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Article

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Can Crude Oil Futures be the Good Hedging Tool for Tyre Equities? Evidence from India

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ABSTRACT

This article examines the cross-hedging performance of crude futures against the tyre equity futures to hedge the tyre equity stocks. Three multivariate conditional volatility models, namely constant conditional correlation (CCC), dynamic conditional correlation (DCC) and diagonal BEKK are applied. Using the conditional covariance and variance from the MGARCH estimates, the optimal hedge ratios (OHRs) are computed. The results of this study show that the volatility spillover exists between the returns of crude oil futures and tyre equity. However, for tyre equities, the best cross hedge is tyre equity futures rather than crude futures. All the MGARCH estimates show better hedging possibility with tyre equity futures, particularly MRF futures.

Keywords: Constant Conditional Correlation, Crude Future, Dynamic Conditional Correlation, Diagonal BEKK, Tyre Equity, Tyre Equity Futures
JEL Classifications: G21; G30

1. INTRODUCTION

The tyre industry in India contributes 3% for manufacturing GDP and 0.5% for the total GDP. The growth of this industry is more than the automobile industry which is considered as the mother for tyre industry. Presently, India is a marginal player in the world tyre market, but opportunities are tremendous because of the economies of scale, increasing income level of the people and easy access to core raw material rubber (Ghosh et al., 2011). With these strong fundamentals, we believe that the investor's interest in tyre equities is very high to earn a good amount of dividend and capital appreciation. However, on the other hand, a couple of studies have mentioned volatile raw material price pressure as well. For example, Meher et al. 2020; Daddikar and Rajgopal, (2016); Kansara, (2018); Shyam, (2019) have studied the impact of volatile crude oil price and synthetic rubber price on the performance of tyre manufacturing equities in India. The increased cross border movements of goods and services have increased volatility in Indian equity market (Pinto et al., 2020; Kumar et al., 2020; Bagchi, 2017; Pandey and Vipul, 2018; Bolar et al., 2017; Hawaldar, 2018; 2016). In a volatile market, investors will look for a hedging tool to minimize the risk of loss for their portfolio. The future derivative with an active market and great volume will be the right tool to hedge the risk portfolio. However, from the Indian tyre equity perspective, a couple of large-cap tyre equities have direct futures and many other medium or small-cap are not traded in the futures and options market. This paper investigates the possibility of a cross hedge for tyre equity stocks in India using crude oil futures traded at MCX India and two actively traded tyre equity futures (Hawaldar et al., 2017a; 2017b; Iqbal, 2015; 2014).

Cross hedge with commodity futures for equity and vice versa has become the subject of interest today with many academicians and practitioners (Iqbal, 2011; Wang and Lee, 2016; Mallikarjunappa and Iqbal, 2003). Crude oil or other energy futures are the actively traded derivatives in several economies and cross hedge with these instruments are widely examined by many researchers. For example, Batten et al. (2017; 2019) stated that the areas of stock and energy sector integrations are critical to managing the risk. Xu (2020) found a negative correlation between the crude oil and the equity returns in the global portfolio of equities. A study by Singh and Sharma (2018) states that for variables crude oil and Sensex, the long-run equilibrium relationship is evident during and pre-crisis phase. Chunhachinda et al. (2018) studied that for Latin American stocks, commodity hedging will be more effective to reduce the portfolio risk but these are more expensive strategies. Olson et al. (2018) studied that the oil and gas equity index was the most effective cross hedge for energy stocks; Abul and Sadorsky (2015) studies the possibility of cross hedge for equity using oil, bond and gold futures. The chance for the cross hedge of equities in the US with energy commodities during the stock market crisis is very high (Junttila et al., 2018). Ahmad et al. (2018) cited a couple of examples for a cross hedge of clean energy equities with crude oil futures and their study revealed that crude oil future is the second-best asset to hedge the clean energy equities. Dutta (2018) claim that equity hedging using oil futures is common. A studies by Meher et al., (2021); Kumar and Maheswaran, (2013); Iqbal and Mallikarjunappa, (2011; 2010) found evidence of return and volatility effects of the oil market on the Indian manufacturing sector. Further, Kansara (2018) in his article in Business line stated that the tyre stocks skid on rising oil prices. To narrate from the above cited studies, the manufacturing industries performance is affected by the volatile oil price and many studies have shown the relationship between oil price and equity market movements. Couple of studies have examined the possibility of cross hedge with crude for equities. However, the study on hedging strategies for Indian tyre equities is not covered so far in the academic literatures. Hence, the possibility of a cross hedge for Indian tyre equities with crude futures or available tyre futures have become the purpose of this empirical study.

Traditionally, the OLS method was used in many studies to compute the minimum variance hedge ratio, but the constant variance and covariance assumption of this model was strongly criticised by many academicians and practitioners in the area of statistics and econometrics. Hence, to compute the minimum variance hedge ratio, researchers today are widely using conditional covariance and variance from the family of multivariate GARCH.

2. CROSS HEDGING: MILESTONES IN METHODOLOGY AND THE PRESENT STATUS

Pioneering studies on hedging and cross hedging by (Johnson, 1960; Ederington, 1979; Miller, 1985; Miller and Luke, 1986) have applied the linear OLS method to estimate the optimal hedge ratio. Grant and Eaker (1989) have used the OLS method to compare the cross hedge effectiveness of different agricultural commodities. Benet (1990) has employed the OLS method to examine the possibility of cross hedge using commodity futures to minimise foreign exchange risk. Braga and Martin (1990) employed Anderson's revised OLS technique to examine the feasibility of cross hedge for Soybean meal price with Soybean futures. This was continued for a period of 15–20 years, where researchers were using linear OLS regression of changes in the price of cash asset on changes in the price of futures (Kumar et al., 2018; Iqbal and Mallikarjunappa, 2009; 2007). Thereby the beta coefficient (constant slope) of the regression equation will become the optimal hedge ratio. Nelson and Plsser (1982) stated that the macroeconomic time series will depict serial correlation and the predictions of these series using OLS are useless. Hence, to overcome this problem, Benninga et al. (1983) suggested the use of the log return series in the regression model to avoid spurious constants in hedging. Dahlgran (2000) and Kim et al. (2015) have used log return series to compute the hedge ratio using the OLS method. The general form of the OLS regression is shown in the following equation. In the following equation, the TE_t is the logged returns of the tyre equity spot prices and CF_t is log-returns of crude oil futures prices with maturity T:

$$\log TE_t - \log TE_{t-1} = a + b\left(\log CF_{t,T} - \log CF_{t-1,T}\right) + \varepsilon_t \quad (2.1)$$

Where b in the above equation is the estimated minimum variance hedge ratio.

However, Eq. (2.1) ignores the lagged values of future and cash return series which leads to serially correlated errors. Chang et al. (2011) claim that the financial asset variance and covariance are time-varying. Baillie and Myers (1991) states that the covariance of spot and futures prices are time-varying. In addition, Adams and Gerner (2012) opined that the OLS approach does not capture time-varying conditional volatility. Thus, the recent studies in the field of hedge ratio estimation have employed and suggested to use of the Generalised Autoregressive Conditional Heteroskedasticity (GARCH) model of (Bollerslev, 1986; Engle, 1982). For example, Abul and Sadorsky (2015) concluded that to hedge stock price with oil, the hedge ratio using the Asymmetric Dynamic Conditional Correlations (ADCC) model from the family of MGARCH is most effective. Ahmad et al. (2018) have applied MGARCH family models (DCC, ADCC and GO- GARCH) to estimate the time-varying optimal hedge ratios for clean energy equities. Chunhachinda et al. (2018) use the DCC – GARCH model to find the dynamic correlations between commodities and international equity portfolios. Cifarelli and Paladino (2015); Kim and Park (2016) uses bivariate GARCH models to estimate the time-varying conditional correlation. Sharma and Rodriguez (2019) have used the DCC GARCH model to analyse the hedging role of crude oil in the equity market of the United States. The asymmetric Power Arch (APARCH) model was adopted by Bagchi (2017) to analyse the relationship between crude oil price volatility and BSE Sensex. Pandey and Vipul (2018) uses the multivariate GARCH model BEKK to examine the volatility spillover from crude oil to the BRICS stock market.

