The World Economy

The World Economy (2010)
doi: 10.1111/j.1467-9701.2010.01227.x

US–Euro Area Monetary Policy Interdependence: New Evidence from Taylor Rule-based VECMs

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1. INTRODUCTION

SINCE January 2008, the US Federal Reserve (Fed) has enacted a series of interest rate cuts on its target rate as a reaction to the current subprime crisis. The federal funds rate has been decreased from 4.25 per cent at the beginning of 2008 to a range of 0 to 0.25 per cent at the end of last year. In the first half of 2008, the cut in the US interest rate fuelled speculations that the European Central Bank (ECB) would be forced to soften its position as a monetary policy 'hawk' as well. However, the day after the US interest rate cut in January 2008, 'the ECB made clear that it would not bow easily to pressure for euro area interest rate cuts' (Akins, 2008), which highlighted the contrast between the ECB and the Fed. Against the big pressure to cut the interest rate, the ECB even raised the interest rate in July by 25 basis points. This notable increase of its main interest rate apparently contradicted a popular argument that the ECB follows the Fed in its monetary policies but was probably *inter alia* due to much higher structural rigidities in the euro area (Belke and Gros, 2002). However, in the last quarter of 2008, the situation turned out

We are grateful for valuable comments from the participants in the All China Economics (ACE) International Conference 2007 in Hong Kong, especially Hugh Metcalf, Niklas Potrafke, Louis Yeung and Lili Yan. We are also grateful for the valuable comments from Daniel L. Thornton at the Eighth Annual Missouri Economics Conference 2008, hosted by the Federal Reserve Bank of St. Louis and the University of Missouri-Columbia, and Hamdi Raissi, Christoph Hanck and Ahmed El Ghini at the Second International Workshop on Computational and Financial Econometrics 2008 in Neuchâtel, Switzerland.

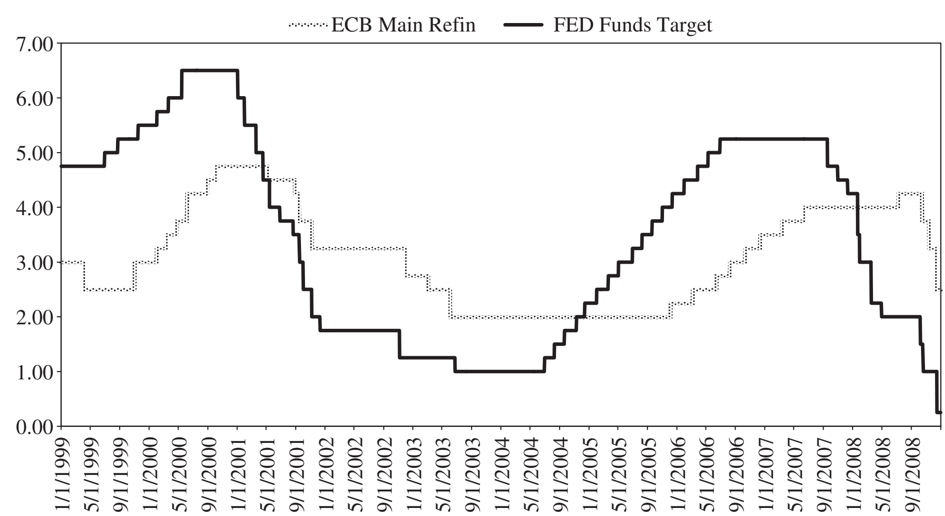
to be the opposite: within three months, the ECB sharply cut its interest rate by a total 175 basis points.

The interest rate developments across the Atlantic in 2008 brought an old debate back to the fore: does the ECB follow the Fed in its monetary policy? Is there any co-movement pattern between the two central banks?[1]

Since the introduction of the euro, there has been always some discussion on a possible leader–follower relationship between the ECB and the Fed, particularly at the early stage of the introduction of the euro. The reaction of the ECB to monetary and economic shocks was described as slow. Some researchers and economists pointed out that there might be a time-lag effect, or more precisely a leader–follower relationship between the monetary policies of the ECB and the Fed (see e.g. Belke and Gros, 2005; Ullrich, 2006). In contrast to the ECB, the Fed is widely regarded as reacting more quickly to market and economic shocks or changes. Due to its special institutional character, the change of policy rates made by the ECB was apparently slower than those made by the Fed corresponding to the same economic or market turmoil.

The origin of the hypothesis suggesting a leader–follower relationship comes from a time-lag effect on the central bank policy rates between the ECB and the FED, which is illustrated in Figure 1. From Figure 1 we can see that in the

FIGURE 1
Monetary Policy Rates of the ECB and the Fed



Note:
The data were obtained from the websites of the ECB and the Fed, respectively.

[1] For a recent survey on relevant studies on the issue of US–euro area monetary policy interdependence see, for instance, Eijffinger (2008).

early stages of establishment of the euro, from 1999 to mid-2002, there was an obvious rough correlation between the ECB and the Fed, on which the 'leader–follower' argument has been based. However, this pattern did not continue after the end of 2002. Instead, the reaction of the ECB became relatively simultaneous with the Fed during the period 2003 to mid-2004. After mid-2004, the reaction of the ECB to economic shocks backslid and a leader–follower pattern appeared again till the end of 2008. Due to the complexity of the patterns over the different periods, it seems more appropriate to further investigate an interdependent relationship between the ECB and the Fed, rather than to only test for a leader–follower pattern over the corresponding time span.

An investigation of monetary policy interdependence between the ECB and the Fed has two aspects. On one hand, there could be 'contemporaneous' interdependence, which presents a long-run equilibrium relationship, or co-movement, between the two interest rates (Scotti, 2006, p. 18). On the other hand, a possible leader–follower pattern could exist between the two central banks, and, more concretely, the ECB may follow the Fed in making its monetary policy.

