ECB Policy Response to the Euro/US Dollar Exchange Rate

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ECB POLICY RESPONSE TO THE EURO/US DOLLAR EXCHANGE RATE[1]

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First Draft

Abstract

The exchange rate is an important part of transmission mechanism in the determination of monetary policy because movements in the exchange rate have significant effect on the macroeconomy. Measuring the reaction of monetary policy to the movements in exchange rate has some difficulties due to the simultaneous response of monetary policy on the exchange rate and the possibility that both variables respond several other variables. This study will use an identification method based on the heteroscedasticity in the high-frequency data. In particular, shifts in the importance of exchange rate relative to monetary policy shocks, and the estimated changes in the covariance between the shocks that result, allow us to measure the reaction of interest rates to changes in exchange rates. This study comes up with unbiased estimates with heteroscedasticity based identification approach and results of this paper suggest that ECB systematically respond to the exchange rate movements but that quantitative effects are small. The empirical results indicate that a 1 point rise (fall) in the exchange rate tends to decrease (increase) the three-month interest rate by around 20 basis points. Small and negative reaction coefficient implies that ECB may respond to the movements in exchange rate only to the extent warranted by their impact on the macroeconomy, since it affects the expected inflation and future output path.

JEL codes: E44, E52, G12

Keywords: Monetary Policy; Exchange Rates; Identification through Heteroscedasticity; European Central Bank; Monetary Policy Reaction

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1. Introduction

There are three main channels through which exchange rate affects the macroeconomy. The appreciation will lower real GDP by expenditure switching and it will further lower inflation because the price of imported goods will not increase as rapidly with the appreciation of currency (Taylor, 2001). Lastly, changes in exchange rate also generate wealth effects that may have a significant impact on consumption and investment which are several components of aggregate demand. Because of households' inter-temporal smoothing behaviour, a direct decrease in net wealth may lead to a drop in consumption. The depreciation can increase the value of collateral which may reduce agents' external financing constraints and enhance final spending in accordance with the "broad credit channel".

Because of these important impacts of movements in exchange rate on aggregate demand, output and inflation which are components of policy rule, there may be a relation between exchange rate and monetary policy rule. The main objective of this paper is to measure the reaction of monetary policy to the exchange rate and try to determine the role of exchange rate in the monetary policy rule. In particular, the following question is tried to be answered; what is correct estimate of the impact of exchange rate on monetary policy for ECB?

Although monetary policy response to exchange rate has been studied largely in the empirical literature, there are some difficulties in measuring this effect. To begin with, while monetary policy is affected by the exchange rate changes, exchange rate also responds to the changes in the monetary policy; i.e. there is a simultaneous response of both variables to each other so, the direction of causality is difficult to establish. Moreover, there are other unobservable common factors affecting both of short term interest rates and exchange rates such as macroeconomic news and change in the risk preference. Hence, measurement is complicated due to the endogeneity problem and the possibility of omitted relevant variables.

The exchange rate in a policy rule is studied in the empirical literature largely, however general empirical studies ignore the endogeneity problem and eliminate numerous factors affecting interest rate and exchange rate. Therefore, empirical studies benefiting the OLS, 2SLS, VAR and IV approach cannot appropriately separate the response of monetary policy to the exchange rate and produce strongly biased results. In this study, to address these problems, we apply a new identification approach developed by Rigobon (1999) that response of monetary policy based on the heteroskedasticity of exchange rate shocks. In particular shift in the importance of the exchange rate shocks relative to the monetary policy shocks thereby estimated changes in variance-covariance matrix between shocks make measure the responsiveness of monetary policy to exchange rate possible. Heteroskedasticity based identification is relatively new method and this paper presents the first study to employ this approach to measure policy reaction to the exchange rate movements for ECB data.

The impact of asset prices on conduct monetary policy debates have increased over the last decade. Taylor (2001) argues that a monetary policy rule that reacts directly to the exchange rate, as well as to inflation and output, sometimes works worse than policy rules that do not react directly to the exchange rate. However, Bernanke and Gertler (1999, 2001) argue that monetary policy should react to asset price movements only to the extent warranted by their impact on expected inflation. Along the similar line, Rigobon and Sack (2003) find that the Federal Reserve reacts significantly to changes in stock market. Their findings suggest that policy-makers are reacting to asset price movements to the extent warranted by their implications for the economy. In the context of discussing impact of asset prices on monetary policy, Governor Jean-Claude Trichet stated that financial indicators: stock prices, housing prices, exchange rates are also analyzed in depth and their assessment is made in the context of maintaining price stability over the medium term, and the ECB does not react to their signals unless price stability is endangered. Conversely, the empirical findings of this paper indicate that ECB systematically respond to the exchange rate movements and reaction coefficient is significantly negative and small. Since the estimated policy reaction coefficient is within reasonable range of the magnitude, it appears that ECB systematically responds to exchange rate movements only to offset the expected pass-through of exchange rate shocks to inflation and output.

The paper proceeds as follows. Section 2 briefly describes the related studies in literature and the contribution of the paper. Section 3 discusses the problems of simultaneous equations and omitted variables and demonstrates why other widely used identification methods are inappropriate in this context. