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Abstract

This paper establishes the link of microstructure and macroeconomic factors with the time-varying conditional correlation of foreign exchange and excess equity returns. By using the proposed DCC model with exogenous variables, capital flows and interest rate differentials are shown to be significant determinants of this correlation which is inclusive of the short-run variation of both asset returns. The results also provide evidence of the dynamic behavior of global investors as they seek parity in equity returns between home and foreign markets to reduce exchange rate risks.

JEL: C32, F31, G15

Key words: uncovered equity parity, order flow, ADCCX

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The software programs used in this paper were written in Eviews and are available from the author upon request. Comments are welcome.

1. Introduction

Short-run dynamics of nominal exchange rates are difficult to predict using macroeconomic models. Meese and Rogoff (1983a, 1983b) and Rogoff (2001) and the survey of the literature by Frankel and Rose (1995) have shown the failure of these models to capture the behavior of exchange rates in short horizons. However, the recent shift from macroeconomic to microstructure approach gave rise to more plausible models that can account for a large proportion of the variations in the movement of exchange rates. In microstructure models of exchange rates, Evans and Lyons (2002a, 2002b) revealed that order flow can explain 45% to 78% of the variation of the daily returns of the most liquid currencies. It is defined by Evans and Lyons (2002a) as a measure of buying and selling pressure or simply the difference between buyer-initiated and seller-initiated trade.

Related to order flow is the movement of equities across financial markets. Hau and Rey (2004) showed that equity flows have grown from 4% of GDP for 1975 in the United States (US) to 245% of the GDP in 2000 and argued that this movement in equity significantly influences the short-run dynamics of foreign exchange balances. In this interaction between equity and exchange rate, Brooks, et al. (2001) observed that there is a negative correlation between foreign exchange return and *excess* equity return.

Hau and Rey (2006) referred to this phenomenon of negative correlation as uncovered equity parity. They explained that home equity return in excess of foreign equity return corresponds to the depreciation of the home currency. The depreciation is driven by domestic purchases of foreign equities to reduce exchange rate risks. Under complete market assumption this risk can be hedged and eliminated but Levich, et al. (1999) found that only a small fraction of institutional investors actually hedge exchange rate risks so Hau and Rey (2004, 2006) concluded that although the foreign exchange market is very liquid there are limits to the foreign exchange arbitrage trading that investors may conduct in a complete market setting.

They also provided a plausible explanation to how equity and exchange returns relate to each other in integrated financial markets using portfolio shifts. Changes in asset allocation produce capital flows that find their way to the foreign exchange market. They also argued that exchange rates are primarily a function of investment flows resulting from limited forex arbitrage of risk-averse speculators. Furthermore, they posited that portfolio rebalancing moves the conditional correlation between equity and foreign exchange returns where the correlation structure between foreign exchange return and excess equity return is constant, although they did consider a structural change in the correlation between two periods.

In the new micro exchange rate economics using microstructure theory, Evans and Lyons (2002a) demonstrated that foreign exchange order flow and the exchange rate are not endogenous although both are simultaneously determined. They found that the innovations in the exchange rate are driven largely by order flow but not the other way. This phenomenon supports what they called pressure hypothesis where the causality goes from order flow to exchange rates. This observed dynamics are consistent with the theoretical models of Glosten and Milgrom (1985) and Kyle (1985) and the empirical investigation of Evans and Lyons (2002b, 2006), Payne (2003) and Froot and Ramadorai (2005) where order flows provide information about payoffs and they therefore drive prices.

Obstfeld and Rogoff (2000) have observed that fundamentals fail to explain the movement of exchange rates. However, Hau and Rey (2006) showed that correlation exists between foreign exchange return and capital flows while Evans and Lyons (2002a, 2006) used regression to show that order flows and interest rate differentials significantly impact the foreign exchange return.

The dynamic conditional correlation (DCC) model of Engle (2002) and its extensions are widely used in the volatility literature and some of its applications in finance have been made by Manera, et al. (2006) on spot and forward oil price returns, Cappiello, et al. (2006) on international bond and equity returns, Billio, et al. (2006) sectoral asset allocation, Lanza, et al. (2006) on oil forward and future prices, Kuper and Lestano (2007) on stock markets and interest rates, among others. Incorporating exogenous variables in the DCC models is very important in evaluating potential determinants of time-varying conditional correlation between asset returns and this direction was suggested by Hafner and Franses (2003), Cappiello, et al. (2006) and Feng (2006).

