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Summary

This paper estimates the dynamic conditional correlations in the returns on WTI oil one-month forward prices, and one-, three-, six-, and twelve-month futures prices, using recently developed multivariate conditional volatility models. The dynamic correlations enable a determination of whether the forward and various futures returns are substitutes or complements, which are crucial for deciding whether or not to hedge against unforeseen circumstances. The models are estimated using daily data on WTI oil forward and futures prices, and their associated returns, from 3 January 1985 to 16 January 2004. At the univariate level, the estimates are statistically significant, with the occasional asymmetric effect in which negative shocks have a greater impact on volatility than positive shocks. In all cases, both the short- and long-run persistence of shocks are statistically significant. Among the five returns, there are ten conditional correlations, with the highest estimate of constant conditional correlation being 0.975 between the volatilities of the three-month and six-month futures returns, and the lowest being 0.656 between the volatilities of the forward and twelve-month futures returns. The dynamic conditional correlations can vary dramatically, being negative in four of ten cases and being close to zero in another five cases. Only in the case of the dynamic volatilities of the three-month and six-month futures returns is the range of variation relatively narrow, namely (0.832, 0.996). Thus, in general, the dynamic volatilities in the returns in the WTI oil forward and future prices can be either independent or interdependent over time.

Keywords: Constant conditional correlations, Dynamic conditional correlations, Multivariate GARCH models, Forward prices and returns, Futures prices and returns, WTI oil prices

JEL Classification: C32, G10, Q40

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1. Introduction

Substantial research has been undertaken on spot, forward and futures markets of both physical and financial commodities. Much of the research on analyzing the connection between spot, forward and futures prices, and their associated returns, has concentrated on the unbiasedness or efficient market hypothesis and, when such prices are non-stationary, on cointegration among these variables. Hypotheses regarding efficient markets are important for understanding optimal decision making in terms of hedging and speculation. They are also crucial for making financial decisions about the optimal allocation of portfolios of assets in terms of their multivariate returns and associated risks.

Little or no research has been undertaken on analyzing the volatilities (or risks) associated with these portfolios of returns at the multivariate level. Shocks to returns can be decomposed into predictable and unpredictable components. There are two predictable components in these shocks to returns, namely the serial correlation in shocks to the conditional mean and the volatility in the conditional variance. These volatilities can vary over time, either conditionally, as in GARCH-type models, or randomly, as in Stochatic Volatility (SV) models. SV models are typically computationally intensive, even at the univariate level. Extensions to multivariate SV models are presently at a relatively early stage of development. On the other hand, univariate and multivariate GARCH models have become widely established in theoretical and empirical finance and financial econometrics. The structural and statistical properties have been fully developed, and the computational requirements are not generally burdensome, except in special circumstances.

In the case of modelling multivariate returns, such as the returns on the forward and futures prices of different maturities in the market for WTI oil, the shocks to returns not only have dynamic interdependence in risks, but also in the conditional correlations. This is an extension of the constant (or static) conditional correlation approach to analyzing multivariate risks associated with portfolios of assets.

The purpose of this paper is to estimate the dynamic conditional correlations in the returns on WTI oil one-month forward prices, and one-, three-, six-, and twelve-month futures prices, using recently developed multivariate conditional volatility models. The dynamic correlations will enable a determination of whether the forward and various futures returns are substitutes or complements,

which are crucial for deciding whether or not to hedge against unforeseen circumstances. The models are estimated using daily data on WTI oil forward and futures prices, and their associated returns, from 3 January 1985 to 16 January 2004. At the univariate level, the estimates are statistically significant, with the occasional asymmetric effect in which negative shocks have a greater impact on volatility than positive shocks. There can be substantial differences among the estimated constant and dynamic conditional correlations. It is found that the dynamic volatilities in the returns in the WTI oil forward and future prices can be either independent or interdependent over time.

The plan of the paper is as follows. Section 2 analyses market efficiency and volatility in the energy market. Alternative multivariate volatility models are discussed in Section 3. The data used in the empirical analysis and the resulting estimates are presented in Section 4. Some concluding remarks are given in Section 5.

2. Market Efficiency and Volatility in the Energy Market

The literature on the relationships between spot and futures prices of petroleum products has examined issues such as market efficiency and price discovery, but far less attention has been paid to volatility, as well as correlations in the shocks to volatility, in the spot and futures markets. Given the importance of both aspects for the present paper, this section provides a brief discussion of the relevant literature.

2.1. Market Efficiency Literature

A standard definition of market efficiency is that today's price of an item contains all the price information about that item. That is, today's price contains information about people's expectations about the future. The hypothesis that heating oil futures prices are good predictors of spot prices was tested by Bopp and Sitzer (1987), who found that, even when crude oil prices, inventory levels, weather, and other important variables were accounted for, futures prices still made a significant positive contribution to describing past price changes. Serletis and Banack (1990) used daily data for the spot and two-month futures crude oil prices, and for prices of gasoline and heating oil traded

on the New York Stock Exchange (NYMEX), to test for market efficiency, and found evidence that was consistent with this hypothesis.

Crowder and Hamid (1993) used cointegration analysis to test the simple efficiency hypothesis and the arbitrage condition for crude oil futures. In the price discovery literature, Quan (1992) examined the price discovery process for the crude oil market using monthly data, and found that the futures price did not play an important role in this process. Using daily data for NYMEX closing futures prices, Schwartz and Szakmary (1994) found that futures prices strongly dominated in the price discovery relative to the deliverable spots in all three petroleum markets. Gulen (1999) applied cointegration tests in a series of oil markets with pairwise comparisons on post-1990 data, and concluded that oil markets have grown more unified during the period 1994-1996 as compared with the period 1991-1994. Silvapulle and Moosa (1999) examined the daily spot and futures prices of WTI crude using both linear and non-linear causality testing. They found that linear causality testing revealed that futures prices lead spot prices, whereas non-linear causality testing revealed a bi-directional effect. Xiaowen and Tamvakis (2001) investigated information transmission between the NYMEX and London's International Petroleum Exchange, and found that NYMEX was a true leader in the crude oil market. Hammoudeh et al. (2003) also investigated information transmission among NYMEX WTI crude prices, NYMEX gasoline prices, NYMEX heating oil prices, and among international gasoline spot markets, including the Rotterdam and Singapore markets, and found the NYMEX gasoline market to be the true leader.

2.2. Volatility and the Energy Market

Day and Lewis (1993) compared the forecasts of crude oil volatility using GARCH(1,1), EGARCH(1,1), implied volatility and historical volatility models, based on daily data from November 1986 to March 1991. Using OLS regressions of realized volatility on out-of sample forecasts, they examined the unbiasedness of the forecasts. The accuracy of out-of sample forecasts was compared using traditional criteria such as the mean forecast error, mean absolute error, and root mean squared error. They also analysed the within-sample information content of implied volatility, by including it as predictor in the GARCH and EGARCH models. It was found that both implied volatilities, as well as the GARCH and EGARCH conditional volatilities, contributed incremental volatility information. The null hypothesis that implied volatilities subsumed all information contained in observed returns was rejected, as was the hypothesis that option prices had

no additional information. This would indicate that a composite forecast based on implied volatility and GARCH estimates would yield superior results as each would contribute unique information that was not contained in the other. However, empirical evidence indicated that the GARCH forecasts and historical volatility did not add substantial explanatory power to forecasts that were based on implied volatilities.