The purpose of this research is two-fold. Former, we estimate three MGARCH models, namely CCC, DCC and diagonal BEKK for the returns on spot tyre equity prices with two tyre equity futures and crude oil futures prices. Later, we calculate the Optimal Hedge Ratios (OHRs) for effective hedging strategies.

3. ECONOMETRIC MODELS

3.1. Multivariate Conditional Volatility Models

The CCC model of Bollerslev (1990) assumes constant conditional correlations, while the DCC model of Engle (2002) and the BEKK model of Engle and Kroner (1995) accommodate dynamic conditional correlations. Consider the multivariate GARCH model CCC of Bollerslev (1990).

$$y_t = E(y_t ç F_{t-1}) + e_t \quad (3.1)$$

$$\text{Var}\left(\varepsilon_t F_{t-1}\right) = \Omega_t$$

Where F_{t-1} is the - area quantified by all the available information till time t–1 and Ω_t is the conditional covariance matrix, which is positive definite and symmetric.

$$\Omega_t = \begin{pmatrix} \sigma_{CF,t} & 0 \\ 0 & \acute{o}_{TE,t} \end{pmatrix}\begin{pmatrix} 1 & \rho \\ \rho & 1 \end{pmatrix}\begin{pmatrix} \sigma_{CF,t} & 0 \\ 0 & \sigma_{TE,t} \end{pmatrix} \quad (3.2)$$

$$\Omega = \begin{pmatrix} \sigma_{CF,t}{}^2 & \rho.\sigma_{CF,t}.\sigma_{TE,t} \\ \rho.\sigma_{CF,t}.\sigma_{TE,t} & \sigma_{TE,t}{}^2 \end{pmatrix}$$

Ω_t has a particular decomposition of three matrices. The first and third matrix in Eq. 3.1 is diagonal matrices, where the diagonal elements are given by the conditional standard deviations of the logged returns of the crude future (CF) and tyre equity (TE) price series. The second matrix is the conditional correlation matrix, where the element ρ in the matrix is a conditional correlation between the return series of crude future and tyre equity. The first element in the resultant matrix of the decomposed matrices is the conditional variance of the crude future return series and the second diagonal element is the variance of the tyre equity return series. The off-diagonal elements in the resultant matrix are the rho times the conditional standard deviations of the two-return series. The $\sigma_{CF,t}{}^2$ and $\sigma_{TE,t}{}^2$ in Ω_t matrix are given by Eq. (3.3), they are the univariate GARCH (1,1) specifications.

$$\sigma_{CF,t}{}^2 = \alpha_{CF} + \alpha \in^2_{CF,t-1} + \beta_{CF}\sigma_{CF,t-1}{}^2 \quad (3.3)$$

$$\sigma_{TE,t}{}^2 = \alpha_{TE} + \alpha \in^2_{TE,t-1} + \beta_{TE}\sigma_{TE,t-1}{}^2$$

The CCC model assumes that conditional correlation ρ is constant over time. Engle (2002) extended the CCC MGARCH to accommodate the dynamic correlationin within the model. For the conditional covariance matrix in Eq. (3.2).

$$\text{The covariance matrix } \Omega_t = D_t R_t D_t \quad (3.4)$$

The D_t, R_t, D_t in Eq. (3.4) are the decomposed matrices of covariance matrix Ω_t. The D_t and D_t are the diagonal matrices, where the conditional standard deviations of the logged returns of the crude future (CF) and tyre equity (TE) price series are vectors. The conditional standard deviations are given by Eq. (3.3), which are the univariate GARCH (1,1) specifications. The second matrix is the dynamic conditional correlation matrix; the off-diagonal elements in this matrix are the dynamic conditional correlation ρ_t between the return series of crude future and tyre equity. The general formation of R_t as that appeared in Engle (2002) work is presented in Eq. 3.5.

$$R_t = \left(diag\left(Q_t\right)\right)^{-\frac{1}{2}} Q_t \left(diag\left(Q_t\right)\right)^{-\frac{1}{2}} \quad (3.5)$$

$$Q_t = S\left(1 - \alpha - \beta\right) + \alpha\left(\varepsilon_{CF,t-1}\varepsilon_{TE,t-1}\right) + \beta Q_{t-1} \quad (3.6)$$

Where Q_t is the dynamic covariance matrix of the standardised epsilons, S is the unconditional correlations of $\varepsilon_{CF,t}$ $\varepsilon_{TE,t}$ and $(\alpha+\beta)<1$. This implies that $Q_t > \mathbf{0}$, if $\alpha = \beta = 0$, Q_t in Eq. 3.6 is as same as CCC. As Q_t is conditional on the vector of standardised epsilons, Eq. 3.6 is a conditional covariance matrix, and S is the unconditional correlations of $\varepsilon_{CF,t}$ $\varepsilon_{TE,t}$. This DCC method of estimation is a simple two-step method using the likelihood function, while the DCC is not linear (Chang et al., 2013).

An alternative time-varying conditional model used in many hedging strategy studies is the BEKK model. Chang et al. (2013) and Chang et al. (2011) opined that the positive definite conditional covariance matrices in BEKK are the attractive property in it. The general formation of BEKK multivariate GARCH (11) is presented in Eq. 3.7.

$$H_t = C'C + A'\varepsilon_{t-1}\varepsilon'_{t-1}A + B'H_{t-1}B \quad (3.7)$$

Where *C, A* and *B* in the above equation are individual element of the matrices, and they are given as

$$A = \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix}, B = \begin{bmatrix} b_{11} & b_{12} \\ b_{21} & b_{22} \end{bmatrix}, C = \begin{bmatrix} C_{11} & 0 \\ C_{21} & C_{22} \end{bmatrix}$$

The study of Caporin and McAleer (2008; 2009) has critically compared the BEKK and DCC model of multivariate GARCH, where the diagonal version of BEKK is also discussed there in detail.

3.2. Optimal Hedge Ratios

To compute the optimal hedge ratios, we have used the conditional covariance matrix obtained from different multivariate GARCH models. Eq. 3.8. is used to compute the OHR (optimal hedge ratio) from conditional covariance for tyre equity spot with tyre equity futures and crude futures.

$$\gamma^*_t \middle| \Omega_{t-1} = \frac{h_{SF,t}}{h_{F,t}} \quad (3.8)$$

Where, h_{SF},t is the conditional covariance of the spot tyre equity returns with the two tyre futures and crude futures return. The $h_{F,t}$ is the conditional variance of tyre futures and crude futures. For full deriviation of Eq. 3.8. (Chang et al., 2013; Chang et al., 2011; Tansuchat et al., 2010).

4. DATA

The daily closing prices of selected tyre equities, two nearby tyre equity futures and nearby crude futures (that is the futures contract for which the maturity is very nearby to the present date) are used in this empirical study. 10 listed tyre manufacturing companies equities are selected based on their trade volume in NSE (National Stock Exchange) India. The selected companies are Apollo, Balakrishna, Ceat, Goodyear, Govind, JK Tyres, Krypton, MRF, PTL and TVS. After adjustment for missing values, the 3167 price observations from June 21, 2005 to September 8, 2020 are obtained from the official websites of NSE India and MCX India. However, the tyre equity futures daily observations were available from November 1, 2010 hence, the 2138 price observations till September 8, 2020 are obtained from the official website of NSE India. The logged returns futures prices and select tyre equity prices are computed using the log function $r_{ji,t} = \ln(\frac{P_{ij,t}}{P_{ij,t-1}})$, where $P_{ij,t}$ and $P_{ij,t-1}$ are the closing prices of crude futures and tyre equity returns for days t and t-, respectively.

