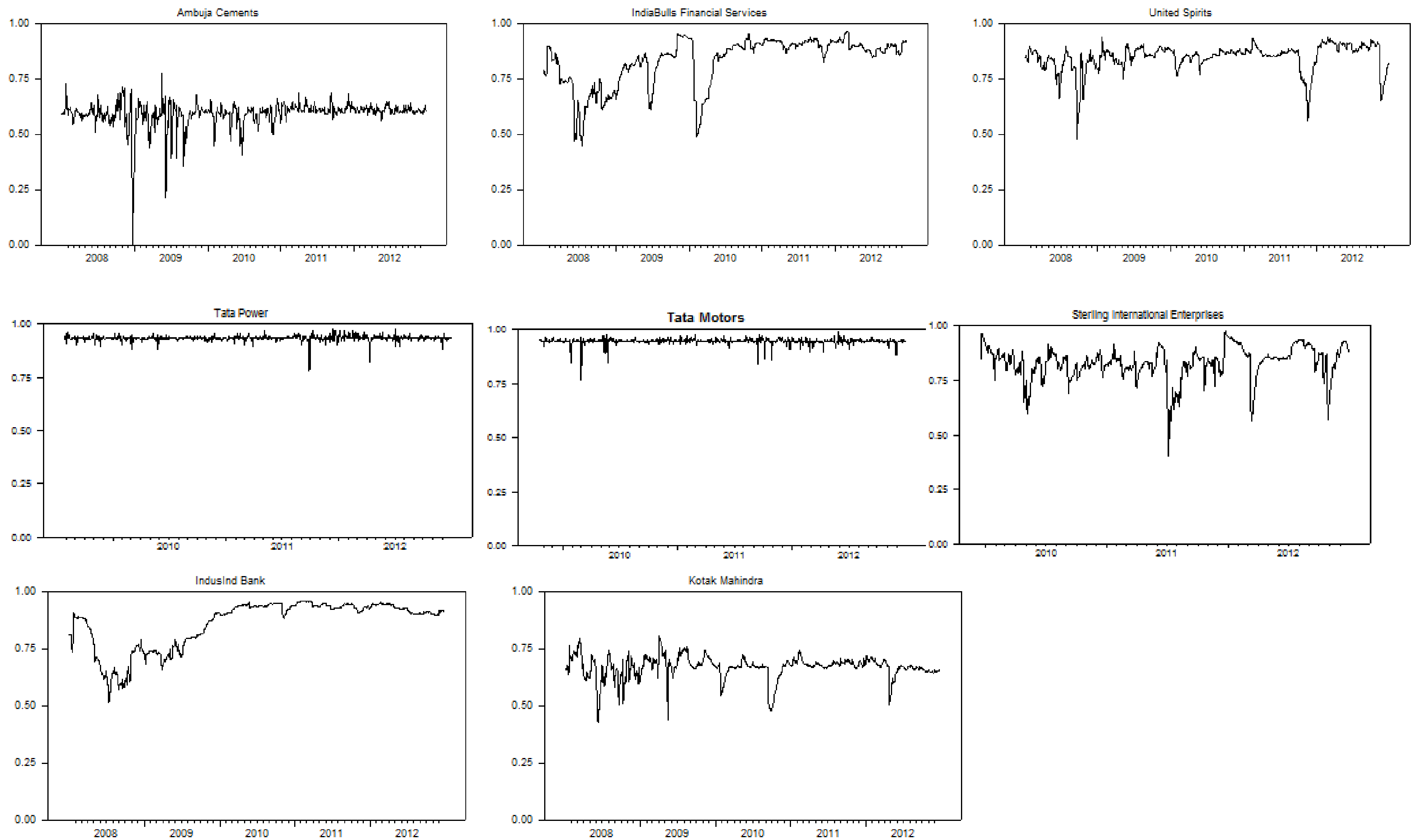
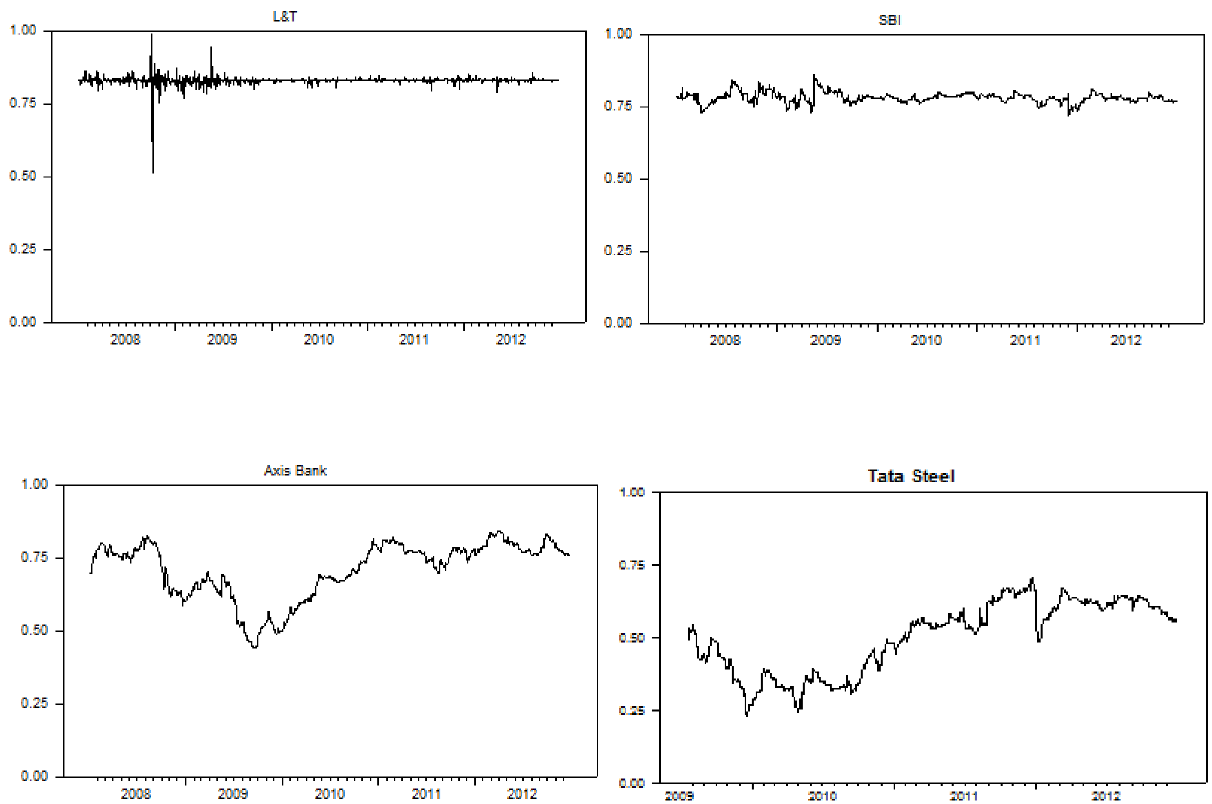