Tests for the accuracy of forecasts based on traditional forecast error criteria also support the conclusion that the implied volatilities alone are sufficient for market professionals to predict short-run volatilities of up to two months. Duffie and Gray (1995) constructed in-sample and out-of-sample forecasts for volatility in the crude oil, heating oil, and natural gas markets over the period May 1988 to July 1992. Forecasts from GARCH(1,1), EGARCH(1,1), bivariate GARCH(1,1), regime switching, implied volatility, and historical volatility predictors were compared with the realized volatility in terms of root mean squared error. They found that implied volatility yielded the best in-sample and out-of-sample forecasts, and that historical volatility forecasts were superior to their GARCH counterparts in the out-of-sample forecasts.

3. Modelling Multivariate Volatility

The purpose of the empirical section is to model the volatility in the returns of one-month WTI forward oil prices, and one-, three-, six-, and twelve-month oil futures prices. The estimated multivariate models are the Constant Conditional Correlation (CCC) Multivariate GARCH model of Bollerslev (1990) and the Dynamic Conditional Correlation (DCC) model of Engle (2002). The specification, as well as the structural and statistical properties, of these models are discussed briefly in this section.

Consider the following specification:

$$y_t = E\left(y_t \mid F_{t-1}\right) + e_t$$

$$e_t = D_t h_t, \tag{1}$$

where $y_t = (y_{1t},...,y_{mt})'$, $h_t = (h_{1t},...,h_{mt})'$ is a sequence of independently and identically distributed (iid) random vectors, F_t is the past information available up to time t, $D_t = diag\left(h_{1t}^{1/2},...,h_{mt}^{1/2}\right)$, m is the total number of oil price returns to be analysed, and $t = 1,\ldots, n$. Bollerslev (1990) assumed that the conditional variance for each return, h_{it}, $i = 1,\ldots, m$, follows a univariate GARCH process, that is,

$$h_{it} = w_i + \sum_{j=1}^{r} a_{ij} e_{i,t-j}^2 + \sum_{j=1}^{s} b_{ij} h_{i,t-j} \tag{2}$$

where a_{ij} represents the ARCH effects, or the short-run persistence of shocks to return i, and b_{ij} represents the GARCH effects, or the contribution of shocks to return i to long-run persistence, namely $\sum_{j=1}^{r} a_{ij} + \sum_{j=1}^{s} b_{ij}$.

Although the CCC specification in (2) has a computational advantage over some other multivariate GARCH models, such as the BEKK model of Engle and Kroner (1995), which models conditional covariances, CCC nevertheless assumes independence of the conditional variances across returns and does not accommodate asymmetric behaviour. In order to accommodate the asymmetric impacts of positive and negative shocks, Glosten, Jagannathan and Runkle (1992) proposed the asymmetric GARCH, or GJR, specification for the conditional variance which, for $r = s = 1$, is given by:

$$h_{it} = w_i + a_i e_{i,t-1}^2 + g_i I_{i,t-1} e_{i,t-1}^2 + b_i h_{i,t-1} \tag{3}$$

where

$$I_{it} = \begin{cases} 0, & e_{it} \geq 0 \\ 1, & e_{it} < 0 \end{cases}$$

is an indicator function to distinguish between positive and negative shocks on conditional volatility.

The parameters of models (1), (2) and (3) are typically obtained by maximum likelihood estimation (MLE) using a joint normal density for h_t. When h_t does not follow a joint (multivariate) normal distribution, the solution to maximizing the likelihood function is defined as the Quasi-MLE (QMLE).

It is important to note that the conditional correlations are assumed to be constant for the CCC model. From equation (1), it follows that $e_t e_t' = D_t h_t h_t' D_t$, so that $E\left(e_t e_t' \mid F_{t-1}\right) = \Omega_t = D_t \Gamma D_t$. The conditional correlation matrix is defined as $\Gamma = D_t^{-1} \Omega_t D_t^{-1}$, where Γ has typical constant element r_{ij} = r_{ji}, for $i, j = 1,\ldots, m$ and $t = 1,\ldots, n$.

When $m = r = s = 1$, such that a univariate model is specified, the necessary and sufficient condition for the existence of the second moment of e_t in model (2), that is $E\left(e_t^2\right) < \infty$, is $a_1 + b_1 < 1$. This condition is also sufficient for the QMLE to be consistent and asymptotically normal. For the GJR(1,1) model (3) $w_1 > 0$, $a_1 + g_1 > 0$ and $b_1 > 0$ are sufficient conditions to ensure that the conditional variance $h_{1t} > 0$. The short-run persistence of positive (respectively, negative) shocks is given by a_1 (respectively, $a_1 + g_1$). Under the assumption that the conditional shocks h_{1t}, $t = 1,\ldots, n$, follow a symmetric distribution, the average short-run persistence is $a_1 + g_1/2$, and the average long-run persistence is $a_1 + g_1/2 + b_1$. Ling and McAleer (2002a) showed that the necessary and sufficient condition for $E\left(e_t^2\right) < \infty$ in the GJR(1,1) model is $a_1 + g_1/2 + b_1 < 1$. McAleer, Chan and Marinova (2002) established the log-moment condition for GJR(1,1), namely $E\left(\log\left(\left(a_1 + g_1 I_1\left(h_{1t}\right)\right)h_{1t}^2 + b_1\right)\right) < 0$, and showed that it is sufficient for the consistency and asymptotic normality of the QMLE for GJR(1,1). If the log-moment condition is satisfied, the second moment condition, namely $a_1 + g_1/2 + b_1 < 1$, is also sufficient for consistency and asymptotic normality of the QMLE for GJR(1,1).

Unless h_t is a sequence of iid random vectors, the assumption of constant conditional correlation will not be valid. In order to capture the dynamics of time-varying conditional correlation, Γ_t, Engle (2002) and Tse and Tsui (2002) proposed the closely related DCC model and the Variable Conditional Correlation (VCC) Multivariate GARCH model, respectively. The DCC model, which is a special case of the VCC model, is given as

$$\Gamma_t = (1 - q_1 - q_2)\,\Gamma + q_1 h_{t-1} h'_{t-1} + q_2 \Gamma_{t-1} \qquad (4)$$

in which q_1 and q_2 are scalar parameters to capture the effects of previous shocks and previous dynamic conditional correlations on current dynamic conditional correlations.

The purpose of the following empirical section is to investigate the asymmetric and interdependent effects of the conditional volatilities in the returns to the WTI oil forward and futures prices.

4. Data and Empirical Results

The univariate and multivariate GARCH models are estimated using daily data on WTI oil one-month forward price (WFORW) and one- (WFUT1), three- (WFUT3), six- (WFUT6), and twelve-month (WFUT12) futures prices, and their associated returns, for the period 3 January 1985 to 16 January 2004.