Table 1 shows the descriptive statistics for the prices and logged returns of crude futures tyre equity futures and the selected tyre equities. The mean returns of futures and spot tyre equities are very low, but the corresponding standard deviations of returns are much higher. The presence of fat tails is evident from the very high kurtosis for all the return series. The negative skewness statistics for Apollo, Balakrishna, Crude futures, JK tyresPTL MRF futures and Apollo futures indicates the extreme losses (longer left tail). The right tail or the gain is evident from the positive skewness statistics in Ceat, Goodyear, Govind, Krypton and TVS return series. The Jarque-Bera statistics of all the return series signify that the series are not normally distributed.

The Augmented Dickey-Fuller (ADF) unit root tests for the price level series except for JK tyres in Table 2 are not statistically significant at 1% level. So, they are not stationary or they contain a unit root. However, all the return series of selected tyre equity, tyre futures and crude futures are stationary and hence are I (1).

Table 3 presents the computed Pearson correlation coefficients of the closing prices of crude futures and the spot tyre equity. Except for Goodyear and JK tyres, the prices of other tyre equities are negatively correlated with crude futures price. Rubber is the core raw material used in the production of tyres. The Indian tyre industry is depending on supplies from the natural rubber and synthetic rubber sector. (Misurelli and Cantrell, 1997) stated that the final products of crude namely butadiene, styrene and acrylonitrile are the core ingredients for manufacturing synthetic rubber. Moreover, (Kansara, 2018) stated in a business paper that Indian tyre stocks are skidding on rising crude prices. In such situations, hedging a tyre equity portfolio with crude futures may serve the risk management purpose. An investor, who is long with tyre equity, may take a short position with crude futures and vice versa. Alternatively, the cross hedge with other tyre equity futures is also an option. The equity prices of Apollo, Balakrishna, Ceat, Goodyear and TVS are highly positively correlated with MRF futures prices and the equity prices of Govind JK tyre and Krypton are

Table 1: Descriptive statistics

Panel a: tyre stock and crude oil future returns							
Returns	**Mean**	**Maximum**	**Minimum**	**Std. Dev.**	**Skewness**	**Kurtosis**	**Jarque-Bera**
Apollo	−0.00025	0.18	−2.24	0.05	−30.81	1418.46	264885034.26
Balakrishna	0.00019	0.18	−1.64	0.04	−19.79	726.02	69188609.91
Ceat	0.00072	0.26	−0.15	0.03	0.88	10.58	7994.12
Crude	0.00002	0.22	−0.33	0.02	−0.16	22.73	51387.67
Goodyear	0.00081	0.22	−0.21	0.03	0.74	12.61	12464.38
Govind	−0.00058	0.29	−0.36	0.04	0.36	7.43	2658.22
JK Tyre	−0.00018	0.17	−1.45	0.04	−14.44	521.74	35618675.14
Krypton	−0.00043	0.57	−0.40	0.04	0.65	16.49	24221.97
MRF	0.00100	0.18	−0.38	0.02	−0.22	27.45	78907.92
PTL	0.00013	0.41	−1.59	0.05	−11.64	359.25	16818358.02
TVS	0.00096	0.25	−0.17	0.03	0.74	9.37	5648.80
Apollo Futures	0.00021	0.11	−0.28	0.03	−0.87	11.19	6249.10
MRF futures	0.00085	0.11	−0.16	0.02	−0.07	8.33	2529.52
Panel b: tyre stock and crude oil future prices							
Prices	**Mean**	**Maximum**	**Minimum**	**Std. Dev.**	**Skewness**	**Kurtosis**	**Jarque-Bera**
Apollo	145.13	401.40	15.36	88.01	0.397	2.08	195.42
Balakrishna	682.97	2494.60	114.30	405.34	0.906	4.07	585.82
Ceat	567.50	2003.35	31.70	547.02	0.750	2.29	363.30
Crude	3910.80	7201.00	1289.00	1069.93	0.516	2.62	159.72
Goodyear	467.44	1274.05	55.15	316.56	0.608	2.23	273.73
Govind	17.05	53.70	0.87	9.34	0.476	3.14	122.34
JK Tyre	125.26	680.20	30.25	73.27	3.825	22.86	59773.12
Krypton	20.02	98.55	6.19	13.00	2.599	11.20	12441.74
MRF	27319.20	80821.00	1537.95	24815.11	0.615	1.83	381.33
PTL	45.90	170.90	6.50	33.50	1.745	5.08	2176.02
TVS	1182.77	4213.45	46.00	1246.62	0.776	2.11	423.90
Apollo Futures	157.42	299.55	46.40	68.16	0.06	1.78	134.59
MRF futures	37817.45	81202.70	5559.45	23477.97	0.09	1.56	186.91

Table 2: Augmented Dickey-Fuller test for unit root

Panel a: tyre stock and crude oil future prices					
Prices	**t - Statistic**	**Test critical values**			**P-value**
		1% level	**5% level**	**10% level**	
Apollo	−2.45	−3.43	−2.86	−2.57	0.13
Balakrishna	−2.02	−3.43	−2.86	−2.57	0.28
Ceat	−1.07	−3.43	−2.86	−2.57	0.73
Crude	−2.21	−3.43	−2.86	−2.57	0.20
Goodyear	−0.95	−3.43	−2.86	−2.57	0.77
Govind	−2.68	−3.43	−2.86	−2.57	0.08
JK Tyre	−4.01	−3.43	−2.86	−2.57	0.00
Krypton	−2.91	−3.43	−2.86	−2.57	0.04
MRF	−0.58	−3.43	−2.86	−2.57	0.87
PTL	−3.15	−3.43	−2.86	−2.57	0.02
TVS	−1.12	−3.43	−2.86	−2.57	0.71
Apollo Futures	−1.60	−3.43	−2.86	−2.57	0.48
MRF Futures	−1.02	−3.43	−2.86	−2.57	0.74
Panel b: tyre stock and crude oil future returns					
Returns	**t-statistic**	**Test critical values**			**P-value**
		1% level	**5% level**	**10% level**	
Apollo	−21.71	−3.43	−2.86	−2.57	0.000
Balakrishna	−92.20	−3.43	−2.86	−2.57	0.000
Ceat	−49.34	−3.43	−2.86	−2.57	0.000
Crude	−51.44	−3.43	−2.86	−2.57	0.000
Goodyear	−48.26	−3.43	−2.86	−2.57	0.000
Govind	−46.11	−3.43	−2.86	−2.57	0.000
JK Tyre	−48.65	−3.43	−2.86	−2.57	0.000
Krypton	59.78	−3.43	−2.86	−2.57	0.000
MRF	−48.71	−3.43	−2.86	−2.57	0.000
PTL	−71.96	−3.43	−2.86	−2.57	0.000
TVS	−51.42	−3.43	−2.86	−2.57	0.000
Apollo Futures	−46.24	−3.43	−2.86	−2.57	0.001
MRF Futures	−21.88	−3.43	−2.86	−2.57	0.000

Entries in bold indicate that the null hypothesis is rejected at the 1% level

Table 3: Correlation between crude futures and tyre equity price and return series

Tyre equity	**Crude futures**		**MRF equity futures**		**Apollo equity futures**	
	Price series	**Return series**	**Price series**	**Return series**	**Price series**	**Return series**
Apollo	−0.21	0.041	0.83	0.57	1.000	0.99
Balakrishna	−0.30	0.047	0.88	0.16	0.787	0.16
Ceat	−0.18	0.054	0.92	0.51	0.906	0.49
Goodyear	0.04	0.049	0.96	0.39	0.837	0.38
Govind	−0.14	0.015	−0.19	0.27	0.147	0.23
JK Tyre	0.26	0.033	−0.01	0.30	0.334	0.32
Krypton	−0.21	0.049	−0.50	0.05	−0.352	0.06
MRF	−0.10	0.030	1.00	0.99	0.833	0.56
PTL	−0.28	0.025	0.26	0.18	0.323	0.17
TVS	−0.23	0.056	0.84	0.32	0.850	0.32

Entries in bold indicate that the correlation values are significant at the 5% level

negatively correlated. Similarly, the correlation of Balakrishna, Ceat, Goodyear, MRF and TVS equity prices are highly positive with Apollo futures.