Figure: 6.14: Dynamic Conditional Correlations of LSE-listed Indian GDRs with their underlying stocks listed in NSE



ANNEXURE # 1: DCC GARCH Models of AC, IB and IFS

Panel A1.1: DCC GARCH Model of Ambuja Cements (AC)

	AC_G	AC_S	NIFTY	LuXX	INR-EUR
I. Returns Equations: $E(y_{i,t}/I_{t-1}) = y_{i,t} - r_{i,t)}$					
Constant	6.822e-04 (6.264e-04)	0.00137** (5.496e-04)	7.624e-04** (3.305e-04)	3.092e-04 (3.187e-04)	1.394e-04 (1.642e-04)
II. Volatility Equations: $E(r^2_{i,t}/I_{t-1})$					
Constant	4.690e-06*** (1.761e-06)	1.369e-05*** (3.226e-06)	2.159e-06*** (6.532e-07)	2.053e-06** (8.761e-07)	3.862e-07** (1.744e-07)
$r^2_{i,t-1}$	0.063*** (0.00406)	0.081*** (0.008)	0.090*** (0.009)	0.088*** (0.011)	0.038*** (0.007)
$h_{i,t-1}$	0.930*** (0.004)	0.893*** (0.012)	0.906*** (0.010)	0.906*** (0.012)	0.954*** (0.008)
III. Correlation Equation: $E(\varepsilon_{i,t}\varepsilon_{j,t}/I_{t-1})$					
$\varepsilon_{i,t-1}\varepsilon_{j,t-1}$	0.033*** (0.006)				
$q_{i,j,t-1}$	0.753*** (0.056)				
Algorithm Employed	BHHH				
Number of Iterations for Convergence	82				
$r^2_{i,t-1} + h_{i,t-1}$	0.993	0.975	0.996	0.994	0.992

Panel A1.2: DCC IGARCH Model of IndusInd Bank (IB)