This paper has two main contributions. First, an extension of the DCC model is proposed by incorporating exogenous variables in the evolution of the time-varying correlation. And second, using this DCC model, it is shown that the time-varying conditional correlation of the foreign exchange and excess equity returns varies across time and is driven by capital flows and interest rate differentials. The approach here differs largely from the problem currently being addressed in the literature, the modeling the dynamics of foreign exchange returns. Typically regression is used to measure the impact of order flow on exchange rate returns like in Evans and Lyons (2002a) and Dunne, et al. (2004), while this paper employs a conditional correlation model with exogenous variables to link the impact of two relevant variables on the time-varying correlation.

This paper is organized as follows. Section 2 presents the DCC model with exogenous variables. Section 3 specifies the time-varying correlation model of foreign exchange and excess equity returns. Section 4 discusses the data. Section 5 contains the results and discussion, and Section 6 concludes.

2. Asymmetric DCC Model with Exogenous Variables

The DCC model of Engle (2002) has the following specification. Let y_t be an $N \times 1$ vector of asset returns and $\Im_{t-1}$ a sigma algebra of information up to time $t-1$, without loss of generality μ_t is assumed to be zero, so

$$\begin{aligned} & y_t = \mu_t + \varepsilon_t \\ & \varepsilon_t = H_t^{1/2} u_t \text{ where } u_t \sim N(0, \mathrm{I}) \\ & \varepsilon_t \mid \Im_{t-1} \sim N(0, H_t). \end{aligned} \tag{1}$$

The conditional covariance matrix H_t can be expressed as a function of the DCC,

$$H_t = D_t R_t D_t = \left(\rho_{ij,t}\sqrt{h_{ii,t} h_{jj,t}}\right) \tag{2}$$

$$R_t = Q_t^{*-1} Q_t Q_t^{*-1}\text{, where } Q_t^* = diag\left(\sqrt{q_{ii,t}}\right) \tag{3}$$

where Q_t evolves according to

$$\left(\overline{Q} - \mathrm{A}'\overline{Q}\mathrm{A} - \mathrm{B}'\overline{Q}\mathrm{B}\right) + \mathrm{A}'(\varepsilon_{t-1}^* \varepsilon_{t-1}^*{}')\mathrm{A} + \mathrm{B}' Q_{t-1} \mathrm{B}. \tag{4}$$

This model was extended by Cappiello, et al. (2006) to include asymmetric effects, that is Q_t evolves according to

$$\left(\overline{Q} - \mathrm{A}'\overline{Q}\mathrm{A} - \mathrm{B}'\overline{Q}\mathrm{B} - \Gamma'\overline{N}\Gamma\right) + \mathrm{A}'(\varepsilon_{t-1}^* \varepsilon_{t-1}^*{}')\mathrm{A} + \mathrm{B}' Q_{t-1} \mathrm{B} + \Gamma'(n_{t-1} n_{t-1}{}')\Gamma \tag{5}$$

which is the Asymmetric DCC (ADCC) model.

Here $\varepsilon_t^* \sim N(0, R_t)$ is an $N \times 1$ vector of standardized residuals where $\varepsilon_{i,t}^* = \varepsilon_{i,t} h_{ii,t}^{-\frac{1}{2}}$ and $n_t = I\left(\varepsilon_t^* < \tau\right) \circ \varepsilon_t^*$ captures the asymmetric effects and where τ is typically set to zero. A, B

and Γ are $N \times N$ diagonal matrices where $\mathrm{A} = diag\left(\sqrt{\alpha}\right)$, $\mathrm{B} = diag\left(\sqrt{\beta}\right)$ and $\Gamma = diag\left(\sqrt{\eta}\right)$. To ensure positive definiteness of Q_t it is assumed that α, β and η are non-negative coefficients satisfying $\alpha + \beta + \delta\eta < 1$ where δ is the maximum eigenvalue of $\overline{Q}^{-\frac{1}{2}}\left(\overline{N}\right)\overline{Q}^{-\frac{1}{2}}$ which was derived by Cappiello, et al. (2006). Furthermore, $\hat{\overline{Q}} = T^{-1}\sum_{t=1}^{T}\varepsilon_t^* \varepsilon_t^{*}{}'$ and $\hat{\overline{N}} = T^{-1}\sum_{t=1}^{T} n_t n_t{}'$ serve as estimators of $\overline{Q}$ and $\overline{N}$, respectively.