Figures 1-3 show the returns to the one-month forward price and the one-, three-, six-, and twelve-month futures prices. It is clear from these graphs that there is substantial clustering in the returns, and hence also in the corresponding volatilities. The returns in all the series are similar with regard to the presence of some extreme observations and the possible outlier corresponding to the first Gulf Crisis in January 1991.

The univariate estimates of the conditional volatilities based on the forward and futures returns are given in Tables 1 and 2. The three entries for each parameter are their respective estimates, asymptotic t-ratios and Bollerslev-Wooldridge (1992) robust t-ratios. The results in Table 1 are used to estimate the CCC model of Bollerslev (1990) and the DCC model of Engle (2002). Both the short- and long-run persistence of shocks are significant for forward and futures returns. The ARCH (GARCH) effect is the largest (smallest) for the twelve-month futures returns. Although the second moment condition is not satisfied for the twelve-month futures price returns, the log-moment condition is always satisfied, so that the QMLE are consistent and asymptotically normal.

The univariate GJR estimates in Table 2 are reasonably similar to the corresponding estimates in Table 1. At the univariate level, the estimates of the asymmetric effect in which negative shocks have a greater impact on volatility than positive shocks are significant only when the asymptotic t-ratios are used. The second moment condition is not satisfied for the forward and twelve-month futures returns, but the log-moment condition is always satisfied, so that the QMLE are consistent and asymptotically normal.

Constant conditional correlations between the volatilities of forward and futures returns using the CCC model based on estimating univariate GARCH(1,1) models for each returns are given in Table 3. For the five returns, there are ten conditional correlations, with the highest estimated constant conditional correlation being 0.975 between the standardized shocks to the volatilities in the three-month and six-month futures returns, and the lowest being 0.656 between the standardized shocks to the volatilities in the forward and twelve-month futures returns. The calculated constant conditional correlations would seem to be consistent with a reasonable expectation that the correlation decreases as the length of the forward contract increases.

Finally, the DCC estimates of the conditional correlations between the volatilities of forward and futures returns based on estimating univariate GARCH(1,1) models for each returns are given in Table 4. Based on the asymptotic standard errors, the estimates of the two DCC parameters are always statistically significant, which makes it clear that the assumption of constant conditional correlation is not supported empirically. The short run persistence of shocks on the dynamic correlations is greatest between the forward returns and the one-month futures returns, followed closely by the forward returns and the three-month futures returns.

The time-varying nature of the conditional correlations is highlighted by the dynamic conditional correlations between the standardized shocks to the forward and futures returns in Figures 4-13. These dynamic correlations vary dramatically, being negative in four of ten cases, close to zero in another three cases, and in the middle range for two other cases. Only in the case of the dynamic correlations between the three-month and six-month futures returns is the range of variation relatively narrow, namely (0.832, 0.996) (see Table 5). Therefore, while the dynamic conditional correlations vary considerably, it is only in one of ten cases that the variations do not lead to an economically meaningful range of variation.

The skewness and kurtosis of the dynamic conditional correlations indicate a strong negatively skewed distribution. As an example, we may consider Figure 4, which gives the DCC estimates between the forward and one-month futures returns. The mean correlation from Table 5 is 0.894, which is very close, but not identical to, the CCC estimate of 0.884. The informational value of the DCC estimate can be evaluated by examining the time series behaviour of the time-varying conditional correlations in Figure 4, as well as the maximum and minimum dynamic levels, as reported in Table 5. The maximum value of 0.998 means that, on the corresponding day, forward and one-month futures returns would have the same risk, so that taking a position in the forward or futures market would be equally risky for a one-month horizon. However, if we consider the minimum dynamic conditional correlation of -0.291, we could conclude that shocks to the conditional volatilities would not be perfect substitutes in terms of risk. In general, the dynamic volatilities in the returns to the WTI oil forward and future prices can be either independent or interdependent over time.

5. Conclusion

Substantial research has been undertaken on the spot, forward and futures markets for both physical and financial commodities. Much of the research on analyzing the relationship between spot, forward and futures prices, and their associated returns, has concentrated on the unbiasedness or efficient market hypothesis and, when such prices are non-stationary, on cointegration among these variables.

Hypotheses regarding efficient markets are important for understanding optimal decision making in terms of hedging and speculation. They are also crucial for making financial decisions about the optimal allocation of portfolios of assets in terms of their multivariate returns and the associated risks.

However, little or no research has been undertaken on analyzing the volatilities (or risks) associated with these portfolios of returns at the multivariate level. Shocks to returns can be decomposed into predictable and unpredictable components. There are two predictable components in these shocks to returns, namely the serial correlation in shocks to the conditional mean and the volatility in the conditional variance. These volatilities can vary over time, as in univariate and multivariate

GARCH models, which have become widely established in theoretical and empirical finance and financial econometrics.

In the case of modelling multivariate returns, such as the returns on the forward and futures prices of different maturities in the market for WTI oil, the shocks to returns may not only have dynamic interdependence in risks, but also in the conditional correlations. This is an extension of the constant (or static) conditional correlation approach to analyzing multivariate risks associated with portfolios of assets.

In this paper we estimated the dynamic conditional correlations in the returns on WTI oil one-month forward prices, and one-, three-, six-, and twelve-month futures prices, using recently developed multivariate conditional volatility and conditional correlation models. The dynamic correlations enabled a determination of whether the shocks to the volatilities in the forward and futures returns of various maturities were substitutes or complements. Such empirical estimates are crucial for deciding whether or not to hedge against unforeseen circumstances.

The univariate and multivariate GARCH models were estimated using daily data on WTI oil one-month forward prices and one-, three-, six, and twelve-month futures prices, and their associated returns, for the period 3 January 1985 to 16 January 2004.

The univariate estimates of the conditional volatilities based on the forward and futures returns were statistically significant, and were used to estimate the CCC model of Bollerslev (1990) and the DCC model of Engle (2002). Although the second moment condition was not satisfied for the twelve-month futures price returns, the log-moment condition was always satisfied, so that the QMLE were always consistent and asymptotically normal.

An asymmetric model based on the univariate GJR model gave estimates that were reasonably similar to the corresponding symmetric estimates. The estimates of the asymmetric effect, in which negative shocks have a greater impact on volatility to positive shocks, were significant based on the asymptotic t-ratios. The second moment condition was not satisfied for the forward and the twelve-month futures returns, but the log-moment condition was always satisfied, so that the QMLE were always consistent and asymptotically normal.

Constant conditional correlations between the volatilities of forward and futures returns were estimated using the CCC model based on estimating univariate GARCH(1,1) models. Among the five returns, there were ten conditional correlations, with the highest estimated constant conditional correlation being 0.975 between the standardized shocks to the volatilities in the three-month and six-month futures returns, and the lowest being 0.656 between the standardized shocks to the volatilities in the forward and twelve-month futures returns.

Based on the asymptotic standard errors, the DCC estimates of the conditional correlations between the volatilities of forward and futures returns based on estimating univariate GARCH(1,1) models for each returns were always statistically significant. This result made it clear that the assumption of constant conditional correlation was not supported empirically. This was highlighted by the dynamic conditional correlations between the forward and futures returns, which varied dramatically. Moreover, the skewness and kurtosis of the dynamic conditional correlation indicated a strong negatively skewed distribution. Only in the case of the dynamic volatilities of the three-month and six-month futures returns was the range of variation relatively narrow. In general, the dynamic volatilities in the returns in the WTI oil forward and future prices could be either independent or interdependent over time.