Different methodologies have been used for testing the leader–follower relationship between the ECB and the Fed, as well as the interdependence between them. The Granger-causality test was used by Garcia-Cervero (2002) and Belke and Gros (2002, 2005) for testifying a leader–follower relationship. Ullrich (2005) estimated linear equations with an OLS method to test for the interdependence, by incorporating the interest rate of one central bank into the other bank's reaction function; Breuss (2002) also estimated a linear equation but with the generalised method of moments (GMM) to investigate whether the ECB follows the policy steps of the Fed.

In our analysis, we employ a partial vector error correction model (VECM) and a general VECM to test for interdependence and a possible leader–follower relationship between the two central banks. Based on the special features of the partial VECM and the general VECM models, we are able to identify interdependence in the long-run cointegrating equations and evidence of short-run interest rate smoothing dynamics in the error correction framework (Judd and Rudebusch, 1998). Both the partial VECM and the general VECM pay attention to the non-stationarity of the time series variables, which has been too often ignored in earlier Taylor Rule estimations (Gerlach-Kristen, 2003). Hence, interest rate rules estimated using the cointegration approach are, in contrast to the traditional Taylor Rule, stable in sample and tend to forecast better out of sample. In addition, in the partial and general VECM frameworks, we are able to test for a leader–follower pattern by checking weak exogeneity of the interest rates in the system.

In order to explain the interdependence of monetary policies across the Atlantic, we need to know how monetary policy decisions are made in the euro area as well as in the US. The Taylor reaction function (Taylor, 1993) has been justified by many researchers to be an appropriate framework for describing the monetary policies of the ECB and the Fed,[2] according to which interest rates are determined by time-varying variables like inflation rate, output gap and lagged values of the interest rates. Therefore, in our estimations, the Taylor Rule represents the basic framework for both of the econometric models.

The remainder of this paper is structured as follows. In Section 2, we give a brief explanation of the Taylor Rule, which provides a theoretical framework for the empirical estimations in the following sections. In Section 3, we present the econometric methods and the empirical models. The data and variables are described in Section 4. The empirical results are summarised in Section 5 with corresponding economic explanations of the findings. The last section concludes.

2. THEORY OF THE TAYLOR RULE

Since it was published in 1993, the Taylor Rule (Taylor, 1993) has been widely accepted to describe the monetary policies in different countries, particularly for the ECB and the Fed. A general time-variant Taylor Rule reaction function without coefficient specification could be expressed as:

$$\begin{aligned} i_t^T &= \pi_t + a_0 o_t + a_1(\pi_t - \pi^*) + r^* + \varepsilon_t \\ &= \beta_0 + \beta_1 \pi_t + \beta_2 o_t + \varepsilon_t, \end{aligned} \tag{1}$$

where i_t^T is the Taylor Rule rate, r^* is the equilibrium real policy rate, π_t is the inflation rate over the previous four quarters, π^* is the target inflation rate, o_t is the per cent deviation of real GDP from a target (output gap), and ε_t is an error term. a_0 and a_1 are coefficients of the original equation, where both a_0 and a_1 are greater than zero. For the derived equation, $\beta_0 = r^* - a_1\pi^*$, $\beta_1 = 1 + a_1$ and $\beta_2 = a_0$. All parameters are expected to be greater than zero.

The empirical estimation of the Taylor Rule often relates the nominal interest rate to its own lags. This approach, as Judd and Rudebusch (1998, p. 2) pointed out, allows the possibility of a gradual adjustment of the nominal interest rate to achieve the rate recommended by the Taylor Rule. Similarly, a Taylor reaction function proposed by Clarida et al. (1998, 2000) was also modified by incorporating interest rate smoothing for the euro area.

A typical dynamic Taylor reaction function with interest rate smoothing can be derived from the equation $i_t = (1-\rho)i_t^T + \rho i_{t-1} + \varepsilon_t$, where i_t is the nominal interest rate, ρ is the smoothing parameter (see e.g. Judd and Rudebusch, 1998; Ulrich, 2005; Belke and Polleit, 2007). The interest rate is then dependent on the inflation rate and the output gap, and plus its own lags:

[2] See e.g. Gerdesmeier and Roffia (2004) for the ECB, and Judd and Rudebusch (1998) for the Fed.

$$\begin{aligned} i_t &= (1-\rho)i_t^T + \rho i_{t-1} + \varepsilon_t \\ &= (1-\rho)(\beta_0 + \beta_1\pi_t + \beta_2 o_t) + \rho i_{t-1} + \varepsilon_t \\ &= A_0 + A_1\pi_t + A_2 o_t + A_3 i_{t-1} + \varepsilon_t, \end{aligned} \tag{2}$$

where A_0 is the new constant and A_1, A_2 and A_3 are the new coefficients of π_t, o_t and i_{t-1}, respectively, and

$$\begin{aligned} A_0 &= (1-\rho)\beta_0 = (1-\rho)(r^* - a_1\pi^*) > 0, \\ A_1 &= (1-\rho)\beta_1 = (1-\rho)(1+a_1) > 0, \\ A_2 &= (1-\rho)\beta_2 = (1-\rho)a_0 > 0, \\ A_3 &= \rho > 0. \end{aligned}$$

Most of the empirical tests on the Taylor Rule have corroborated the positive signs of A_0, A_1, A_2 and A_3.[3] Hence, we expect that an increase of the inflation rate or the output gap will result in a rising interest rate, and the higher the lagged interest rate is, the higher is the current interest rate.

In addition to this dynamic model, some other macroeconomic variables have also been considered for inclusion in the Taylor reaction functions. Eleftheriou et al. (2006), for instance, summarise different Taylor Rule specifications for the ECB monetary policy in the existing literature. According to them, the inflation rate, the output gap and the lagged interest rate are the most preferred variables in the Taylor Rule estimations. We will strictly follow this preferred specification in our analysis.