In this paper, a model of ADCC which incorporates exogenous variables that drive the time-varying conditional covariance is proposed. Let X_t be a $p \times 1$ vector of exogenous variables, ξ be a $p \times 1$ vector of parameters and K be an $N \times N$ matrix that can either be an identity matrix or matrix of ones. The following specification for the proposed model has the following evolution of Q_t,

$$\left(\overline{Q} - \mathrm{A}'\overline{Q}\mathrm{A} - \mathrm{B}'\overline{Q}\mathrm{B} - \Gamma'\overline{N}\Gamma - \mathrm{K}\xi'\overline{X}\right) + \mathrm{A}'(\varepsilon_{t-1}^* \varepsilon_{t-1}^{*}{}')\mathrm{A} + \mathrm{B}'Q_{t-1}\mathrm{B} + \Gamma'(n_{t-1}n_{t-1}{}')\Gamma + \mathrm{K}\xi' X_{t-1} \qquad (6)$$

which is called ADCCX, where $\hat{\overline{X}} = T^{-1}\sum_{t=1}^{T} X_t$ is the estimator of $\overline{X}$. It can be easily shown that the ADCCX regresses to a DCCX model if $\eta = 0$; to the ADCC model if $\xi = 0$; and, to the DCC model if $\eta = 0$ and $\xi = 0$.

To ensure the positive definiteness of Q_t, K is set as an identity matrix. It is further specified that $\xi' = \left(\xi_1 \quad \cdots \quad \xi_p\right)'$ where $\xi_k = \sqrt{\xi_k^{(k)}}$ be $\xi_k^{(k)} \in (0,1)$. This condition on ξ_k, however, might be very restrictive because it implies that the exogenous variables only drive the conditional variances $q_{ii,t}$ but not the conditional covariances $q_{ij,t}$ where $i \neq j$. However, since the conditional correlation $r_{ij,t}$ is equal to $q_{ij,t}\left(q_{ii,t}q_{jj,t}\right)^{-1/2}$, it is still indirectly a function of the exogenous variables. This restriction can be relaxed by setting K as a matrix of ones instead. Another concern about having $\xi_k = \sqrt{\xi_k^{(k)}}$ is that it restricts the sign of the parameters to be non-negative. This is very limited and does not allow for the exogenous variable to have a negative impact on the conditional covariance Q_t. A remedy would be to allow ξ_k to take on a positive or negative value when K is an identity matrix provided that the positive definiteness of Q_t, $\forall t$ is not violated.

The maximum likelihood estimator of the ADCCX model is derived in the Appendix.

3. DCC Models of Foreign Exchange and Equity Returns

The indicator of uncovered equity parity is expected to be time-varying that is why a model that accounts for the variation in the correlation of foreign exchange and equity returns is necessary. This proposition is consistent with the dynamic behavior of investors when they react to changes in the economic environment by shifting their portfolio allocations between two markets. The ADCCX model in the previous section is used to model this time-varying correlation and is specified as follows. Let

$$R_t\left(-dE_t,\left(dS_t^{f*}-dS_t^h\right)\right)=f\left(Q_t\right) \tag{7}$$

where Q_t follows the evolution of the ADCCX model in Eq. (6) so that

$$\begin{aligned}&\overline{Q}-\mathrm{A}'\overline{Q}\mathrm{A}-\mathrm{B}'\overline{Q}\mathrm{B}-\Gamma'\overline{N}\Gamma-\mathrm{K}\xi_1\overline{dK}-\mathrm{K}\xi_2\overline{di}\\&+\mathrm{A}'(\varepsilon_{t-1}^*\varepsilon_{t-1}^*{}')\mathrm{A}+\mathrm{B}'Q_{t-1}\mathrm{B}+\Gamma'(n_{t-1}n_{t-1}{}')\Gamma+\mathrm{K}\xi_1\left(dK_{t-1}^f-dK_{t-1}^{h*}\right)+\mathrm{K}\xi_2 d\left(i_{t-1}^{f*}-i_{t-1}^h\right).\end{aligned} \tag{8}$$

Excess equity return is the difference between foreign and home log stock market index returns, $dS_t^{f*}-dS_t^h$. The foreign exchange return dE_t is the log return of E_t where E_t is in foreign currency per home currency so that foreign currency's appreciation against the home currency means $-dE_t>0$. Capital flows is the difference between the net foreign equity purchases by home residents and the net home equity purchases by foreigners, $dK_t^f-dK_t^{h*}$. Interest rate differential $i_t^{f*}-i_t^h$ is the difference between the foreign and home interest rates. The $\overline{dK}$ and $\overline{di}$ are equal to the mean of $dK_t^f-dK_t^{h*}$ and $d\left(i_t^{f*}-i_t^h\right)$, respectively. Alternative models ADCC, DCC and DCCX follow from Eq. (8) by setting the appropriate parameters to zero.