Future research includes a more detailed examination of the design of an optimal hedging strategy based on estimating a wider range of models yielding dynamic conditional correlations.

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Figure 1: Returns to Forward Prices for WTI, 3 January 1985 – 16 January 2004

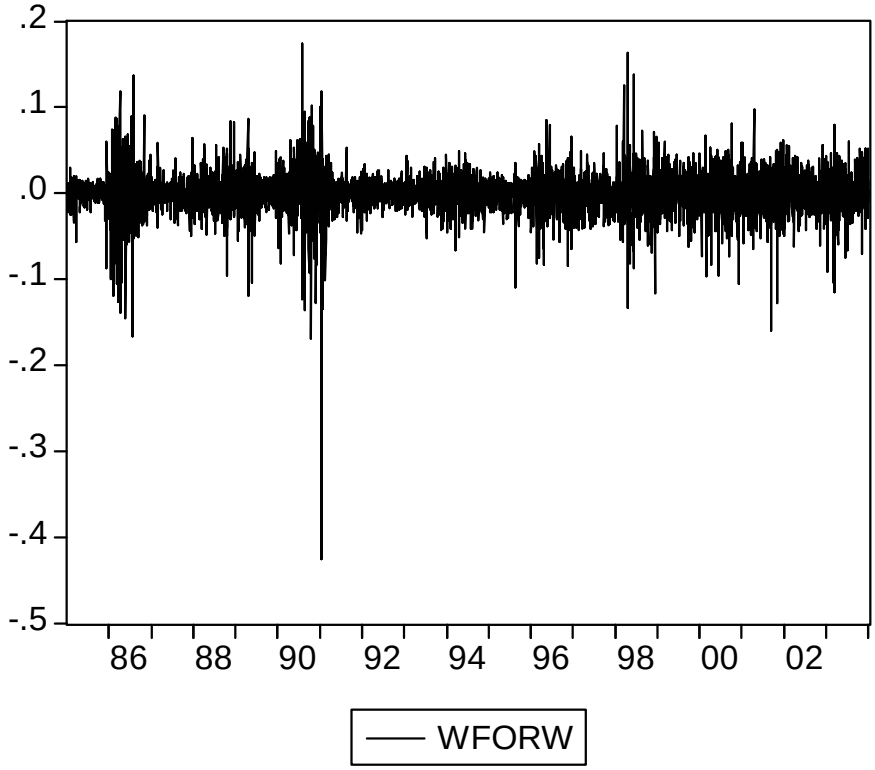
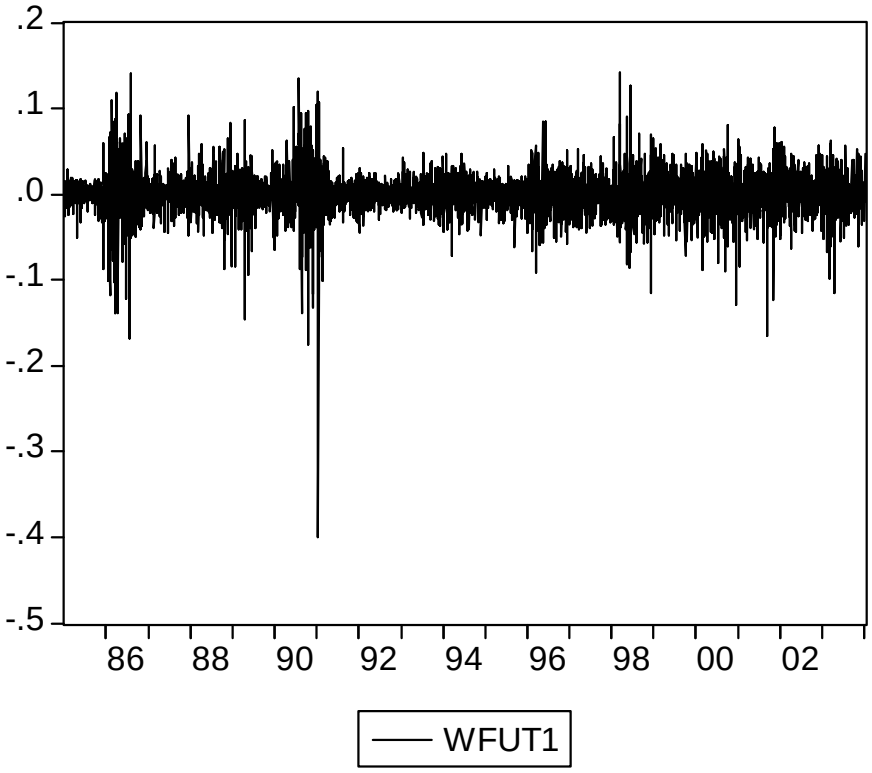


Figure 2: Returns to One- and Three-month Futures Prices for WTI, 3 January 1985 – 16 January 2004