3. EMPIRICAL MODELS

Many studies and empirical estimations on the Taylor reaction functions have ignored the non-stationarity feature of the time series variables (Gerlach-Kristen, 2003). In our analysis we take into account the possible non-stationarity in the variables, and carry out unit roots for all the time series variables implemented. The precondition for the cointegration test, which is an essential part of the VECM, is that all the variables should be non-stationary at their level, but become stationary at the same order; for example, in our estimations, they are expected to be integrated of order one, or I(1).

[3] The results of positive signs of these parameters are maintained in the Taylor Rule estimations for both the Fed and the ECB. For the Fed, see the work of Judd and Rudebusch (1998); for the ECB, see the works of Gerlach-Kristen (2003), Gerdesmeier and Roffia (2004) and Eleftheriou et al. (2006). For a survey of specifications of Taylor reaction functions as simple rules for monetary policy see, for instance, Clarida et al. (1999, pp. 1695ff).

When this precondition is satisfied, we are able to carry out cointegration tests among the level variables, and then estimate the degree of interdependence and check for a leader–follower relationship in the partial and the general VECM frameworks.

a. Cointegration Test

If a linear combination of the non-stationary variables, which for example are all I(1), is stationary, then the variables are said to be cointegrated (Granger, 1986, p. 215). In this case, the linear combination of the variables presents a long-run equilibrium relationship among the variables (Granger, 1986, pp. 215–16). In our empirical analysis, the cointegration test is a precondition for an application of the empirical framework of the VECMs. As we incorporate the Taylor Rule variables into the partial and the general VECMs, the cointegration tests are carried out among these variables. When the number of variables is larger than two, there might be more than one cointegrating equation (Engle and Granger, 1987, p. 254). Hence, it is necessary to test for the cointegrating rank, i.e. the number of cointegrating relations among the variables. In the estimations, we first check for the cointegrating rank and then use the results of the cointegrating rank as a pre-determined condition for further estimations in the partial and the general VECM framework.

b. Partial VECM

As shown in Figure 1, there is an obvious co-movement between the two interest rates, which could be interpreted as a possible long-run equilibrium relation. This long-run relationship can be checked by the cointegration test and expressed in a cointegrating equation. If the cointegrating equation exists, we can use a partial VECM to capture the long-run relation between the interest rates in the cointegrating equation, together with a short-run dynamic reaction function based on the Taylor Rule.

In our partial VECM framework, we deal with two endogenous variables, i.e. the US and the euro area interest rates, and four exogenous variables, i.e. the inflation rates and the output gaps in both currency areas. A reduced form of the partial VECM can be written as below:[4]

$$\Delta i_t = (\alpha\beta')i_{t-1} + \Gamma_1 \Delta i_{t-1} + \cdots + \Gamma_{p-1}\Delta i_{t-p+1} + Bx_t + \varepsilon_t, \tag{3}$$

where i_t is the vector of endogenous variables, $i_t = (i_t^{ECB}, i_t^{Fed})'$; x_t is the vector of exogenous variables, $x_t = (\pi_t^{ECB}, o_t^{ECB}, \pi_t^{Fed}, o_t^{Fed})'$. β is the cointegration

[4] For a more detailed explanation of the partial VECM see Johansen (1992). For a practical application see, for instance, Woo (1999).

vector, which specifies the long-run equilibrium relation. α is the error correction vector, which represents the short-run adjustment when the economy deviates from the equilibrium level, and $\alpha\beta' = \Pi$. Γ_j ($j = 1,\ldots, p - 1$) is a matrix of the structural coefficients for a dynamic interest smoothing process. B is the coefficient matrix on the exogenous variables. In case of significance of the coefficients in B we have to reject the hypothesis that the Taylor Rule does not hold. ε_t is a two-dimensional error vector. Under the partial VECM, the error terms in the vector ε_t are white noise errors.

For a better understanding of the functions of the coefficient, we display each individual equation as below:

$$\begin{aligned}
\Delta i_t^{ECB} &= a_{10} + a_{11}\left(i_{t-1}^{ECB} + \gamma_1 i_{t-1}^{Fed}\right) + \varphi_{11}\Delta i_{t-1}^{ECB} + \cdots + \varphi_{1i}\Delta i_{t-i}^{ECB} \\
&\quad + \eta_{11}\Delta i_{t-1}^{Fed} + \cdots + \eta_{1i}\Delta i_{t-i}^{Fed} + b_{11}\pi_t^{ECB} + b_{12}o_t^{ECB} + b_{13}\pi_t^{Fed} \\
&\quad + b_{14}o_t^{Fed} + \varepsilon_{1t}, \\
\Delta i_t^{Fed} &= a_{20} + a_{21}\left(i_{t-1}^{ECB} + \gamma_1 i_{t-1}^{Fed}\right) + \varphi_{21}\Delta i_{t-1}^{ECB} + \cdots + \varphi_{2i}\Delta i_{t-i}^{ECB} \\
&\quad + \eta_{21}\Delta i_{t-1}^{Fed} + \cdots + \eta_{2i}\Delta i_{t-i}^{Fed} + b_{21}\pi_t^{ECB} + b_{22}o_t^{ECB} + b_{23}\pi_t^{Fed} \\
&\quad + b_{24}o_t^{Fed} + \varepsilon_{2t}.
\end{aligned} \tag{4}$$

For testing interdependence, we need to check the significance of the coefficients in the vector β. Since one of the coefficients in the vector β has been pre-defined as 1 (see the term $\left(i_{t-1}^{ECB} + \gamma_1 i_{t-1}^{Fed}\right)$ in equation (4)), we only need to consider the coefficient γ_1. If γ_1 is significant, then the null hypothesis of no interdependence can be rejected.