Following from the exogenous proposition about order flows by Evans and Lyons (2002a, 2006) and Froot and Ramadorai (2005), capital flows is taken as exogenous and the sign of the parameter ξ_1 is negative which indicates that capital flows move to satisfy the uncovered equity parity proposition by Hau and Rey (2006). Under the assumption of perfect price flexibility, the sign of the parameter ξ_2 is positive which implies that if the foreign interest rate rises it makes the foreign assets more attractive than before resulting in excess foreign equity return. However, the foreign currency depreciates in accordance with uncovered interest parity.

4. Data

The excess equity return, foreign exchange rate return, and capital flow data were sourced from the Princeton University website of Hélène Rey. The data included in this study are those of Germany and the United Kingdom (UK), considered the largest and most liquid equity and foreign exchange markets in Europe during the period under consideration, vis-à-vis the United States (US). The home country refers to the US. The data consists of monthly observations from January 1980 to December 2001 for a total of 264 observations.

In particular, $dS_t^{f*} - dS_t^h$ is the difference between the log foreign stock market index return and the log US stock market index return, $-dE_t > 0$ is the foreign currency's appreciation against the dollar, $dK_t^f - dK_t^{h*}$ is the difference between the net foreign equity purchases by US residents and the net US equity purchases by foreigners normalized by the average flows in the past 12 months, and $i_t^{f*} - i_t^h$ is defined as the difference between end-of-the-month yields of the foreign and US interest rates. With UK and the US the spread is the difference between 3-month T-bill yields which were downloaded from of the Bank of England and the US Federal Reserve websites, respectively. The interest differential between Germany and the US is derived from the 1-year T-bond yields, taken from EconStat.com.

5. Results and Discussion

The results begin with the GARCH(1,1) model of the returns. Table 1 suggests that foreign exchange returns exhibit heteroskedasticity based on the significant coefficients of the GARCH models. These show that the pound and the mark demonstrate persistency in the conditional variance even at the monthly returns. The volatility of excess equity returns is highly persistent for British equities while German equities display large short-run shocks.

The initial DCC models are given in Table 2, these are the ADCC models for both Germany and UK which indicate that there is no asymmetric effect between foreign exchange and excess equity returns since η is not significant. The absence of asymmetric effect implies that the magnitude of impact of either sign of the returns on the correlation does not significantly differ. This also suggests that a DCCX model is adequate for this purpose and Table 3 reports the parameter estimates of the four models without asymmetric effect arising from the special cases of Eq. (8).

Table 1. GARCH(1,1) Models of Foreign Exchange and Excess Equity Returns

Parameters	Foreign Exchange Returns		Excess Equity Returns	
	Germany	UK	Germany	UK
$a_0^{\#}$	0.0010 (0.0010)	0.0002 (0.0002)	0.0230** (0.0095)	0.0022 (0.0018)
a_1	0.0214 (0.0340)	0.0696** (0.0338)	0.1707** (0.0833)	0.1266** (0.0577)
b_1	0.8853*** (0.1119)	0.9098*** (0.0398)	0.0000 (0.2908)	0.7103*** (0.1607)

$a_0{}^{\#}$ is multiplied by a factor of 10

Table 2. ADCC Models of Foreign Exchange and Excess Equity Returns

	Germany	UK
α	0.0338 (0.0248)	0.0150 (0.0409)
β	0.9349*** (0.0569)	0.8790** (0.0810)
η	0.0105 (0.0524)	0.0986 (0.0710)
AIC	2.0066	2.0133
SIC	2.0473	2.0540
Log L	-260.86	-261.75

Table 3. DCC and DCCX Models of Foreign Exchange and Excess Equity Returns

Parameters	Germany				UK			
	DCC	DCCX1a	DCCX1b	DCCX2	DCC	DCCX1a	DCCX1b	DCCX2
α	0.0160 (0.0287)	0.0174 (0.0224)	0.0257 (0.0240)	0.0350* (0.0187)	0.0207 (0.0444)	0.0174 (0.0324)	0.0411 (0.0451)	0.0009 (0.0337)
β	0.9518*** (0.0983)	0.9494*** (0.0450)	0.9212*** (0.0450)	0.9254*** (0.0307)	0.8943*** (0.1095)	0.9196*** (0.0461)	0.9141*** (0.1143)	0.9285*** (0.0465)
ξ_1	–	-0.0054 (0.0065)	–	-0.0151** (0.0065)	–	-0.0122 (0.0080)	–	-0.0163* (0.0088)
ξ_2	–	–	0.2209 (0.3833)	0.5203* (0.2781)	–	–	0.1909 (0.3004)	0.4834** (0.2135)
AIC	1.9932	2.0031	1.9999	2.0245	2.0073	2.0179	2.0080	1.9937
SIC	2.0203	2.0438	2.0407	2.0789	2.0345	2.0587	2.0487	2.0480
Log L	-260.10	-260.40	-259.99	-262.23	-261.96	-262.36	-261.05	-258.17