Figure 1 presents the line graph of crude futures, tyre futures and selected tyre equity prices. Apollo, Balakrishna, Ceat, Goodyear, MRF and TVS equity prices move in the same direction. But these price line charts are in a slightly opposite direction to the crude futures price graph, suggesting they are negatively correlated. Hawaldar et al., (2017) and Hawaldar and Kumar (2017) stated that the global oil sector was in recession during the period from 2014 till 2016, the tyre equity and tyre futures in Figure 1 show upward trend during this oil price crisis period. Figure 2 shows the price line chart of crude futures and selected tyre equity returns. This depicts volatility clustering in the series. Volatility clustering is evident in Ceat, Goodyear, Govind, Krypton, MRF, TVS, MRF futures, Apollo futures and crude futures price series. The periods of high volatility are followed by periods of relatively high volatility and vice versa.

5. EMPIRICAL RESULTS AND INTERPRETATION

The multivariate conditional volatility models in this study are estimated with help of STATA 15 and EViews 10 packages for

Figure 1: Tyre equity spot, tyre futures and crude futures prices

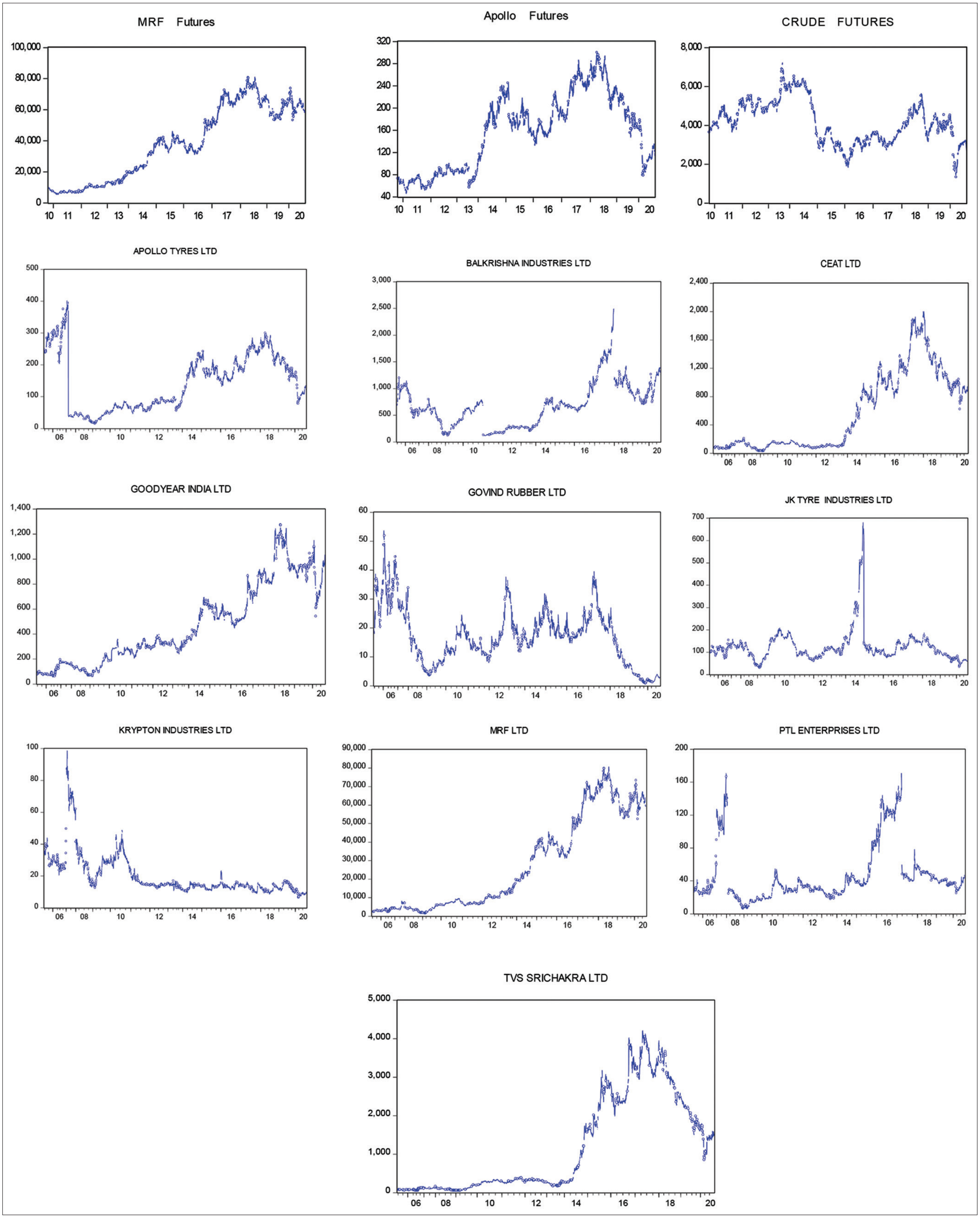


Figure 2: The logarithm of daily tyre equity spot, tyre futures and crude futures returns