	IB_G	IB_S	NIFTY	LuXX	INR-EUR
I. Returns Equations: $E(y_{i,t}/I_{t-1}) = y_{i,t} - r_{i,t)}$					
Constant	0.002*** (0.001)	0.002*** (0.001)	0.001** (0.000)	0.000 (0.000)	0.000 (0.000)
II. Volatility Equations: $E(r^2_{i,t}/I_{t-1})$					
Constant	0.000*** (0.000)	0.000*** (0.000)	0.000*** (0.000)	0.000*** (0.000)	0.000*** (0.000)
$r^2_{i,t-1}$	0.043*** (0.005)	0.040*** (0.004)	0.050*** (0.006)	0.068*** (0.008)	0.032*** (0.005)
$h_{i,t-1}$	0.957*** (0.005)	0.960*** (0.004)	0.950*** (0.006)	0.932*** (0.008)	0.968*** (0.005)
III. Correlation Equation: $E(\varepsilon_{i,t}\varepsilon_{j,t}/I_{t-1})$					
$\varepsilon_{i,t-1}\varepsilon_{j,t-1}$	0.018*** (0.002)				
$q_{i,j,t-1}$	0.981*** (0.002)				
Algorithm Employed	BFGS				
Number of Iterations for Convergence	39				
$r^2_{i,t-1} + h_{i,t-1}$	1.000	1.000	1.000	1.000	1.000

Panel A1.3: DCC IGARCH Model of IndiaBulls Financial Services (IFS)

	IFS_G	IFS_S	NIFTY	LuXX	INR-EUR
I. Returns Equations: $E(y_{i,t}/I_{t-1}) = y_{i,t} - r_{i,t)}$					
Constant	0.001 (0.001)	0.001 (0.001)	0.001** (0.000)	0.000 (0.000)	0.000 (0.000)
II. Volatility Equations: $E(r^2_{i,t}/I_{t-1})$					
Constant	0.000*** (0.000)	0.000*** (0.000)	0.000*** (0.000)	0.000*** (0.000)	0.000*** (0.000)
$r^2_{i,t-1}$	0.019*** (0.003)	0.020*** (0.002)	0.069*** (0.008)	0.069*** (0.008)	0.030*** (0.005)
$h_{i,t-1}$	0.981*** (0.003)	0.980*** (0.002)	0.931*** (0.008)	0.931*** (0.008)	0.970*** (0.005)
III. Correlation Equation: $E(\varepsilon_{i,t}\varepsilon_{j,t}/I_{t-1})$					
$\varepsilon_{i,t-1}\varepsilon_{j,t-1}$	0.028*** (0.003)				
$q_{i,j,t-1}$	0.967*** (0.004)				
Algorithm Employed	BFGS				
Number of Iterations for Convergence	115				
$r^2_{i,t-1} + h_{i,t-1}$	1.000	1.000	1.000	1.000	1.000

Note:
Three/two/one stars indicate significance at 1%, 5% and 10% respectively. Standard errors are shown within parenthesis.
X_G refers to LuxSE-listed GDR of Company X, while X_S refers to the underlying stock of the company X listed in NSE/BSE.

ANNEXURE # 2: DCC GARCH Models of KM and US

Panel A2.1: DCC GARCH Model of Kotak Mahindra Bank (KM)

	KM_G	KM_S	NIFTY	LuXX	INR-EUR
I. Returns Equations: $E(y_{i,t}/I_{t-1}) = y_{i,t} - r_{i,t)}$					
Constant	9.555e-04 (6.823e-04)	0.002* (0.001)	6.875e-04** (3.380e-04)	3.157e-04 (3.531e-04)	1.231e-04 (1.803e-04)
II. Volatility Equations: $E(r^2_{i,t}/I_{t-1})$					
Constant	2.193e-05*** (5.807e-06)	3.805e-04*** (9.860e-05)	3.468e-06*** (1.063e-06)	2.205e-06** (9.521e-07)	3.572e-07* (2.059e-07)
$r^2_{i,t-1}$	0.102*** (0.017)	0.088*** (0.024)	0.087*** (0.012)	0.088*** (0.013)	0.039*** (0.009)
$h_{i,t-1}$	0.881*** (0.019)	0.691*** (0.075)	0.904*** (0.013)	0.907*** (0.014)	0.954*** (0.011)
III. Correlation Equation: $E(\varepsilon_{i,t}\varepsilon_{j,t}/I_{t-1})$					
$\varepsilon_{i,t-1}\varepsilon_{j,t-1}$	0.030*** (0.006)				
$q_{i,j,t-1}$	0.897*** (0.027)				
Algorithm Employed	BFGS				
Number of Iterations for Convergence	75				
$r^2_{i,t-1} + h_{i,t-1}$	0.983	0.779	0.991	0.995	0.993