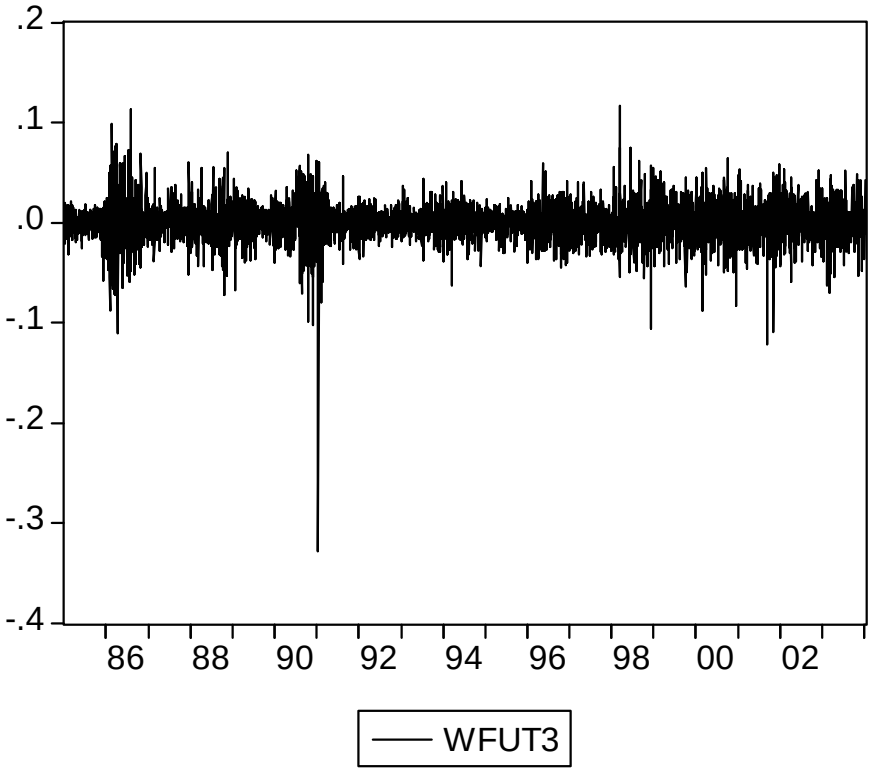
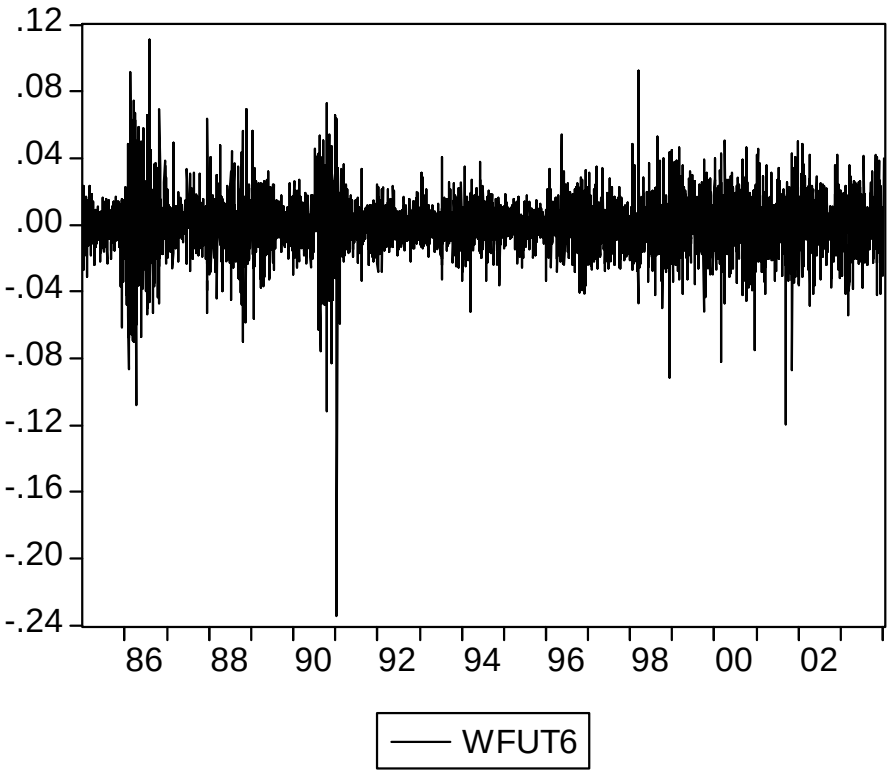


Figure 3**:** Returns to Six- and Twelve-month Futures Prices for WTI, 3 January 1985 – 16 January 2004