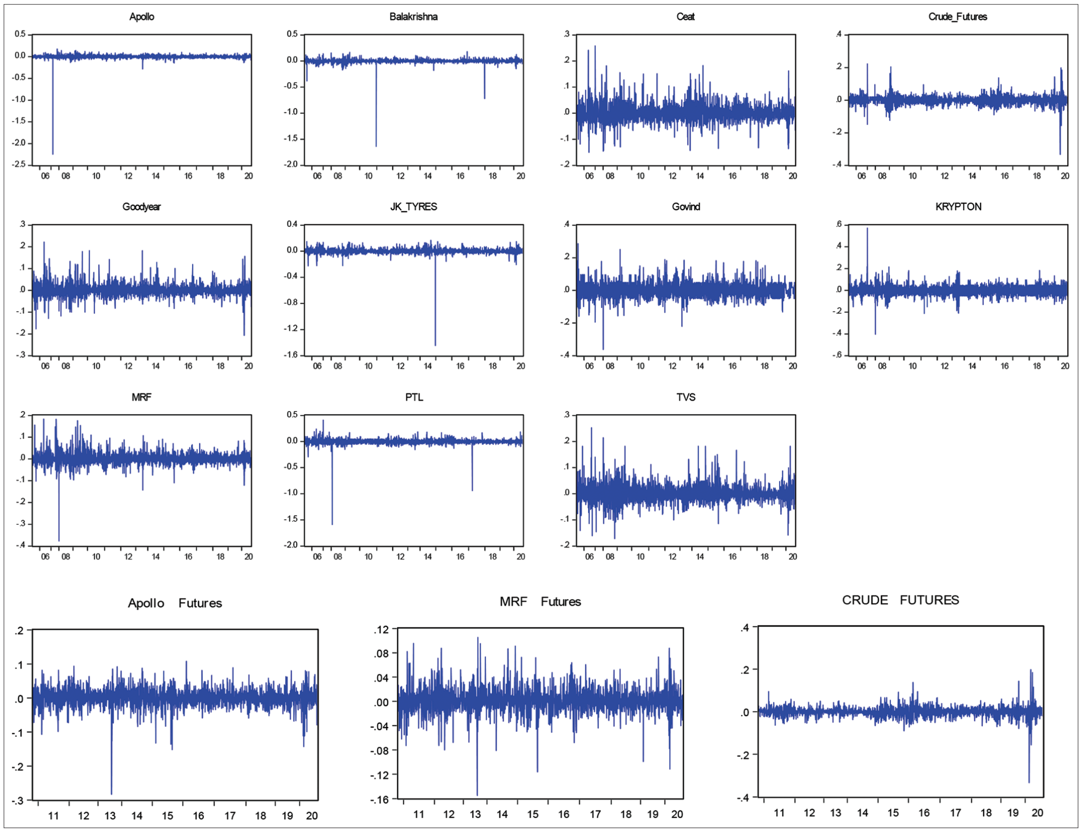


Table 4: CCC estimates

Tyre equity	ARCH	GARCH	Total	CCC	Log-likelihood	AIC
Panel a: MRF equity future						
APOLLO	0.10	0.10	0.21	0.57	10955.01	−10.24
Balakrishna	0.06	0.85	0.92	0.32	10890.91	−10.18
CEAT	0.08	0.84	0.92	0.52	10902.71	−10.19
Goodyear	0.08	0.82	0.89	0.35	11168.00	−10.44
GOVIND	0.07	0.85	0.92	0.25	9618.95	−8.99
JK TYRE	0.08	0.83	0.91	0.48	10631.42	−9.94
Krypton	0.07	0.84	0.91	0.05	9471.02	−8.85
MRF	0.06	0.82	0.88	0.99	15094.62	−14.11
PTL	0.08	0.83	0.91	0.19	10128.79	−9.45
TVS	0.07	0.87	0.94	0.29	10752.05	−10.04
Panel b: Apollo equity future						
Tyre equity	**ARCH**	**GARCH**	**Total**	**CCC**	**Log-likelihood**	**AIC**
APOLLO	0.06	0.84	0.90	0.99	14252.19	−13.32
Balakrishna	0.07	0.83	0.90	0.29	10198.24	−9.53
CEAT	0.10	0.85	0.94	0.53	10225.60	−9.56
Goodyear	0.08	0.86	0.93	0.38	10458.25	−9.78
GOVIND	0.08	0.86	0.93	0.24	8948.22	−8.36
JK TYRE	0.08	0.85	0.93	0.32	9741.73	−9.11
Krypton	0.07	0.86	0.93	0.06	8837.57	−8.26
MRF	0.07	0.86	0.94	0.56	10954.59	−10.24
PTL	0.07	0.86	0.93	0.16	9452.229	−8.84
TVS	0.06	0.89	0.95	0.30	10076.76	−9.42
Panel c: Crude oil future						
Tyre equity	**ARCH**	**GARCH**	**TOTAL**	**CCC**	**Log-likelihood**	**AIC**
APOLLO	0.10	0.89	0.99	0.037	14976.38	−9.45
Balakrishna	0.11	0.89	1.00	0.041	15313.83	−9.67
CEAT	0.11	0.89	1.00	0.028	14971.98	−9.45
Goodyear	0.11	0.88	0.99	0.026	15550.3	−9.82
GOVIND	0.10	0.89	0.98	0.041	13686.08	−8.64
JK TYRE	0.11	0.89	1.00	0.004	14813.94	−8.63
Krypton	0.10	0.88	0.98	0.003	13705.98	−9.43
MRF	0.11	0.89	1.00	−0.012	15855.96	−10.01
PTL	0.11	0.88	0.99	0.044	14199.54	−8.96
TVS	0.11	0.89	0.99	0.019	14953.85	−9.44

Entries in bold indicate that the estimates are significant at the 5% level

econometric analysis. Table 4 presents the CCC estimations for the tyre equity return series versus MRF equity future, Apollo equity future and crude future return series in pane a, b and c respectively. The ARCH (α) and GARCH (β) estimates of conditional variance for selected tyre equity returns with MRF equity futures, Apollo equity futures and crude futures are statistically significant at the level of 5%. The ARCH estimates are low (less than 0.11), and the GARCH estimates are high and close to one (greater than 0. 89). In the case of the tyre equity cash market and futures market, the long-run persistence is close to one. This is the indication of a long memory process, where the shock in the volatility series leads to future volatility for a long period of time. Further, the ($\alpha + \beta < 1$), for both tyre equity cash and futures markets, which satisfies the second movement and log condition to prove the QMLE to be consistent and asymptotically normal (McAleer et al., 2007). The CCC estimates between the volatility of all selected tyre equity returns and MRF equity futures returns are statistically significant at 5%. Similarly, the CCC estimates between the volatility of selected tyre equity returns and Apollo equity futures return. The CCC estimates for the volatility of tyre equities of Balakrishna and PTL with crude futures are statistically significant with the lowest CCC values of 0.041 and 0.044 respectively. The CCC estimates between the volatility of cash and futures returns of MRF tyres and Apollo tyres are close to one that is 0.99 for both. The CCC estimates for the shocks to the volatility of Balakrishna, Ceat, Goodyear, Govind, JK tyres and TVS equity returns with the MRF and Apollo futures returns are greater than 0.24. However, the conditional correlations for the volatility of Krypton and PTL with all the three futures returns are less than 0.20. Therefore, the chance of cross hedge for the tyre equity with available tyre equity futures is more suitable than crude oil futures.

Table 5 presents the DCC estimates of the selected tyre equities returns with MRF futures, Apollo futures and crude oil futures respectively in panel a, b and c. In panel parameters of DCC estimates, lambda1 ($\hat{\theta}1$) and lambda2 ($\hat{\theta}2$) are significant at 5% level for the return series of MRF, Ceat, Apollo, JK tyres, TVS, PTL and Govind with MRF futures return series. Hence, for these return series, the time-invariant conditional correlation hypothesis is not empirically supported. Lambda 1 value for Govind at 0.06 is greatest in the panel, which indicates the short-run persistence from the shocks on the time-varying conditional correlations. Further, the largest

Table 5: DCC estimates

Panel a: MRF equity future						
Tyre equity	**ARCH**	**GARCH**	**Total**	**lambda1**	**lambda2**	**log-likelihood**
Balakrishna	0.09	0.24	0.33	0.00	0.99	9654.80
MRF	0.13	0.16	0.30	0.05	0.02	14576.6
CEAT	0.37	0.15	0.52	0.01	0.99	7488.032
APOLLO	0.67	1.08	1.75	0.01	0.98	10568.57
Goodyear	0.27	0.72	0.99	0.04	0.16	10703.75
JK TYRE	1.02	0.05	1.07	0.00	0.93	9452.681
TVS	0.28	0.48	0.75	0.01	0.91	10277.56
PTL	0.78	0.20	0.98	0.05	0.62	9452.681
Krypton	0.23	0.70	0.92	0.01	0.89	9234.847
GOVIND	0.11	0.75	0.87	0.06	0.60	9319.641
Panel b: Apollo equity future						
Tyre equity	**ARCH**	**GARCH**	**TOTAL**	**lambda1**	**lambda2**	**log-likelihood**
Balakrishna	0.15	0.17	0.32	0.00	0.99	7117.45
MRF	0.25	0.28	0.53	0.02	0.97	10552.47
CEAT	0.31	0.32	0.63	0.06	0.38	7488.032
APOLLO	0.67	1.08	1.75	0.01	0.98	10568.57
Goodyear	0.25	0.73	0.98	0.01	0.58	10063.08
JK TYRE	1.04	0.03	1.07	0.00	0.95	9151.628
TVS	0.33	0.06	0.39	0.06	0.53	6918.356
PTL	0.78	0.20	0.98	0.05	0.62	9452.681
Krypton	0.23	0.70	0.92	0.01	0.89	9234.847
GOVIND	0.11	0.75	0.87	0.06	0.60	9319.641
Panel c: Crude oil future						
Tyre equity	**ARCH**	**GARCH**	**TOTAL**	**lambda1**	**lambda2**	**log-likelihood**
Balakrishna	0.11	0.23	0.34	0.01	0.98	8665.34
MRF	0.55	0.13	0.68	0.01	0.76	14736.64
CEAT	0.10	0.94	1.04	0.00	0.99	13984.60
APOLLO	1.17	0.08	1.25	0.04	0.47	13367.57
Goodyear	0.43	0.49	0.92	0.01	0.42	14548.66
JK TYRE	0.94	0.04	0.98	0.01	0.75	13658.30
TVS	0.42	0.36	0.78	0.02	0.64	14005.07
PTL	0.75	0.23	0.98	0.01	0.64	9343.17
Krypton	0.30	0.61	0.91	0.00	0.99	12937.75
GOVIND	0.17	0.75	0.92	0.01	0.41	12988.01