Panel A2.2: DCC IGARCH Model of United Spirits (US)

	US_G	US_S	NIFTY	LuXX	INR-EUR
I. Returns Equations: $E(y_{i,t}/I_{t-1}) = y_{i,t} - r_{i,t)}$					
Constant	0.001 (0.001)	0.001 (0.001)	0.001*** (0.000)	0.000 (0.000)	0.000 (0.000)
II. Volatility Equations: $E(r^2_{i,t}/I_{t-1})$					
Constant	0.000 *** (0.000)	0.000 *** (0.000)	0.000 *** (0.000)	0.000 *** (0.000)	0.000 *** (0.000)
$r^2_{i,t-1}$	0.058*** (0.006)	0.060*** (0.004)	0.066*** (0.007)	0.071*** (0.007)	0.033*** (0.004)
$h_{i,t-1}$	0.942*** (0.006)	0.940*** (0.004)	0.934*** (0.007)	0.929*** (0.007)	0.967*** (0.004)
III. Correlation Equation: $E(\varepsilon_{i,t}\varepsilon_{j,t}/I_{t-1})$					
$\varepsilon_{i,t-1}\varepsilon_{j,t-1}$	0.035*** (0.004)				
$q_{i,j,t-1}$	0.920*** (0.010)				
Algorithm Employed	BFGS				
Number of Iterations for Convergence	47				
$r^2_{i,t-1} + h_{i,t-1}$	1.000	1.000	1.000	1.000	1.000

Note:
Three/two/one stars indicate significance at 1%, 5% and 10% respectively. Standard errors are shown within parenthesis.
X_G refers to LuxSE-listed GDR of Company X, while X_S refers to the underlying stock of the company X listed in NSE/BSE.

ANNEXURE # 3: DCC GARCH Models of TM, TP, and SI

Panel A3.1: DCC GARCH Model of Tata Motors (TM)

	TM_G	TM_S	NIFTY	LuXX
I. Returns Equations: $E(y_{i,t}/I_{t-1}) = y_{i,t} - r_{i,t)}$				
Constant	0.002*** (0.001)	0.003*** (0.001)	0.001** (0.000)	0.000 (0.000)
II. Volatility Equations: $E(r^2_{i,t}/I_{t-1})$				
Constant	0.000** (0.000)	0.000*** (0.000)	0.000* (0.000)	0.000* (0.000)
$r^2_{i,t-1}$	0.076*** (0.019)	0.106*** (0.023)	0.047*** (0.013)	0.079*** (0.019)
$h_{i,t-1}$	0.798*** (0.062)	0.702*** (0.077)	0.917*** (0.030)	0.906*** (0.024)
III. Correlation Equation: $E(\varepsilon_{i,t}\varepsilon_{j,t}/I_{t-1})$				
$\varepsilon_{i,t-1}\varepsilon_{j,t-1}$	0.088*** (0.014)			
$q_{i,j,t-1}$	0.115 (0.112)			
Algorithm Employed	BFGS			
Number of Iterations for Convergence	51			
$r^2_{i,t-1} + h_{i,t-1}$	0.874	0.807	0.964	0.985

Panel A3.2: DCC GARCH Model of Tata Power (TP)

	TP_G	TP_S	NIFTY	LuXX
I. Returns Equations: $E(y_{i,t}/I_{t-1}) = y_{i,t} - r_{i,t)}$				
Constant	0.001 (0.001)	0.001 (0.00)	0.001** (0.000)	0.000 (0.00)
II. Volatility Equations: $E(r^2_{i,t}/I_{t-1})$				
Constant	0.000*** (0.000)	0.000*** (0.000)	0.000* (0.000)	0.000* (0.000)
$r^2_{i,t-1}$	0.055*** (0.012)	0.060*** (0.013)	0.065*** (0.018)	0.079*** (0.017)
$h_{i,t-1}$	0.910*** (0.020)	0.904*** (0.020)	0.905*** (0.032)	0.907*** (0.020)
III. Correlation Equation: $E(\varepsilon_{i,t}\varepsilon_{j,t}/I_{t-1})$				
$\varepsilon_{i,t-1}\varepsilon_{j,t-1}$	0.065*** (0.013)			
$q_{i,j,t-1}$	0.223* (0.127)			
Algorithm Employed	BFGS			
Number of Iterations for Convergence	50			
$r^2_{i,t-1} + h_{i,t-1}$	0.965	0.965	0.970	0.985