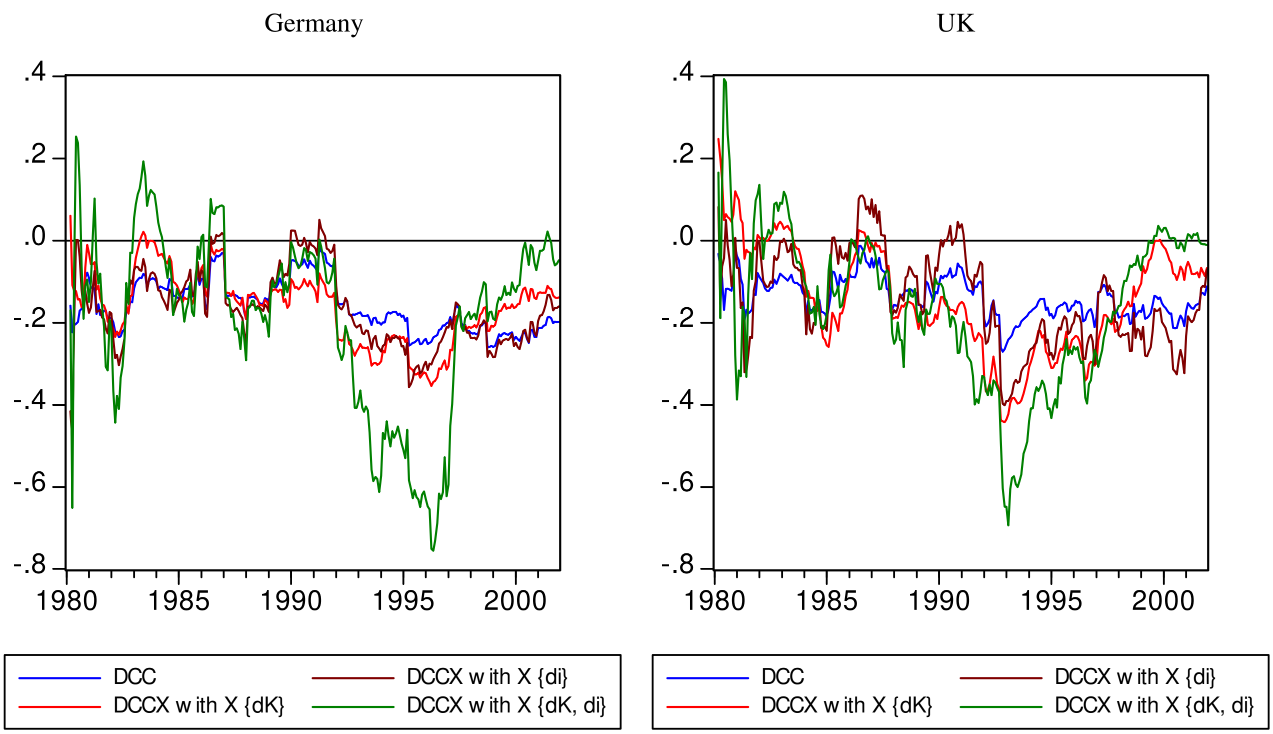
Note: K is a matrix of ones. The $dK_t^f - dK_t^{h*}$ and $d\left(i_t^{f*} - i_t^h\right)$ are stationary according to the Augmented Dickey-Fuller test in both cases.

The conditional correlation of foreign exchange and excess equity returns is highly persistent as shown by the significant parameter estimates of the DCC models and indicates that the correlation between the two is indeed time-varying for both markets. When only one of the exogenous variables is included in the model, DCCX1a and DCCX1b, neither is significant.

Both, however, are significant when they are in the model and the value of the parameter estimates change drastically which signals model misspecification when either variable is excluded. Although not reported here, the estimated asymmetric parameter of the ADCCX model is also not significant for both cases.

The sign of the parameter estimates of capital flows, ξ_1, is correct and is significant in both markets as shown by DCCX2. For the UK market the loglikelihood ratio test between the DCC and the DCCX2 model is significant at the 10% level and confirms the hypothesis in the literature that capital flows together with interest rate differentials significantly account for the short-run dynamics of foreign exchange and excess equity returns. Figure 1 present the graphs of the correlation. The graphs show that the inclusion of the exogenous variables clearly accentuates the negative correlation and confirms the time-varying nature of the uncovered equity parity.

Figure 1. DCC of the Mark (Pound) and the German (British) Excess Equity Returns v.v. the US



The outcome of this estimation shows that net capital flows from the home to the foreign market results in foreign currency appreciation that stabilizes the disparity in equity returns between the two markets when there is excess home equity return. This means that capital flows act to bring equity returns to parity to reduce the exchange rate risk involved when either equity markets have a higher return than the other through portfolio rebalancing according to Hau and Rey (2004).