For establishing a leader–follower pattern, we need to check for weak exogeneity by looking at the significance of the coefficients in the vector α ($\alpha' = (a_{11}, a_{21})$) in equation (4). In the case of the partial VECM, if the US interest rate is weakly exogenous, then there is one-way causation from the US interest rate to the euro interest rate. It indicates that the ECB follows the Fed. According to Johansen (1992), the hypothesis of weak exogeneity of an endogenous variable for the parameters of interest α and β is equivalent to imposing a zero on the corresponding coefficients in the vector α. In other words, the hypothesis of weak exogeneity cannot be rejected if the variables can be characterised as a pure random walk independent of the cointegration/error correction term. In the partial VECM, the hypothesis of weak exogeneity of the US interest rate i_t^{Fed} is H_0: $a_{21} = 0$. If H_0 cannot be rejected, it means the US interest rate is weakly exogenous, and the US interest rate leads the euro interest rate, or, in other words, the ECB follows the Fed. If in addition to $a_{21} = 0$, the coefficients $\varphi_{21} \sim \varphi_{2i}$ are all equal to zero, the US interest rate does not depend upon the lagged values of the euro interest rate and, thus, the US interest rate, i_t^{Fed}, can be considered to be strongly exogenous (Patterson, 2001, p. 674).

c. General VECM

As Maddala (2001, p. 375) pointed out, the classification of variables into endogenous and exogenous is sometimes arbitrary. Due to the anticipated Taylor Rule long-run equilibrium relationship, the Taylor Rule variables, which appear in the partial VECM, are more likely to be reconsidered as endogenous variables, rather than exogenous variables. Hence, we move on to the general VECM and assume all the variables are endogenous, i.e. they are determined within the system, rather than pre-determined outside of the system. Based on the Taylor Rule, we include six endogenous variables in the estimations: the interest rates in two currency areas (i_t^{ECB},i_t^{Fed}), the inflation rates and the output gaps in two currency areas (π_t^{ECB}, π_t^{Fed}, o_t^{ECB}, o_t^{Fed}). A reduced form of the general VECM can be written as:[5]

$$\Delta y_t = \alpha\beta' y_{t-1} + \Gamma_1 \Delta y_{t-1} + \cdots + \Gamma_{p-1}\Delta y_{t-(p-1)} + \varepsilon_t, \tag{5}$$

where y_t is the vector of endogenous variables, $y_t = (i_t^{ECB}, \pi_t^{ECB}, o_t^{ECB}, i_t^{Fed}, \pi_t^{Fed}, o_t^{Fed})'$. ε_t is the error vector. β is the cointegration matrix, α is the error correction matrix, and $\alpha\beta' = \Pi$. Γ_j ($j = 1, \ldots, p - 1$) is a (6×6) matrix for coefficients on lagged endogenous variables.

We re-write the model in a matrix-vector form for a better illustration of the tests:

$$\begin{bmatrix} \Delta i_t^{ECB} \\ \Delta i_t^{Fed} \\ \Delta \pi_t^{ECB} \\ \Delta \pi_t^{Fed} \\ \Delta o_t^{ECB} \\ \Delta o_t^{Fed} \end{bmatrix} = \begin{bmatrix} A_{11} & A_{21} \\ A_{12} & A_{22} \\ A_{13} & A_{23} \\ A_{14} & A_{24} \\ A_{15} & A_{25} \\ A_{16} & A_{26} \end{bmatrix} \begin{bmatrix} B_{11} & B_{21} \\ B_{12} & B_{22} \\ B_{13} & B_{23} \\ B_{14} & B_{24} \\ B_{15} & B_{25} \\ B_{16} & B_{26} \end{bmatrix}' \begin{bmatrix} i_{t-1}^{ECB} \\ i_{t-1}^{Fed} \\ \pi_{t-1}^{ECB} \\ \pi_{t-1}^{Fed} \\ o_{t-1}^{ECB} \\ o_{t-1}^{Fed} \end{bmatrix} + \begin{bmatrix} \gamma_{11,1} & \cdot\cdot & \gamma_{61,1} \\ \gamma_{12,1} & \cdot\cdot & \gamma_{62,1} \\ \gamma_{13,1} & \cdot\cdot & \gamma_{63,1} \\ \gamma_{14,1} & \cdot\cdot & \gamma_{64,1} \\ \gamma_{15,1} & \cdot\cdot & \gamma_{65,1} \\ \gamma_{16,1} & \cdot\cdot & \gamma_{66,1} \end{bmatrix} \begin{bmatrix} \Delta i_{t-1}^{ECB} \\ \Delta i_{t-1}^{Fed} \\ \Delta \pi_{t-1}^{ECB} \\ \Delta \pi_{t-1}^{Fed} \\ \Delta o_{t-1}^{ECB} \\ \Delta o_{t-1}^{Fed} \end{bmatrix} + \cdots$$

$$+ \begin{bmatrix} \gamma_{11,p-1} & \cdot\cdot & \gamma_{61,p-1} \\ \gamma_{12,p-1} & \cdot\cdot & \gamma_{62,p-1} \\ \gamma_{13,p-1} & \cdot\cdot & \gamma_{63,p-1} \\ \gamma_{14,p-1} & \cdot\cdot & \gamma_{64,p-1} \\ \gamma_{15,p-1} & \cdot\cdot & \gamma_{65,p-1} \\ \gamma_{16,p-1} & \cdot\cdot & \gamma_{66,p-1} \end{bmatrix} \begin{bmatrix} \Delta i_{t-(p-1)}^{ECB} \\ \Delta i_{t-(p-1)}^{Fed} \\ \Delta \pi_{t-(p-1)}^{ECB} \\ \Delta \pi_{t-(p-1)}^{Fed} \\ \Delta o_{t-(p-1)}^{ECB} \\ \Delta o_{t-(p-1)}^{Fed} \end{bmatrix} + \begin{bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \varepsilon_3 \\ \varepsilon_4 \\ \varepsilon_5 \\ \varepsilon_6 \end{bmatrix}. \tag{6}$$

[5] For details see Engle and Granger (1987) and Johansen (1992).