Panel A3.3: DCC GARCH Model of Sterling International Enterprises (SI)

	SI_G	SI_S	SENSEX	LuXX
I. Returns Equations: $E(y_{i,t}/I_{t-1}) = y_{i,t} - r_{i,t)}$				
Constant	-4.797e-03*** (1.048e-03)	-3.597e-03*** (9.442e-04)	4.999e-04 (3.607e-04)	1.021e-04 (3.751e-04)
II. Volatility Equations: $E(r^2_{i,t}/I_{t-1})$				
Constant	4.071e-04*** (6.056e-05)	2.544e-04*** (3.711e-05)	2.476e-06 (1.538e-06)	2.068e-06* (1.135e-06)
$r^2_{i,t-1}$	0.332*** (0.046)	0.335*** (0.042)	0.069*** (0.020)	0.089*** (0.020)
$h_{i,t-1}$	0.405*** (0.056)	0.456*** (0.049)	0.911*** (0.028)	0.902*** (0.020)
III. Correlation Equation: $E(\varepsilon_{i,t}\varepsilon_{j,t}/I_{t-1})$				
$\varepsilon_{i,t-1}\varepsilon_{j,t-1}$	0.074*** (0.010)			
$q_{i,j,t-1}$	0.830*** (0.024)			
Algorithm Employed	BFGS			
Number of Iterations for Convergence	75			
$r^2_{i,t-1} + h_{i,t-1}$	0.737	0.791	0.980	0.991

Note:
Three/two/one stars indicate significance at 1%, 5% and 10% respectively. Standard errors are shown within parenthesis
X_G refers to LuxSE-listed GDR of Company X, while X_S refers to the underlying stock of the company X listed in NSE/BSE.

ANNEXURE # 4: DCC GARCH Models of LT & SBI

Panel A4.1: DCC IGARCH Model of Larsen & Toubro (LT)

	LT_LG	LT_S	NIFTY	FTSE 100	INR-GBP
I. Returns Equations: $E(y_{i,t}/I_{t-1}) = y_{i,t} - r_{i,t)}$					
Constant	0.001*** (0.000)	-0.002*** (0.000)	-0.037*** (0.001)	-0.035*** (0.001)	-0.028*** (0.001)
II. Volatility Equations: $E(r^2_{i,t}/I_{t-1})$					
Constant	0.000*** (0.000)	0.000*** (0.000)	0.000*** (0.000)	0.000*** (0.000)	0.000*** (0.000)
$r^2_{i,t-1}$	0.772*** (0.027)	0.264*** (0.002)	0.708*** (0.025)	0.480*** (0.016)	0.492*** (0.018)
$h_{i,t-1}$	0.228*** (0.027)	0.736*** (0.002)	0.292*** (0.025)	0.520*** (0.016)	0.508*** (0.018)
III. Correlation Equation: $E(\varepsilon_{i,t}\varepsilon_{j,t}/I_{t-1})$					
$\varepsilon_{i,t-1}\varepsilon_{j,t-1}$	0.254*** (0.005)				
$q_{i,j,t-1}$	0.776*** (0.030)				
Algorithm Employed	BFGS				
Number of Iterations for Convergence	15				
$r^2_{i,t-1} + h_{i,t-1}$	1.000	1.000	1.000	1.000	1.000

Panel A4.2: DCC GARCH Model of STATE BANK OF INDIA (SBI)

	SBI_LG	SBI_S	NIFTY	FTSE 100	INR-GBP
I. Returns Equations: $E(y_{i,t}/I_{t-1}) = y_{i,t} - r_{i,t)}$					
Constant	9.880e-04 (6.338e-04)	8.855e-04 (5.505e-04)	8.049e-04** (3.252e-04)	5.854e-04** (2.848e-04)	1.295e-04 (1.748e-04)
II. Volatility Equations: $E(r^2_{i,t}/I_{t-1})$					
Constant	1.867e-05*** (6.304e-06)	2.123e-05*** (4.884e-06)	5.401e-06*** (1.465e-06)	3.298e-06*** (9.748e-07)	5.336e-07** (2.578e-07)
$r^2_{i,t-1}$	0.057*** (0.013)	0.073*** (0.012)	0.105*** (0.017)	0.092*** (0.016)	0.052*** (0.012)
$h_{i,t-1}$	0.920*** (0.019)	0.895*** (0.017)	0.878*** (0.018)	0.890*** (0.017)	0.937*** (0.015)
III. Correlation Equation: $E(\varepsilon_{i,t}\varepsilon_{j,t}/I_{t-1})$					
$\varepsilon_{i,t-1}\varepsilon_{j,t-1}$	0.013*** (0.004)				
$q_{i,j,t-1}$	0.928*** (0.021)				
Algorithm Employed	BFGS				
Number of Iterations for Convergence	57				
$r^2_{i,t-1} + h_{i,t-1}$	0.977	0.968	0.983	0.982	0.988