Entries in bold indicate that the estimates are significant at the 5% level

Table 6: Diagonal BEKK estimates

Tyre equity	C			A	B	Log-likelihood	AIC
Panel a: MRF equity future							
APOLLO	1.72E-06	0.032	7.01E-07	0.186	0.981	10920.56	−10.21
				0.175	0.986		
Balakrishna	3.16E-05	0.126	1.46E-04	0.289	0.928	10839.51	−10.13
				0.434	0.777		
CEAT	3.46E-06	0.058	4.23E-06	0.223	0.974	10885.03	−10.17
				0.260	0.969		
Goodyear	1.71E-05	0.078	1.92E-05	0.254	0.949	11140.81	−10.41
				0.307	0.936		
GOVIND	2.07E-05	0.082	1.04E-04	0.249	0.939	9608.348	−8.98
				0.328	0.917		
JK TYRE	7.87E-06	0.079	2.03E-05	0.261	0.961	10566	−9.87
				0.303	0.948		
Krypton	2.19E-05	0.090	0.000331	0.201	0.945	9453.073	−8.83
				0.450	0.795		
MRF	−1.21E-07	0.043	1.69E-07	0.204	0.980	15041.75	−14.06
				0.209	0.980		
PTL	2.88E-05	0.128	1.98E-04	0.220	0.940	10100.77	−9.44
				0.582	0.750		
TVS	1.43E-05	0.062	7.57E-06	0.232	0.959	10744.81	−10.94
				0.266	0.963		
Panel b: Apollo equity futures							
Tyre equity	**C**			**A**	**B**	**log-likelihood**	**AIC**
APOLLO	6.28E-08	0.041	−3.98E-08	0.203	0.981	14226.15	−13.31
				0.203	0.981		
Balakrishna	6.24E-05	0.122	1.61E-04	0.283	0.922	10168.26	−9.5
				0.429	0.727		
CEAT	2.52E-06	0.055	3.95E-06	0.226	0.976	10207.17	−9.54
				0.243	0.969		
Goodyear	1.62E-05	0.061	1.30E-05	0.233	0.963	10448.88	−9.77
				0.262	0.949		
GOVIND	3.18E-05	0.080	1.00E-04	0.254	0.943	8935.94	−8.35
				0.351	0.917		
JK TYRE	6.52E-06	0.068	1.44E-05	0.257	0.967	9923.774	−9.3
				0.265	0.955		
Krypton	3.23E-05	0.093	3.41E-04	0.215	0.949	8820.184	−8.24
				0.429	0.786		
MRF	1.42E-06	0.038	2.08E-06	0.189	0.983	10918.96	−10.21
				0.201	0.977		
PTL	3.62E-05	0.118	1.84E-04	0.205	0.953	9434.642	−8.82
				0.574	0.737		
TVS	1.77E-05	0.056	7.98E-06	0.222	0.965	10060.12	−9.4
				0.251	0.962		
Panel c: Crude oil futures							
Tyre equity	**C**			**A**	**B**	**log-likelihood**	**AIC**
APOLLO	1.00E-05	0.10	0.000173	0.290	0.950	14961.87	−9.44
				0.327	0.821		
Balakrishna	0.00040	0.01	0.001171	0.334	0.936	10206.83	−6.44
				0.025	0.960		
CEAT	1.04E-05	0.08	3.15E-05	0.296	0.951	14943.95	−9.43
				0.280	0.943		
Goodyear	1.09E-05	0.12	5.37E-05	0.281	0.953	15513.00	−9.79
				0.431	0.861		
GOVIND	9.56E-06	0.10	0.000331	0.280	0.951	13660.81	−8.62
				0.374	0.827		
JK TYRE	9.73E-06	0.11	0.000132	0.287	0.954	14785.9	−9.33
				0.382	0.850		
Krypton	9.73E-06	0.12	0.000382	0.267	0.952	13666.2	−8.63
				0.453	0.775		
MRF	1.16E-05	0.07	1.76E-05	0.304	0.950	15828.55	−9.99
				0.237	0.953		
PTL	1.02E-05	0.16	0.000265	0.267	0.956	14161.31	−8.94
				0.589	0.729		
TVS	1.28E-05	0.07	7.09E-06	0.301	0.946	14917.98	−9.42
				0.232	0.970		