The parameter estimate of ξ_2 is positive and correctly signed and also significant in both markets which confirms the result of Evans and Lyons (2002a, 2006). The relevance of interest rates, in which inflation and growth expectations are imbedded, argues for the impact of macroeconomic factors in driving this short-run dynamics of foreign exchange and equity returns.

Figures 2 shows the net capital flows where a positive value indicates a move in net capital towards Germany and UK, respectively, from the US. It is clear that when these graphs are superimposed to Figures 1, respectively, the negative correlations are observed when net capital flows are positive. And indeed, periods of heightened net capital outflow from the US result in higher magnitudes of negative correlation. Similarly, Figure 3 reveals that when

Figure 2. Net Capital Flows of US Purchases of German (UK) Equities and German (UK) Purchases of US Equities

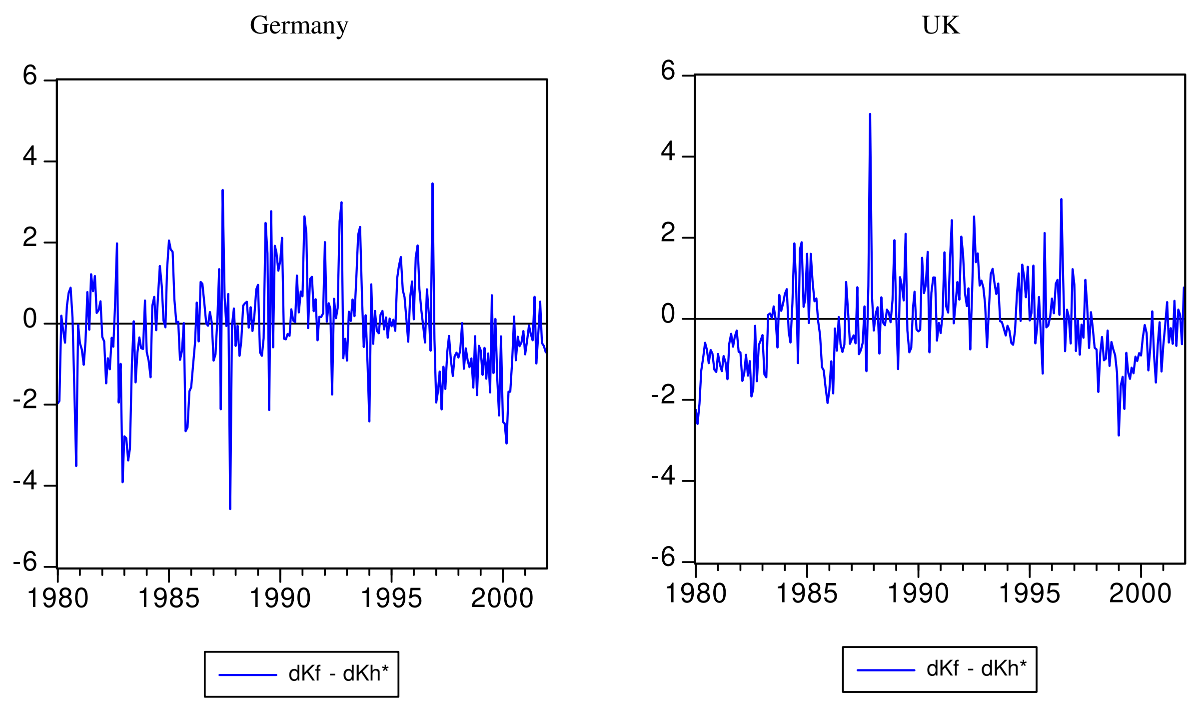
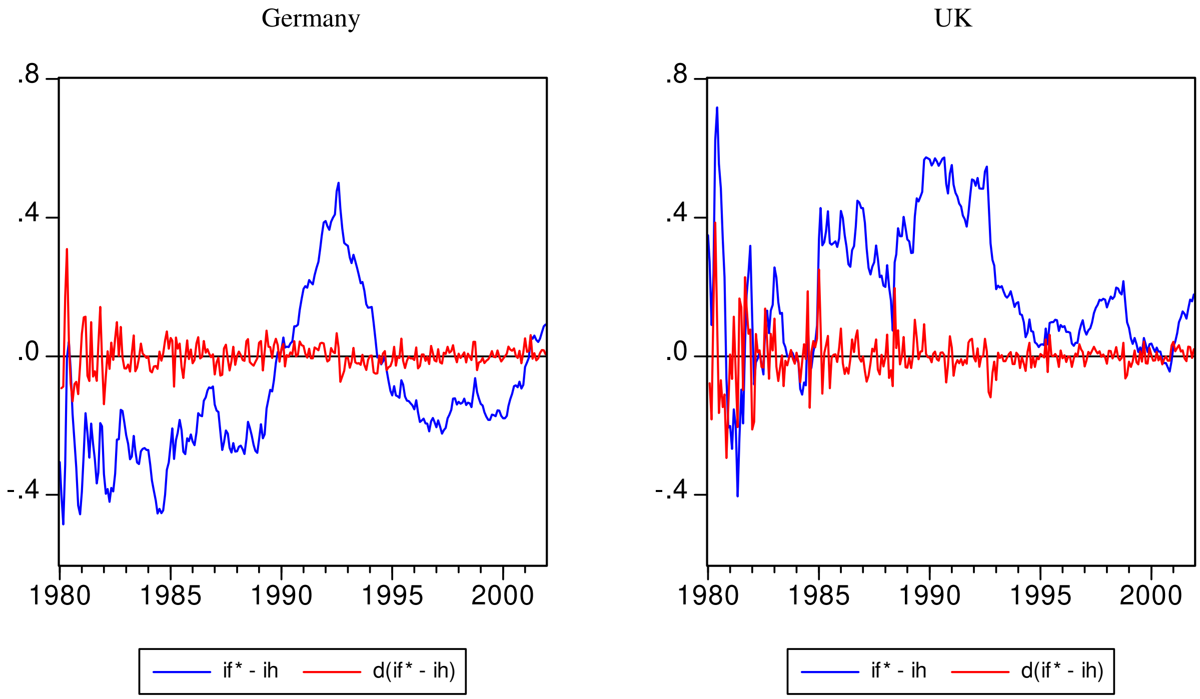