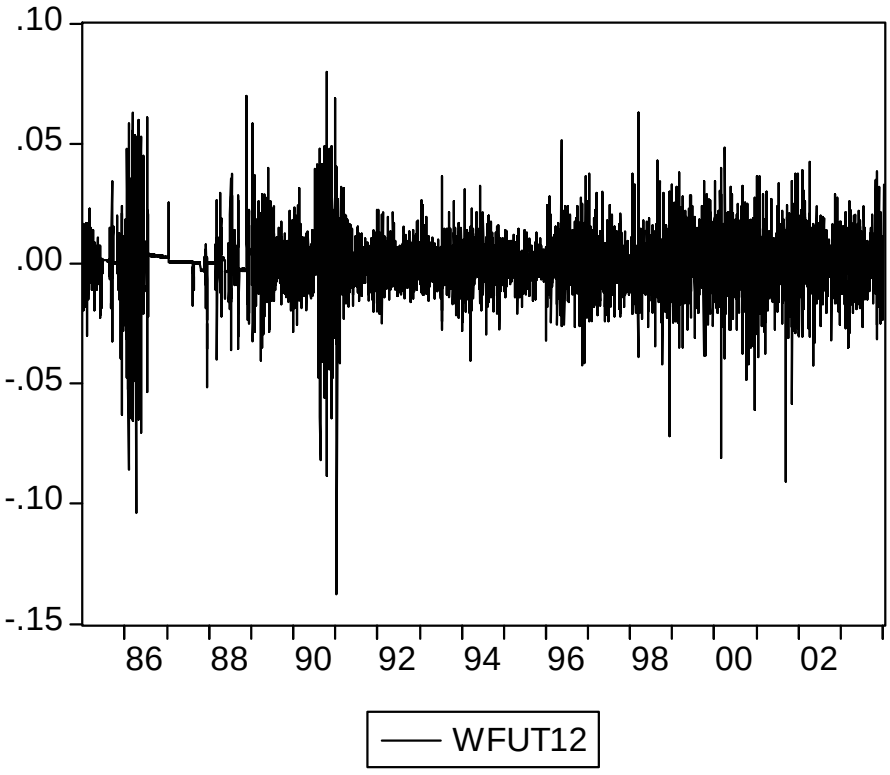


Figure 4: DCC between Forward and One-month Futures Returns

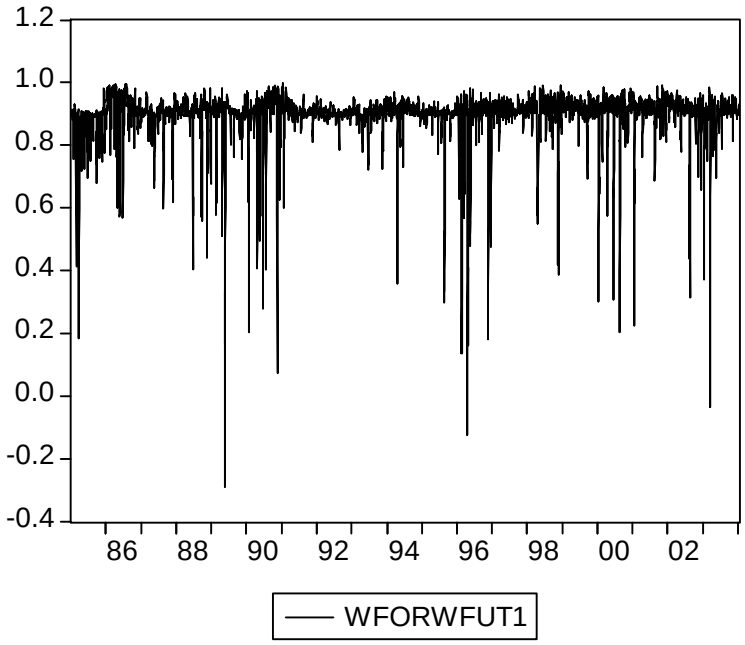


Figure 5: DCC between Forward and Three-month Futures Returns

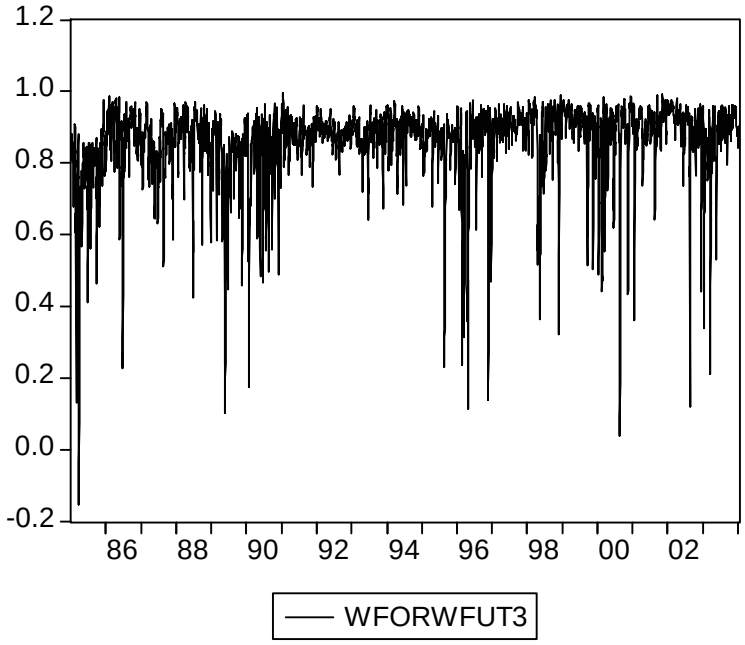


Figure 6: DCC between Forward and Six-month Futures Returns

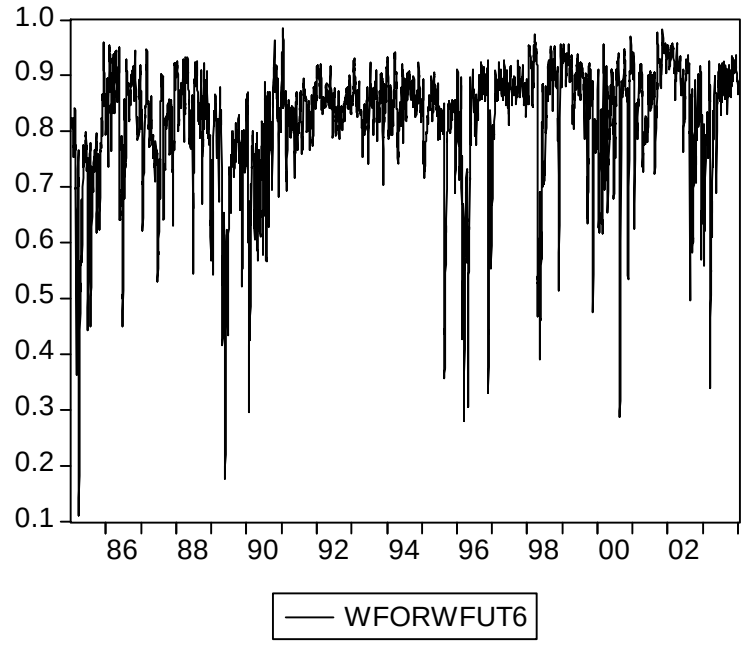


Figure 7: DCC between Forward and Twelve-month Futures Returns

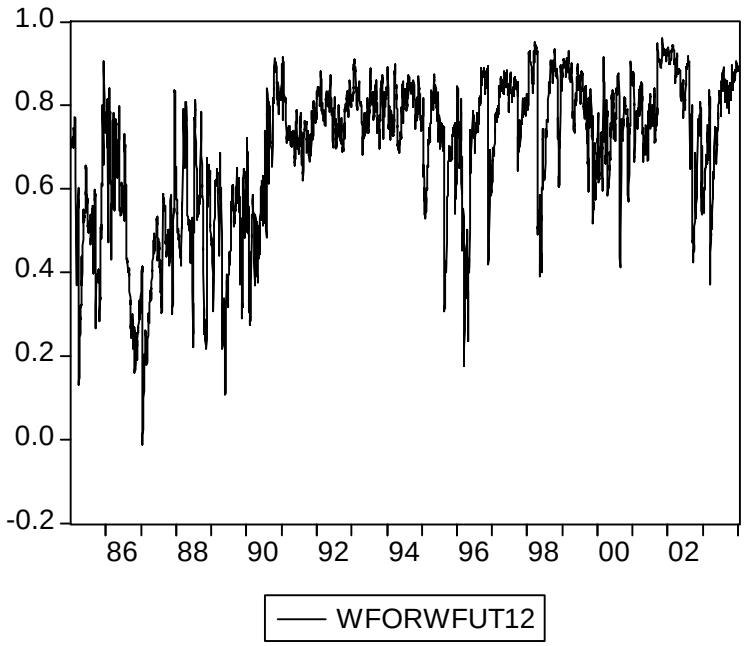


Figure 8: DCC between One- and Three-month Futures Returns

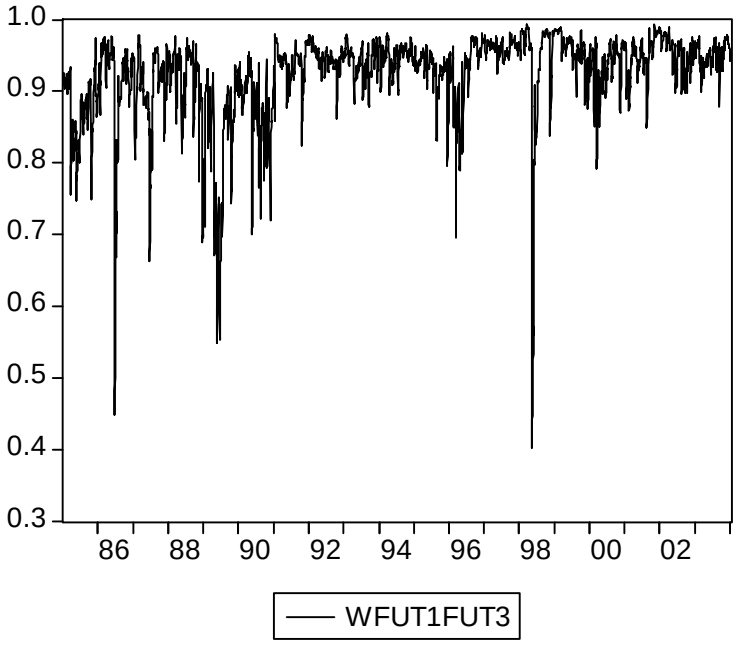


Figure 9: DCC between One- and Six-month Futures Returns

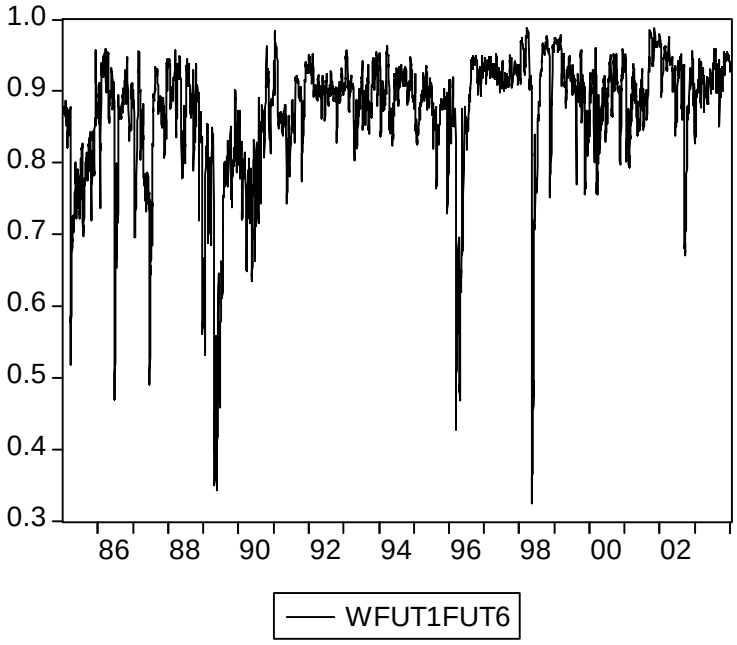


Figure 10: DCC between One- and Twelve-month Futures Returns

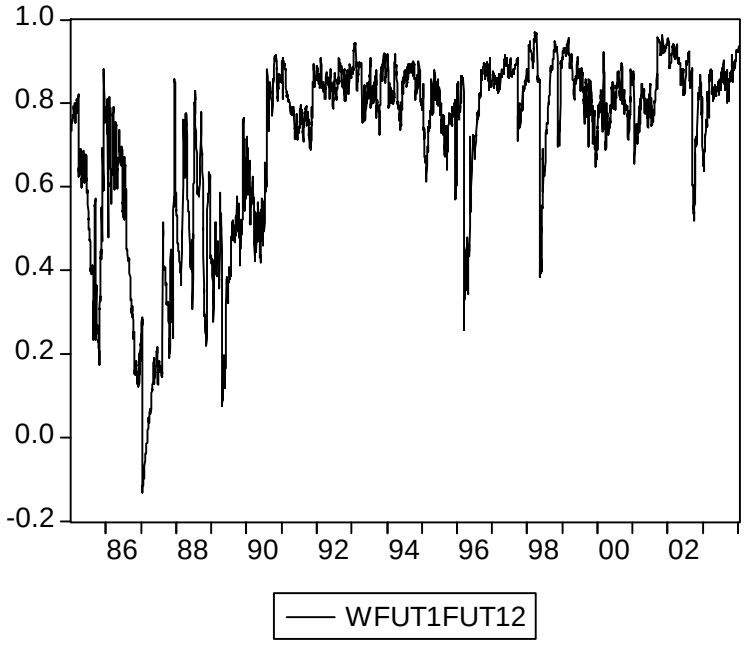


Figure 11: DCC between Three- and Six-month Futures Returns

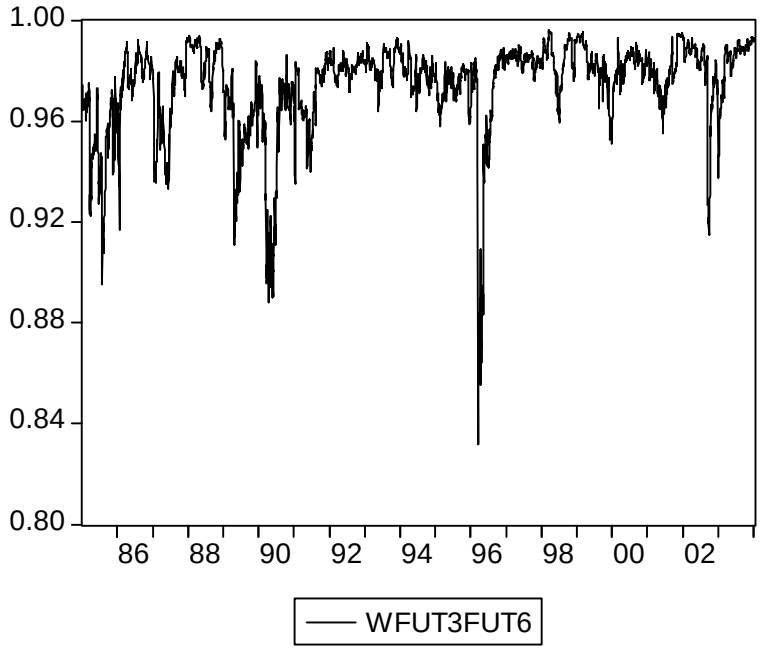


Figure 12: DCC between Three- and Twelve-month Futures Returns

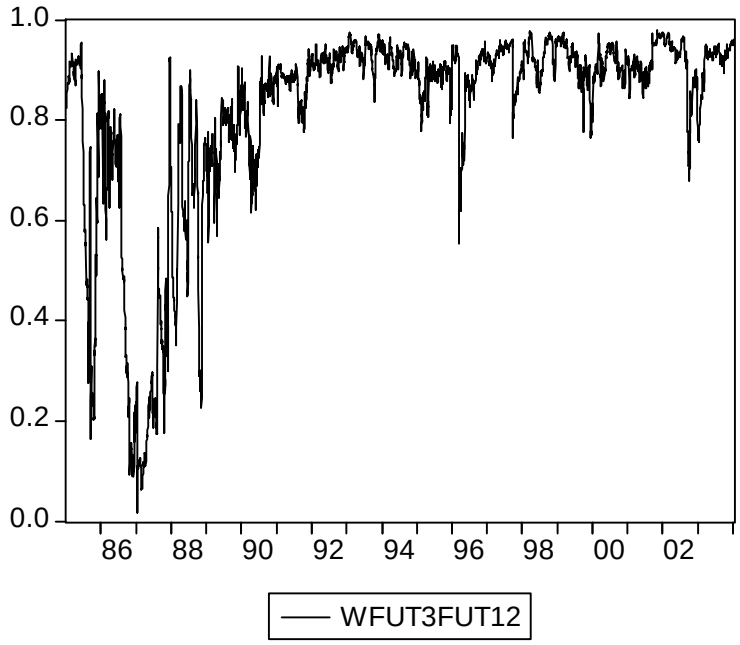


Figure 13: DCC between Six- and Twelve-month Futures Returns

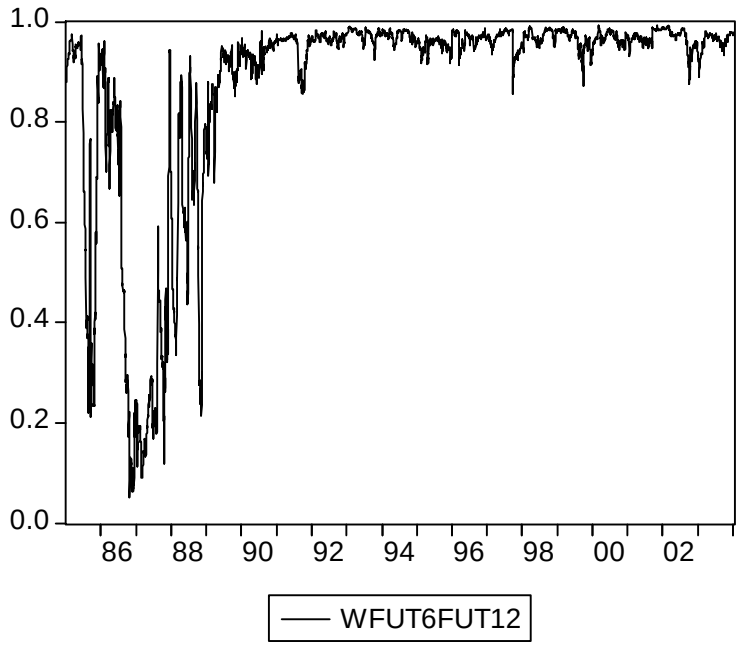


Table 1: Univariate AR(1)-GARCH(1,1) Estimates

Returns	ω	α	β	Log-moment	Second moment
WFORW	4.29E-06	0.114	0.890	-0.009	0.994
	6.259	24.619	180.481		
	3.898	6.235	67.277		
WFUT1	5.04E-06	0.102	0.897	-0.016	0.999
	7.406	22.959	185.918		
	3.978	6.726	76.461		
WFUT3	2.52E-06	0.078	0.919	-0.012	0.997
	7.291	17.066	206.711		
	2.685	7.871	103.907		
WFUT6	3.13E-06	0.090	0.901	-0.020	0.992
	8.693	19.994	177.192		
	3.858	6.699	75.440		
WFUT12	4.82E-08	0.197	0.853	-0.004	1.050
	16.291	55.153	631.711		
	17.763	6.814	50.820		

Note: The three entries for each parameter are their respective estimates, asymptotic t-ratios and Bollerslev-Wooldridge (1992) robust t-ratios.

Table 2: Univariate AR(1)-GJR(1,1) Estimates

Returns	ω	α	γ	β	$\alpha+1/2\gamma$	Log-moment	Second moment
WFORW	4.24E-06	0.134	-0.042	0.892	0.113	-0.014	1.005
	6.246	23.651	-6.211	187.561			
	3.836	3.992	-1.194	65.007			
WFUT1	5.11E-06	0.111	-0.016	0.896	0.103	-0.016	0.999
	7.390	20.421	-2.462	184.325			