Some pre-assumptions are made according to the theory of the Taylor Rule. Based on the Taylor Rule, we can assume that, in the long-run, the interest rate in each country is determined by the domestic inflation rate and the output gap, plus the interest rate from the other country. This assumption implies that some of the coefficients (in our case B_{15}, B_{16}, B_{23}, B_{24}) in the matrix β should be pre-defined as zero. In matrix form, these constraints can be expressed as:

$$\beta = \begin{bmatrix} 1 & B_{21} \\ B_{12} & 1 \\ B_{13} & 0 \\ B_{14} & 0 \\ 0 & B_{25} \\ 0 & B_{26} \end{bmatrix}. \tag{7}$$

A check for weak and strong exogeneity of the endogenous variables is also carried out for the general VECM, with a similar hypothesis as for the partial VECM. Instead of a single coefficient in the error correction vector α in the partial VECM, the hypothesis of weak exogeneity of the US interest rate in the general VECM, for instance, is $A_{12} = 0$ and $A_{22} = 0$. If, in addition, the coefficients of the lagged values of other variables are zero, then the US interest rate is strongly exogenous to the system. Analogous checks are also carried out on all the other endogenous variables.

4. DATA AND VARIABLES

In view of the monetary policy decision time frames on both sides of the Atlantic, we use monthly data in our estimations (see also Breuss, 2002; Gerdesmeier and Roffia, 2004; Ullrich, 2005; Scotti, 2006). The daily realisations are not preferred in our analysis, although they were selected by some other researchers at the early stage of research work for the ECB monetary policy. The daily realisations of the data may have the maximum information, but most of the news on a daily basis presumably comes from financial markets (Belke and Gros, 2005). The sample period for the empirical estimations is from 1999M1 to 2006M12. All the raw data are seasonally adjusted using the Census X-12-ARIMA method.[6] Since the seven-year-long time span in the estimations can present a complete interest rate cycle, this sample period seems to be sufficient to gain reliable estimates.

[6] The Census X-12-ARIMA method is generally adopted by the ECB and the Fed (ECB, 2000).

We decided to leave out the years 2007 and 2008 from our sample. We did so for two reasons. Firstly, the standard theory of the Taylor rule implicitly assumes that the equilibrium real rate is stable over time, whereas in fact it will move about. Secondly, a central bank will sometimes need to change its policy rate simply in order to leave monetary conditions unchanged. Expressed differently, central banks can only fix the short-term nominal rate. However, what a particular level of this rate implies for monetary conditions will depend on short-run inflation expectations and on the equilibrium real rate needed to balance out the economy. Most likely, the latter have changed significantly in the face of the cost and credit shocks experienced during the turbulences of the financial crisis of 2007/08. This has led *inter alia* to an extraordinarily high degree of model uncertainty (Tucker, 2008). We do not argue that it is time now to limit oneself to qualitative analysis. However, we do think it is too early to be able to model structural breaks adequately in this context.

In this paper, we follow Gerdesmeier and Roffia (2004) and use the EONIA rate as a proxy for the ECB monetary policy rate, and follow Judd and Rudebusch (1998) to use the Fed Funds rate for the US monetary policy rate. Both the EONIA rate and the Fed Funds rate are market rates, which are strongly influenced by the monetary policies.

The euro area inflation rate is measured by the year-to-year percentage change in the harmonised index of consumer prices (HICP) for the euro area. The US inflation is calculated on the basis of consumer price index (CPI):

$$\pi_t^{Euro} = 100 * \left(\frac{HICP_t - HICP_{t-12}}{HICP_{t-12}}\right)$$

and

$$\pi_t^{US} = 100 * \left(\frac{CPI_t - CPI_{t-12}}{CPI_{t-12}}\right).$$

The output gaps are derived from the industrial productions for both currency areas as follows:

$$o_t = 100 * (\frac{IP_t - IPtrend_t}{IPtrend_t}),$$

where *IPtrend* presents the potential long-term trend of output which is obtained by using a Hodrick–Prescott filter.

While the interest rate, inflation rate and output gap are likely to be stationary in large samples, the results in the literature suggest that, in order to draw the correct statistical inference, it is desirable to treat them as non-stationary in the relatively short sample studied here *a priori* (Gerlach-Kristen, 2003). However, in order to feel justified in implementing the cointegration test, we

TABLE 1
Unit Root Test Results

Test Description	*ADF Tests, SIC Criterion (p-values)*	
(H_0: Series has a unit root)	*Level*	*First Difference*
EONIA	0.1622	0.004
Euro Area Inflation Rate	0.0179*	0
Euro Area Output Gap	0.1955	0.0001
Fed Funds Rate	0.6602	0.0037
US Inflation Rate	0.3169	0.0152
US Output Gap	0.32	0

Note:
Sample (adjusted) is: Jan. 1999–Dec. 2006. Tests are based on ADF test equations with a constant, but no trend.

explicitly check all the variables for unit roots. For this purpose, we conducted a battery of unit root tests.[7] The results of the ADF tests including a constant but no drift (because the graphs of all series do not show a clear trend) are summarised as an example in Table 1.

A closer inspection of Table 1 reveals that, except for the euro area inflation rate, which is rejected for having a unit root almost at the 1 per cent significance level, all variables appear to contain a unit root at the usual significance levels. What is more, they appear to be stationary after first differencing throughout. In case of the ambiguous results for the euro area inflation rate we would like to argue that it has been subject to much debate (and is still so) whether in limited samples the price level is I(1) or I(2) and, hence, the inflation rate is I(0) or I(1). Moreover, stationarity is a sample property and differencing in case of stationarity of a variable is better than not differencing when it is non-stationary. In other words, from an empirical point of view it is often advantageous to approximate a near-unit root with a unit root, even though it is significantly different from one (Juselius and MacDonald, 2004; Juselius, 2006, pp. 31ff.).