Figure 3. Interest Rate Differential between Germany (UK) and the US, in percent



German and UK interest rates exceed the US interest rates, especially, in periods of large positive differentials, the negative correlations are again observed to be correspondingly large.

These results are evidence of the changing dynamics of investor behavior as they respond to varying risks in the two markets and they highlight the importance of equity return parity for global investors as they seek to minimize the variance of their portfolio holdings. This dynamics can be explained in the sense of the classic Markowitz's efficient frontier. The significance of the capital flows and interest rate differentials suggests that the correlation dynamics of foreign exchange and excess equity returns are subject to both microstructure and macroeconomic factors, at least in the sense of capital flows and interest rates, respectively.

6. Conclusion

The extension of the DCC model by incorporating exogenous variables is a natural direction to take in order to identify the factors that drive the time-varying conditional correlation of asset returns. By employing the DCC model, this paper shows that the correlation between foreign exchange and excess equity returns is time-varying. The DCCX model provides a convenient tool for characterizing this time-varying correlation as a function of capital flows and interest rate differentials.

The optimizing behavior of global investors shows that they seek equity parity to minimize the foreign exchange risk in their portfolios. This paper demonstrates that this behavior results in capital flow movements that adjust both the exchange rate and equity returns in both home and foreign financial markets to satisfy uncovered equity parity. Capital flows contain information about investor decisions, in the microstructure context, and is significant in accounting for the time-varying conditional correlation of the foreign exchange and excess equity returns. This confirms that investor behavior is a rich source of information that can account for the short-run dynamics of foreign exchange rate. Furthermore, the interest rate differentials represent macroeconomic information that arguably drives this correlation as well. The results establish the link of microstructure and macroeconomic factors with the short-run dynamics of foreign exchange and equity returns.

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APPENDIX

Maximum Likelihood Estimation of the ADCCX Model

The likelihood function under the assumption of multivariate normality of y_t is given by

$$L(\theta \mid y_t) = \prod_{t=1}^{T}\left[\frac{1}{\left(\sqrt{2\pi}\right)^N |H_t|^{1/2}} e^{-\frac{1}{2} y_t H_t^{-1} y_t'}\right].$$

Using the two-stage LIML procedure proposed by Engle (2002) the likelihood function is maximized with respect to two sets of parameters in succeeding steps.