	4.010	4.191	-0.524	73.317			
WFUT3	2.26E-06	0.066	0.016	0.924	0.073	-0.011	0.997
	6.694	10.917	2.271	214.241			
	2.435	4.550	0.819	110.516			
WFUT6	2.76E-06	0.075	0.019	0.908	0.084	-0.018	0.993
	7.965	12.748	2.691	182.992			
	3.631	4.188	0.830	82.079			
WFUT12	4.36E-08	0.177	0.025	0.857	0.189	-0.003	1.046
	14.717	32.343	3.534	610.328			
	10.824	3.902	0.352	53.780			

Note: The three entries for each parameter are their respective estimates, asymptotic t-ratios and Bollerslev-Wooldridge (1992) robust t-ratios.

Table 3: CCC Estimates based on GARCH(1,1)

Returns	WFORW	WFUT1	WFUT3	WFUT6	WFUT12
WFORW	1.000				
WFUT1	0.884	1.000			
WFUT3	0.855	0.921	1.000		
WFUT6	0.818	0.871	0.975	1.000	
WFUT12	0.656	0.686	0.787	0.839	1.000

Table 4: DCC Estimates based on GARCH(1,1)

Returns	θ_1	θ_2
WFORW, WFUT1	0.218 17.157	0.506 27.882
WFORW, WFUT3	0.188 5.671	0.746 12.972
WFORW, WFUT6	0.097 9.277	0.869 56.258
WFORW, WFUT12	0.059 7.103	0.934 94.473
WFUT1, WFUT3	0.078 11.160	0.911 112.651
WFUT1, WFUT6	0.070 11.671	0.916 124.294
WFUT1, WFUT12	0.046 9.175	0.953 179.445
WFUT3, WFUT6	0.049 9.505	0.945 151.155
WFUT3, WFUT12	0.051 91.826	0.948 4222.739
WFUT6, WFUT12	0.055 13.340	0.944 226.657

Notes: The model is $\Gamma_t = (1-q_1-q_2)\Gamma + q_1 h_{t-1} h_{t-1}^{'} + q_2 \Gamma_{t-1}$. The two entries for each parameter are their respective estimates and asymptotic t-ratios.

Table 5: Descriptive Statistics for Dynamic Conditional Correlations

Returns	Mean	Min.	Max.	S.D.	Skewness	Kurtosis
WFORW, WFUT1	0.894	-0.291	0.998	0.085	-5.181	40.842
WFORW, WFUT3	0.857	-0.155	0.994	0.112	-3.015	15.776
WFORW, WFUT6	0.818	0.111	0.985	0.107	-1.954	8.281
WFORW, WFUT12	0.689	-0.013	0.960	0.177	-0.971	3.277
WFUT1, WFUT3	0.922	0.403	0.994	0.062	-2.924	16.126
WFUT1, WFUT6	0.869	0.324	0.988	0.088	-2.274	10.046
WFUT1, WFUT12	0.715	-0.133	0.969	0.213	-1.472	4.560
WFUT3, WFUT6	0.974	0.832	0.996	0.019	-2.411	10.800
WFUT3, WFUT12	0.817	0.016	0.980	0.199	-2.183	7.012
WFUT6, WFUT12	0.873	0.051	0.993	0.212	-2.421	7.626