Note:
Three/two/one stars indicate significance at 1%, 5% and 10% respectively. Standard errors are shown within parenthesis.
X_LG refers to LSE-listed GDR of Company X, while X_S refers to the underlying stock of the company X listed in NSE

ANNEXURE # 5: DCC GARCH Models of AB and TS

Panel A5.1: DCC IGARCH Model of Axis Bank (AB)

	AB_LG	AB_S	NIFTY	FTSE 100	INR-GBP
I. Returns Equations: $E(y_{i,t}/I_{t-1}) = y_{i,t} - r_{i,t)}$					
Constant	0.002^{**} (0.001)	0.002^{**} (0.001)	0.001^{***} (0.000)	0.001^{**} (0.000)	0.000 (0.000)
II. Volatility Equations: $E(r^2_{i,t}/I_{t-1})$					
Constant	0.000^{***} (0.000)	0.000^{***} (0.000)	0.000^{***} (0.000)	0.000^{***} (0.000)	0.000^{***} (0.000)
$r^2_{i,t-1}$	0.033^{***} (0.005)	0.038^{***} (0.004)	0.052^{***} (0.006)	0.082^{***} (0.010)	0.039^{***} (0.005)
$h_{i,t-1}$	0.967^{***} (0.005)	0.962^{***} (0.004)	0.948^{***} (0.006)	0.918^{***} (0.010)	0.961^{***} (0.005)
III. Correlation Equation: $E(\varepsilon_{i,t}\varepsilon_{j,t}/I_{t-1})$					
$\varepsilon_{i,t-1}\varepsilon_{j,t-1}$	0.014^{***} (0.002)				
$q_{i,j,t-1}$	0.982^{***} (0.003)				
Algorithm Employed	BFGS				
Number of Iterations for Convergence	37				
$r^2_{i,t-1} + h_{i,t-1}$	1.000	1.000	1.000	1.000	1.000

Panel A5.2: DCC GARCH Model of Tata Steel (TS)

	TS_LG	TS_S	NIFTY	FTSE 100	INR-GBP
I. Returns Equations: $E(y_{i,t}/I_{t-1}) = y_{i,t} - r_{i,t)}$					
Constant	0.001 (9.132e-04)	8.362e-04 (6.453e-04)	8.210e-04** (3.455e-04)	6.766e-04** (3.094e-04)	8.295e-05 (1.835e-04)
II. Volatility Equations: $E(r^2_{i,t}/I_{t-1})$					
Constant	2.666e-04*** (5.715e-05)	5.971e-06 (4.495e-06)	2.292e-06* (1.373e-06)	5.481e-06** (2.159e-06)	1.013e-06* (5.272e-07)
$r^2_{i,t-1}$	0.113^{***} (0.027)	0.035^{***} (0.013)	0.045^{***} (0.013)	0.113^{***} (0.027)	0.037^{***} (0.013)
$h_{i,t-1}$	0.547^{***} (0.086)	0.951^{***} (0.021)	0.936^{***} (0.021)	0.841^{***} (0.038)	0.932^{***} (0.024)
III. Correlation Equation: $E(\varepsilon_{i,t}\varepsilon_{j,t}/I_{t-1})$					
$\varepsilon_{i,t-1}\varepsilon_{j,t-1}$	0.013^{***} (0.002)				
$q_{i,j,t-1}$	0.979^{***} (0.005)				
Algorithm Employed	BFGS				
Number of Iterations for Convergence	71				
$r^2_{i,t-1} + h_{i,t-1}$	0.661	0.986	0.981	0.953	0.969

Note:
Three/two/one stars indicate significance at 1%, 5% and 10% respectively. Standard errors are shown within parenthesis.
X_LG refers to LSE-listed GDR of Company X, while X_S refers to the underlying stock of the company X listed in NSE

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