Entries in bold indicate that the estimates are significant at the 5% level

Figure 3: Optimal hedge ratios based in alternative MGARCH estimates

Panel a: OHRs based on CCC estimates

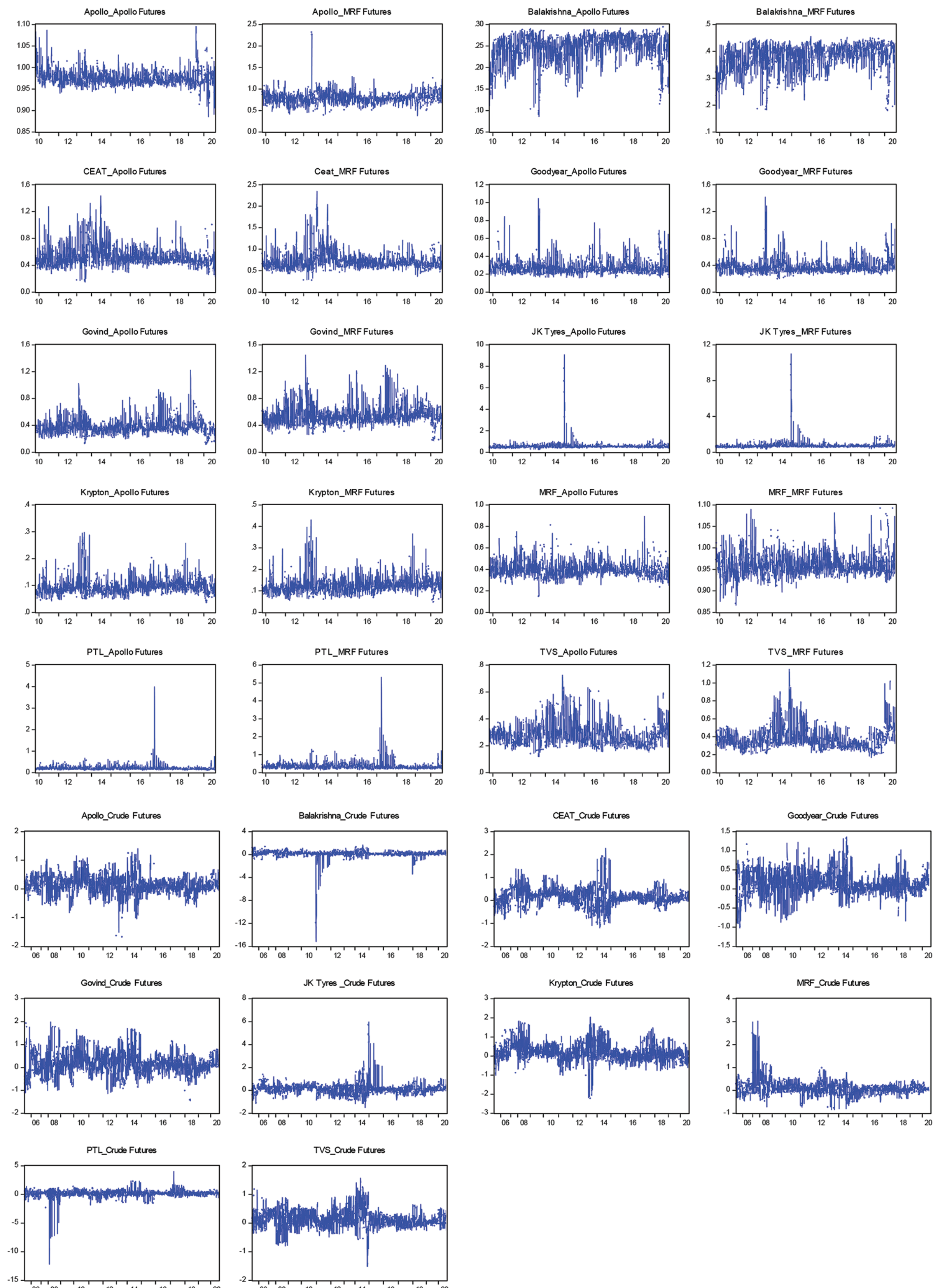


Figure 3: Optimal hedge ratios based in alternative MGARCH estimates (*Continued*)

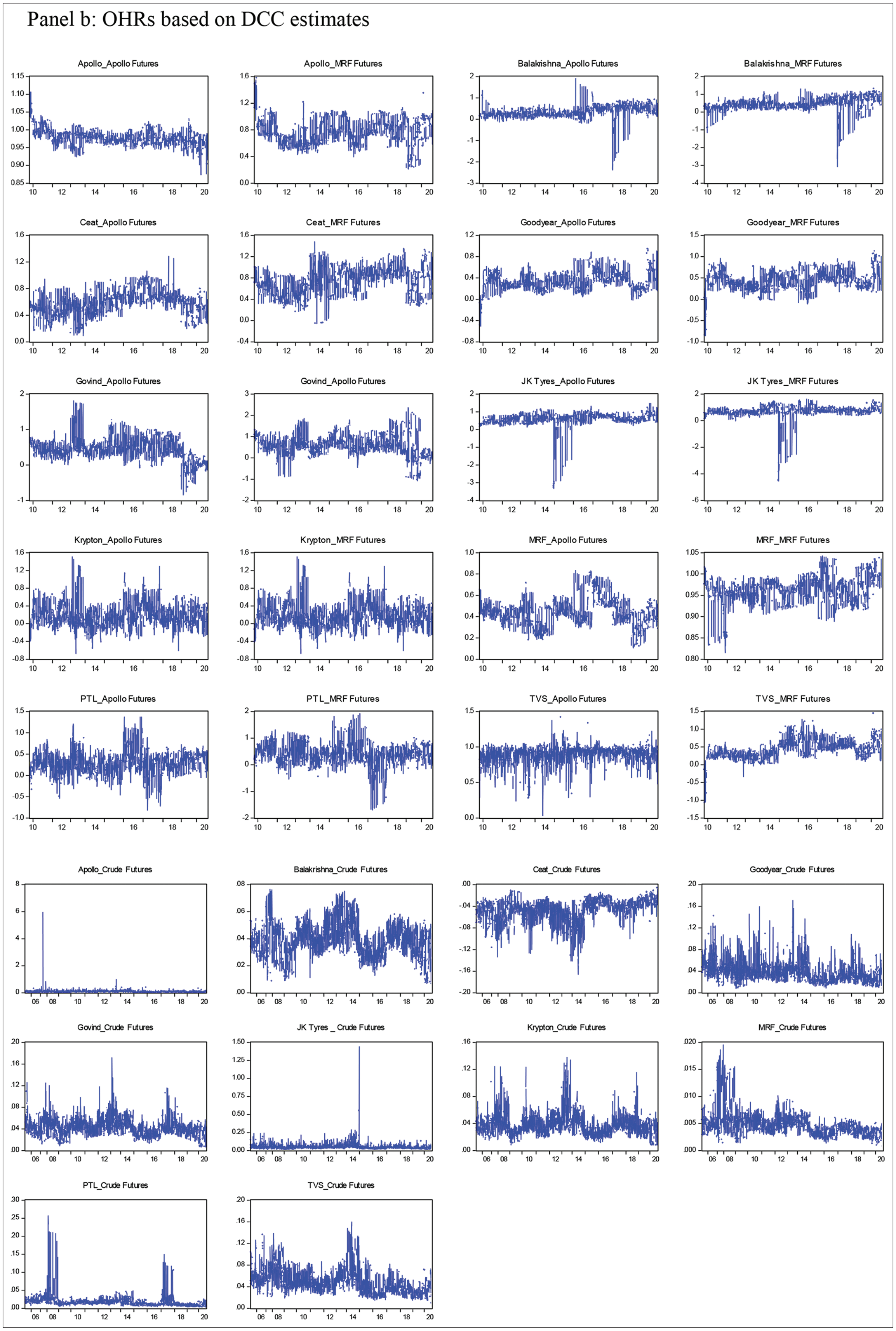
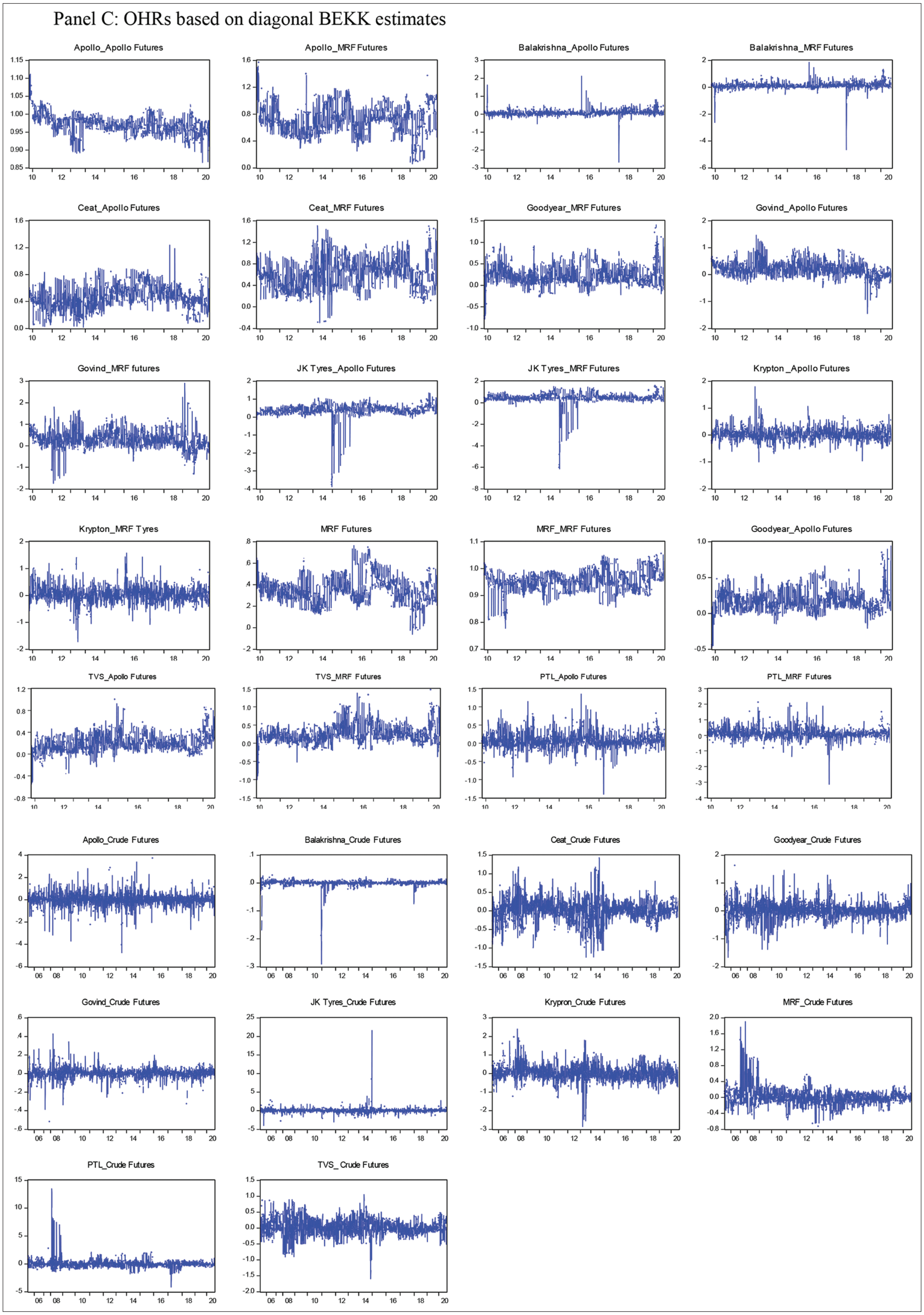