The vector θ consists of GARCH parameters for each element of the N-dimensional y_t and the parameters of Q_t, where $y_t = \varepsilon_t$. Engle and Sheppard (2001) have shown the consistency and asymptotic normality of this two-stage procedure. The loglikelihood function is

$$\log L(\theta_1, \theta_2 \mid y_t) = -\frac{1}{2}\sum_{t=1}^{T}\left(N\log(2\pi) + \log|H_t| + y_t H_t^{-1} y_t'\right)$$

$$= -\frac{1}{2}\sum_{t=1}^{T}\left(N\log(2\pi) + \log|R_t| + 2\log|D_t| + y_t' D_t^{-1} R_t^{-1} D_t^{-1} y_t\right)$$

where θ_1 consists of parameters of the MGARCH model, θ_2 consists of parameters of Q_t. Furthermore, $H_t = D_t R_t D_t$ and $D_t = diag\left(h_{11,t}^{1/2} \ldots h_{NN,t}^{1/2}\right)$. Engle and Sheppard (2001) set R_t as the identity matrix in the first stage estimation,

$$\log L(\theta_1 \mid y_t) = -\frac{1}{2}\sum_{t=1}^{T}\left(N\log(2\pi) + \log|I_N| + 2\log|D_t| + y_t' D_t^{-1} I_N^{-1} D_t^{-1} y_t\right)$$

$$\hat{\theta}_1 = \arg\max[\log L(\theta_1 \mid y_t)]$$

which is equivalent to estimation of the univariate GARCH models of y_t.

The second stage estimation involves

$$\log L(\theta_2 \mid \hat{\theta}_1, y_t) = -\frac{1}{2}\sum_{t=1}^{T}\left(N\log(2\pi) + \log|R_t| + 2\log|\hat{D}_t| + y_t' \hat{D}_t^{-1} R_t^{-1} \hat{D}_t^{-1} y_t\right)$$

where $\varepsilon_t^* = \hat{D}_t^{-1} y_t$. And since $R_t = Q_t^{*-1} Q_t Q_t^{*-1}$ where $Q_t^* = diag\left(\sqrt{q_{iit}}\right)$

$$\log L(\theta_2 \mid \hat{\theta}_1, y_t) = -\frac{1}{2}\sum_{t=1}^{T}\left(N\log(2\pi) + \log|Q_t^{*-1} Q_t Q_t^{*-1}| + 2\log|\hat{D}_t| + \varepsilon_t^{*}{}'(Q_t^{*-1} Q_t Q_t^{*-1})^{-1} \varepsilon_t^*\right).$$

The constant terms $N\log(2\pi)$ and $2\log\left|\hat{D}_t\right|$ are not necessary in the maximization and are dropped from the function so that

$$\log L'(\theta_2 \mid \hat{\theta}_1, y_t) = -\frac{1}{2}\sum_{t=1}^{T}\left(\log\left|Q_t^{*-1}Q_tQ_t^{*-1}\right| + \varepsilon_t^{*}{}'(Q_t^{*-1}Q_tQ_t^{*-1})^{-1}\varepsilon_t^{*}\right)$$

$$\hat{\theta}_2 = \arg\max[\log L'(\theta_2 \mid \hat{\theta}_1, y_t)].$$

An expansion of the second stage loglikelihood function is

$$\log L'(\theta_2 \mid \hat{\theta}_1, y_t) = -\frac{1}{2}\sum_{t=1}^{T}\Big\{\log\left|Q_t^{*-1}\left(\tilde{Q} + \mathrm{A}'(\varepsilon_{t-1}^{*}\varepsilon_{t-1}^{*}{}')\mathrm{A} + \mathrm{B}'Q_{t-1}\mathrm{B} + \Gamma'(n_{t-1}n_{t-1}{}')\Gamma + \mathrm{K}\xi' X_{t-1}\right)Q_t^{*-1}\right|$$

$$+\,\varepsilon_t^{*}{}'\left(Q_t^{*-1}\left(\tilde{Q} + \mathrm{A}'(\varepsilon_{t-1}^{*}\varepsilon_{t-1}^{*}{}')\mathrm{A} + \mathrm{B}'Q_{t-1}\mathrm{B} + \Gamma'(n_{t-1}n_{t-1}{}')\Gamma + \mathrm{K}\xi' X_{t-1}\right)Q_t^{*-1}\right)^{-1}\varepsilon_t^{*}\Big\}$$

where

$\tilde{Q} = \left(\overline{Q} - \mathrm{A}'\overline{Q}\mathrm{A} - \mathrm{B}'\overline{Q}\mathrm{B} - \Gamma'\overline{N}\Gamma - \mathrm{K}\xi'\overline{X}\right)$ and

$$Q_t = \tilde{Q} + \mathrm{A}'(\varepsilon_{t-1}^{*}\varepsilon_{t-1}^{*}{}')\mathrm{A} + \mathrm{B}'Q_{t-1}\mathrm{B} + \Gamma'(n_{t-1}n_{t-1}{}')\Gamma + \mathrm{K}\xi' X_{t-1}.$$

The maximum likelihood estimators of ADCC, DCC and DCCX models can be derived by setting the appropriate parameters to zero.