All in all, thus, it does make sense to also consider the euro area inflation rate as non-stationary at the level. In other words, our unit root test results have satisfied the precondition for a further cointegration test, which is essential for the partial and general VECM estimations.

[7] We carried out ADF tests, KPSS tests and Phillips–Perron tests. The results are available on request.

TABLE 2
Cointegrating Rank (CR) Test Results with Different Lag Selections

Lag Selection on Δi_t (PVECM) or Δy_t (GVECM)	*CR of Partial VECM*	*CR of General VECM*
lag = 0	2	3
lag = 1	2	3
lag = 2	1	2
lag = 3	0	1
lag = 4	0	3
lag = 5	0	2
lag = 6	2	1
lag = 7	0	2
lag = 8	1	4
lag = 9	1	5
lag = 10	0	5
lag = 11	1	6
lag = 12	2	not applicable

Note:
Sample (adjusted) is Jan. 1999–Dec. 2006.

5. RESULTS

a. Cointegration Test Results

The results of the cointegrating rank tests are summarised in Table 2. The test results are subject to the selected lag length. Although we display the results for up to lag = 12, based on the theory of the interest rate smoothing, we would propose a lag length not higher than 2.[8]

The rank test results corresponding to lag = 2 (i.e. rank is 1 for the partial VECM and 2 for the general VECM) can be well explained by econometric and economic theory. For a partial VECM with two endogenous variables (i.e. $k = 2$), the maximum cointegrating rank r should be 1, because the cointegrating rank r among the k endogenous variables should be $0 \leq r \leq k - 1$ (Engle and Granger, 1987, p. 254). For the general VECM estimation, the test results are comparable with the analysis in the previous section, where we expected only two long-run cointegrating relations among the variables. Therefore, we select a lag length of 2 as the assumption for both the partial and the general

[8] As pointed out by Judd and Rudebusch (1998, p. 7), the error-correction framework is useful for the consideration of the interest rate smoothing process. The lag considered in the Taylor reaction function for interest smoothing is widely accepted to be one, as shown in equation (2). Therefore, in our estimations, we will not consider long lags. Here we assume the highest possible lag length as 3. This assumption is consistent with our estimation results of both of the partial and the general VECMs.

TABLE 3
Estimation Results of the Partial VECM

Cointegrating Eq.	*CointEq1* (β)	
i_{t-1}^{ECB}	1	
i_{t-1}^{Fed}	−0.351934***	
c	−0.989375**	
Error Correction	Δi_t^{ECB}	Δi_t^{Fed}
CointEq1	−0.116685***	−0.147683***
Δi_{t-1}^{ECB}	−0.212615**	−0.026327
Δi_{t-2}^{ECB}	0.066868	−0.101978
Δi_{t-1}^{Fed}	0.03545	0.311872***
Δi_{t-2}^{Fed}	−0.062145	0.052443
π_t^{ECB}	0.133693***	0.147422***
o_t^{ECB}	0.030426**	−0.022488
π_t^{Fed}	−0.070023***	−0.070236***
o_t^{Fed}	0.06795***	0.044156***
R-squared	0.501374	0.662628
Adj. R-squared	0.453886	0.630497
Sum sq. resids	1.066265	1.191704
S.E. equation	0.112666	0.119109
F-statistic	10.55787	20.62289
Log likelihood	75.82107	70.64923
Akaike AIC	−1.437012	−1.32579
Schwarz SC	−1.191922	−1.0807
Mean dependent	0.006129	0.004624
S.D. dependent	0.152458	0.195946

Notes:
Sample (adjusted) is Jan. 1999–Dec. 2006.
* Significant at 10 per cent; ** significant at 5 per cent; *** significant at 1 per cent.

VECMs, and the cointegrating ranks for the partial VECM is 1 and for the general VECM it is 2.

b. Estimation Results of the Partial VECM

Based on the cointegration tests, we selected a lag order of two for our estimations. In order to carry out the partial VECM estimations, we need to make an assumption regarding the deterministic trend underlying the data. Five possible deterministic trends are contained in the Johansen procedure (Johansen, 1995, pp. 80–84). Based on the econometric techniques on selecting the deterministic trend (Patterson, 2001, pp. 624–30), we choose the assumption of having no deterministic trend on level data but intercept in cointegrating equations.

In Table 3, we present our estimation results, dividing our presentation of the latter into three parts. The first part delivers the estimated coefficients for the long-run cointegrating equation; the second part delivers the estimated coefficients for the short-run error correction process, with the first column presenting the reaction function of the euro interest rate (in the differencing term), and the second column presenting the reaction function of the US interest rate (also in the differencing term); the last part lists the regression statistics for each equation.

Let us now turn to the interpretation of the results. The strong significance of the coefficient in the vector β, i.e. the coefficient of i_{t-1}^{Fed}, indicates *contemporaneous* interdependence between the interest rates (see the first part in Table 3). Additionally, these figures also indicate that the adjustment of the ECB towards economic shocks has smaller steps than that of the Fed. These results underline the view that compared with the Fed, the ECB is more conservative and less active in making its monetary policy decisions.

The two estimated coefficients in vector α (see the first row of the second part in Table 3) both appear significant and their signs are negative. In the short run, both interest rates adjust to the 'errors', which consists of the deviations from the equilibrium level. The adjustment magnitudes of the two interest rates are similar: about 12 per cent for the ECB and 15 per cent for the Fed. The high significances of the error correction parameters also indicate a clear rejection of the hypotheses of weak exogeneity of both interest rates. Hence, it is not clear at this stage of analysis whether there exists a leader–follower relationship between the two central banks.