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(lix) This paper was presented at the ENGIME Workshop on "Mapping Diversity", Leuven, May 16-17, 2002
(lx) This paper was presented at the EuroConference on "Auctions and Market Design: Theory, Evidence and Applications", organised by the Fondazione Eni Enrico Mattei, Milan, September 26-28, 2002
(lxi) This paper was presented at the Eighth Meeting of the Coalition Theory Network organised by the GREQAM, Aix-en-Provence, France, January 24-25, 2003
(lxii) This paper was presented at the ENGIME Workshop on "Communication across Cultures in Multicultural Cities", The Hague, November 7-8, 2002
(lxiii) This paper was presented at the ENGIME Workshop on "Social dynamics and conflicts in multicultural cities", Milan, March 20-21, 2003
(lxiv) This paper was presented at the International Conference on "Theoretical Topics in Ecological Economics", organised by the Abdus Salam International Centre for Theoretical Physics - ICTP, the Beijer International Institute of Ecological Economics, and Fondazione Eni Enrico Mattei – FEEM Trieste, February 10-21, 2003
(lxv) This paper was presented at the EuroConference on "Auctions and Market Design: Theory, Evidence and Applications" organised by Fondazione Eni Enrico Mattei and sponsored by the EU, Milan, September 25-27, 2003
(lxvi) This paper has been presented at the 4th BioEcon Workshop on "Economic Analysis of Policies for Biodiversity Conservation" organised on behalf of the BIOECON Network by Fondazione Eni Enrico Mattei, Venice International University (VIU) and University College London (UCL) , Venice, August 28-29, 2003
(lxvii) This paper has been presented at the international conference on "Tourism and Sustainable Economic Development – Macro and Micro Economic Issues" jointly organised by CRENoS (Università di Cagliari e Sassari, Italy) and Fondazione Eni Enrico Mattei, and supported by the World Bank, Sardinia, September 19-20, 2003
(lxviii) This paper was presented at the ENGIME Workshop on "Governance and Policies in Multicultural Cities", Rome, June 5-6, 2003
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