Figure 3: Optimal hedge ratios based in alternative MGARCH estimates (*Continued*)



sum of lambda 1 and lambda 2 of Ceat 1.00 (0.01+0.99) indicates the lengthy long-run persistence from the shocks to the conditional correlation. In panel b of Table 5, the lambda 1 and lambda 2 of MRF, Ceat, Apollo, TVS, PTL and Govind are statistically significant at 5% level. Hence the hypothesis of time-invariant conditional correlation from the shocks is not empirically supported for these series. The lambda at 0.06 of Ceat, TVS and Govind indicates the greatest short-run persistence from the shocks to the time-varying conditional correlations. While the total of lambda1 and lambda 2 of MRF at 0.99 (0.02+0.97) is highest in panel b, this proves the lengthy long rum persistence of shocks on the conditional correlation. The last panel in the Table shows the DCC estimates between the crude future returns and selected tyre equity returns. The lambda1 and lambda 2 of the volatility of TVS and PTL return series with crude futures return series at statistically significant. Therefore, the time-invariant conditional correlation assumption is not empirically supported for these series. The highest ladmbda2 value at 0.02 for TVS indicates the largest short-run persistence of the disturbances on the dynamic conditional correlations. The highest lambda 2 value of 0.99 for Ceat and Krypton indicates the longest long run persistence from the disturbances to the conditional correlations.

The estimates of diagonal BEKK and seven parameters are shown in Table 6. The coefficients for conditional variances, conditional covariances, the arch and the GARCH effects for selected tyre equity return with MRF future, Apollo future and crude future are presented in panel a, b and c respectively. The ARCH and GARCH effects for all estimates in Table seven are statistically significant and the sums of these effects are close to one. This gives evidence of volatility spillover between the return series of MRF futures, Apollo futures and crude futures with the selected tyre equities. A and B are the elements of diagonal matrices, they prove the presence of strong GARCH effects and weak ARCH effects. In panel a, the estimates for the covariances are statistically significant for all except Apollo and PTL tyre equity. The estimates of covariances are significant for all tyre equities in panel b, while in panel c only for Balakrishna tyre equity estimate of covariance is not significant. The dynamic covariations in shocks are the indications of these significant results.

Table 7 presents the optimal hedge ratios for selected tyre equities based on different MGARCH estimates. OHR based CCC, DCC and BEKK estimates are shown in panel a, aand c respectively. The average OHR values for Apollo and MRF equity are very high (>0.95) in the 1st and second columns of all the panels, indicating the possibility of an effective direct hedge. The cross-hedge possibility for other tyre stock is affective with tyre equity futures rather than crude futures. In all the 3 panels, the average

Table 7: Alternative hedging strategies

Panel a: Optimal hedge ratio using DCC estimates					
Tyre Equity_Apollo Futures	**OHR**	**Tyre Equity_MRF Futures**	**OHR**	**Tyre Equity_Crude Futures**	**OHR**
Apollo	0.975	Apollo	0.799	Apollo	0.081
Balakrishna	0.246	Balakrishna	0.379	Balakrishna	0.039
Ceat	0.516	Ceat	0.711	Ceat	−0.046
Goodyear	0.271	Goodyear	0.373	Goodyear	0.037
Govind	0.370	Govind	0.539	Govind	0.041
JK Tyre	0.544	JK Tyre	0.720	JK Tyre	0.048
Krypton	0.095	Krypton	0.125	Krypton	0.037
MRF	0.393	MRF	0.959	MRF	0.005
PTL	0.197	PTL	0.339	PTL	0.017
TVS	0.276	TVS	0.374	TVS	0.047
Panel b: Optimal hedge ratio using DCC estimates					
Tyre Equity_Apollo Futures	**OHR**	**Tyre Equity_MRF Futures**	**OHR**	**Tyre Equity_Crude Futures**	**OHR**
Apollo	0.979	Apollo	0.769	Apollo	0.147
Balakrishna	0.344	Balakrishna	0.467	Balakrishna	0.117
Ceat	0.578	Ceat	0.744	Ceat	0.136
Goodyear	0.335	Goodyear	0.443	Goodyear	0.137
Govind	0.433	Govind	0.582	Govind	0.163
JK Tyre	0.581	JK Tyres	0.689	JK Tyre	0.127
Krypton	0.180	Krypton	0.180	Krypton	0.175
MRF	0.436	MRF	0.964	MRF	0.086
PTL	0.287	PTL	0.393	PTL	0.147
TVS	0.891	TVS	0.432	TVS	0.125
Panel c: Optimal hedge ratio using diagonal BEKK estimates					
Tyre Equity_Apollo Futures	**OHR**	**Tyre Equity_MRF Futures**	**OHR**	**Tyre Equity_Crude Futures**	**OHR**
Apollo	0.972	Apollo	0.719	Apollo	0.014
Balakrishna	0.068	Balakrishna	0.112	Balakrishna	0.000
Ceat	0.457	Ceat	0.612	Ceat	0.014
Goodyear	0.177	Goodyear	0.223	Goodyear	0.023
Govind	0.188	Govind	0.287	Govind	0.018
JK Tyre	0.373	JK Tyre	0.445	JK Tyre	0.009
Krypton	0.031	Krypton	0.039	Krypton	0.024
MRF	0.348	MRF	0.955	MRF	0.002
PTL	0.064	PTL	0.109	PTL	−0.003
TVS	0.192	TVS	0.253	TVS	0.024

OHRs with MRF futures are greater than the average OHRs with Apollo futures, suggesting the affective cross hedge with MRF futures rather than Apollo futures. The highest average OHR for the cross hedge is 0.720 for JK tyres with MRF futures and 0.612 for Ceat based on CCC and BEKK estimates respectively. Figure 3 shows the computed time-varying OHRs based on alternative multivariate GARCH estimates.

6. CONCLUSION

This study has analysed the possibility of a cross hedge for selected Indian tyre equities with crude oil futures and two tyre equity futures. Multivariate GARCH models, namely CCC, DCC and diagonal BEKK are estimated between the above-mentioned spot and futures return series. Optimal hedge ratios are computed using the conditional covariance matrices of the estimated CCC, DCC and diagonal BEKK models. In the past, the price of crude has influenced the equity price of tyre companies in India.

The results of the daily observation from June 21, 2005 to September 8, 2020 for the crude oil futures and selected tyre equity returns showed that the volatility spillover exists between these variables. However, the conditional volatility models showed better cross hedge possibility with tyre futures. For MRF and Apollo tyres, a direct hedge is more effective, while for other selected equities the MRF futures is the best underlying for cross hedge. All the selected tyre equities showed a positive correlation with MRF futures, hence, in short with MRF futures to protect the long tyre equity and vice versa are suggested.

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