On the whole, the remaining estimation results reveal a reaction function pattern which is quite close to the Taylor Rule expectation (see the second part in Table 3). The coefficients of the interest rates lagged one month are significant in each equation, respectively, which indicates interest rate smoothing in both reaction functions. The high degree of significance of the coefficients of the inflation rate and the output gap show that both interest rates can be explained well by the Taylor Rule. However, as shown in the first column, the reaction function of the ECB follows the Taylor Rule more closely, with positive signs on domestic inflation rate and output gap. Although it does not have a clear leader–follower relationship, the ECB's monetary policy is obviously affected by changes in the US inflation rate and output gap. Similarly, the economic changes from the euro area also have an impact on the Fed's monetary policy decision, but the Fed's consideration concentrates more on the inflation rate of the euro area (see the second column in Table 3).

A series of diagnostic tests are carried out for the partial VECM.[9] The test results reveal that the estimated partial VECM does not fit very well with the observations. A high goodness of fit is indicated by the empirical realisations

[9] The results of the diagnostic tests are available on request.

TABLE 4
Estimation Results of the General VECM

Cointegrating Equations	*Coint. Eq1* (β_1)	*Coint. Eq2* (β_2)
i_{t-1}^{ECB}	1	−3.43213***
i_{t-1}^{Fed}	−0.055277	1
π_{t-1}^{ECB}	1.238622***	0
o_{t-1}^{ECB}	0.357809***	0
π_{t-1}^{Fed}	0	−1.646774***
o_{t-1}^{Fed}	0	0.395286***
c	−5.441218***	11.46439***

Variables Equations	Δi_t^{ECB}	Δi_t^{Fed}	$\Delta \pi_t^{ECB}$	Δo_t^{ECB}	$\Delta \pi_t^{Fed}$	Δo_t^{Fed}
Coint. Eq1 (α_1)	0.199537***	0.007147	−0.082849	0.317842	0.326713***	−0.279618*
Coint. Eq2 (α_2)	0.108853***	0.031496	−0.01551	0.229087	0.185024***	−0.088634
Δi_{t-1}^{ECB}	−0.257565***	0.127658	0.45526**	−0.246455	−0.731358**	0.536449
Δi_{t-2}^{ECB}	−0.039576	−0.07267	0.073322	−0.456668	−0.799707**	0.51927
Δi_{t-1}^{Fed}	0.134963	0.383863***	−0.162263	0.7095	0.238386	0.781277*
Δi_{t-2}^{Fed}	−0.061976	0.046551	−0.205339	−0.854145	−0.097655	−0.819459*
$\Delta \pi_{t-1}^{ECB}$	−0.142651**	0.00863	−0.041469	−0.430191	0.142855	−0.217006
$\Delta \pi_{t-2}^{ECB}$	−0.046541	0.033244	0.148369	0.225207	0.078673	0.144393
Δo_{t-1}^{ECB}	−0.028679	−0.001086	0.017691	−0.828468***	−0.162347***	0.078715
Δo_{t-2}^{ECB}	−0.003568	−0.015711	0.019395	−0.541822***	−0.086585*	0.067269
$\Delta \pi_{t-1}^{Fed}$	0.029861	−0.011764	0.063193	0.355498	0.381338***	0.073291
$\Delta \pi_{t-2}^{Fed}$	0.090401***	0.094049**	−0.189715***	0.418792	−0.381303***	0.001223
Δo_{t-1}^{Fed}	0.006408	0.014018	0.019568	0.175645	0.086476	−0.041813
Δo_{t-2}^{Fed}	0.002983	0.010939	−0.029471	0.287884	0.09531	0.0229
R-squared	0.577965	0.650283	0.178113	0.459475	0.417909	0.198174
Adj. R-squared	0.508516	0.592735	0.042866	0.370528	0.322122	0.066228
Sum sq. resids	0.902483	1.235309	3.914333	49.53453	9.420592	17.95933
S.E. equation	0.106882	0.125047	0.222595	0.791846	0.345323	0.476795
F-statistic	8.322172	11.29977	1.316948	5.165716	4.362892	1.501935
Log likelihood	83.57577	68.97816	15.34861	−102.6696	−25.49016	−55.4925
Akaike AIC	−1.496253	−1.182326	−0.029002	2.509023	0.849251	1.494462
Schwarz SC	−1.115002	−0.801074	0.352249	2.890274	1.230502	1.875714
Mean dependent	0.006129	0.004624	0.008966	0.037039	0.009126	0.00196
S.D. dependent	0.152458	0.195946	0.227525	0.99805	0.419421	0.493414

Notes:
Sample (adjusted) is Jan. 1999–Dec. 2006.
* Significant at 10 per cent; ** significant at 5 per cent; *** significant at 1 per cent.

of the R-squared and adjusted R-squared values, and also by the AR roots graph and Granger-causality Wald test statistics. However, the LM tests show the possible residual serial correlations. Additionally, the presence of heteroscedasticity also indicates that the variance of the coefficients tends to be underestimated. We tried different alternative specifications of the partial VECM, but cannot get rid of the problems. Hence, we proceed by trying to get better results by moving all the exogenous variables into the cointegrating relations and keeping all the variables as endogenous in the general VECM estimation.

c. Estimation Results of the General VECM

We carried out the estimation tests for the general VECM with the same trend assumptions as for the partial VECM. The results under the constraints of equation (6) in Section 3 are summarised in Table 4.

As for Table 3, Table 4 presents the estimation results in three parts. The first part delivers the results of the long-run equilibrium relations among the endogenous variables. The second part delivers the results for the short-run error correction process. In the second part, each column corresponds to an equation in the general VECM. The first two columns are the reaction functions of the euro and the US interest rates in first differences, the remaining columns correspond to the equations of inflation rates and output gaps in both currency areas. Below the coefficients summary, the third part of the table lists the regression statistics for each equation.

The significance of most coefficients contained in vector β indicates long-run equilibrium relationships among the variables. However, only in the second cointegrating equation is the coefficient of the interest rate (the coefficient of i_{t-1}^{ECB}) significant. Therefore, there exists only one possible interdependent relationship between the two interest rates and the Taylor Rule terms. Contrary to our expectations from our long-run Taylor Rule based assumptions, the long-run equilibrium relations between the variables revealed by the estimation results do not fit the Taylor Rule exactly. Although the magnitude of the estimated coefficient parameters falls within the theoretical range, the signs on the coefficients of the Taylor Rule terms – inflation and the output gap – are mostly contradictory to the theory.[10] Nevertheless, the interdependent relationship between the interest rates is clearly corroborated by the results. In cointegrating equation (2), the estimated parameter for coefficient B_{21}, is –3.43, so if there is 1 per cent increase on the US interest rate, then contemporaneously

[10] As we see in Section 2, the signs for the Taylor Rule terms should be opposite to the interest rate. In the case of the VECM, they should be negative, because the interest rates and the Taylor Rule terms appear on the same side of the equation in the cointegrating equation.

there will be about $(1/3.43)*100\% = 29\%$ increase on the ECB interest rate. This result is very close to the result of the partial VECM (35 per cent). The possible explanation for a smaller magnitude is the impact of the inflation rate and the output gap in the cointegrating equation.

The estimation results for the short-run coefficients deliver clear evidence of weak and strong exogeneity on some endogenous variables. The US interest rate and the euro area inflation rate appear to be weakly exogenous to the model, while the output gaps of both areas appear to be strongly exogenous. What concerns us most is the apparent weak exogeneity of the US interest rate. As the coefficients A_{12} and A_{22} are both statistically insignificant, the hypothesis of weak exogeneity for the US interest rate i_t^{Fed} cannot be rejected. Hence, the US interest rate is rather a variable pre-determined outside of the model, and the decision of the ECB interest rate is dependent on the US interest rate. In this sense, we could say the ECB follows the Fed in making monetary policy decisions.

As in the partial VECM estimations, we carry out a series of diagnostic tests on the estimated model.[11] The results show a good fit of the model to the observations. The R-squared and adjusted R-squared values are also better than those we obtained from the partial VECM estimations. The more important aspect is that the residual tests show no serial correlation or heteroscedasticity in the error terms. In this sense, the general VECM explains the data better than the partial VECM.

6. CONCLUSIONS

In this paper, we analyse the monetary policy interdependence between the ECB and the Fed for the period ranging from 1999 to 2006. Two alternative models are employed in the estimations, a partial VECM and a general VECM. Both models are based on the dynamic Taylor Rule reaction function.

Unlike the results obtained by some other researchers,[12] we find out clear monetary policy interdependence between the ECB and the Fed. However, a leader–follower relationship is only shown in the results of the general VECM.

The empirical results of the partial VECM indicate a strongly significant long-run equilibrium relation (interdependence) between the two central banks' interest rates. Although the test for weak exogeneity failed to reveal a clear

[11] The results of the diagnostic tests are available on request.

[12] The results in the literature on testing interdependence and a leader–follower pattern between the ECB and the Fed vary among the researchers. For example, Belke and Gros (2005) found neither a clear follower pattern nor interdependence; Ullrich (2005) found a follower pattern but no evidence to interdependence; Scotti (2006) found evidence of synchronisation but no follower behaviour; Ehrmann and Fratzscher (2005) found that the euro area and the US have become generally more interdependent after the advent of EMU.

leader–follower relationship, the development of the ECB's interest rate is obviously affected by the changes of the US inflation rate and output gap, which present the regional economic shock effect in the US. This result could explain why the ECB was facing heavy pressure to cut the interest rate due to the subprime crisis in the US in the first half of 2008, i.e. out of the estimated sample. On the other hand, the economic shocks from the euro area also have an impact on the Fed's monetary policy decision, but the Fed apparently attaches greater importance to the inflation pressure in the euro area. One weak aspect of our partial VECM is that the diagnostic tests reveal possible residual serial correlation and heteroscedasticity of the error terms, which we are not able to get rid of and might indicate remaining misspecifications, or incompleteness of the model. Hence, we move on to the estimation of a general VECM, and leave the further exploration of the partial VECM open to future research.

The estimation results of the general VECM also indicate long-run interdependence between the two interest rates. The numerical equilibrium relations between the ECB and the Fed estimated in both of the partial VECM and the general VECM are very close. In the partial VECM, a 1 per cent change in the US interest rate will be accompanied by a 0.35 per cent change in the euro area interest rate, while in the general VECM, this elasticity turns out to be 0.29 per cent. Comparing with the Fed, the ECB appears to be more conservative and less active in adjusting its monetary policy decisions towards economic shocks. The weak exogeneity test in the general VECM reveals a clear leader–follower relation between the Fed and the ECB, according to which the ECB follows the Fed in its monetary policy.

Our result is consistent with the literature. Based on a vector error correction model imposing long-run cointegration between the relevant interest rates, for instance, Chinn and Frankel (2005) conclude that, although financial integration has increased a lot, the direction of the effects runs predominantly from the US to the euro area. The introduction of EMU has not alleviated this asymmetry. Most recently, the sharp interest rate cuts by the ECB in the last quarter of 2008 corroborated the argument that the ECB, although not willing to admit it, does indeed follow the Fed. Moreover, Eijffinger (2008) imposes a long-run cointegrating relationship upon both the euro area and the US short-term and long-term interest rates, using a vector error correction specification. Also in this study, for both the short-term and the long-term interest rate, the cointegrating relationship runs from the US to the euro area.

Although we have obtained seven years of observations for our estimation, the time span is still relatively short. Estimation based on a longer time span is recommended in future research. In this analysis, we follow the preference concluded on the research work of Eleftheriou et al. (2006) to include only the inflation rate, the output gap, and lagged variables in the Taylor Rule framework.

However, the selection of variables might be biased due to the lack of a strong econometric corroboration of an exclusion of other economic variables. Further investigation with some other variables such as the exchange rate of the dollar *vis-à-vis* the euro, is recommended here. We leave this task for further research.

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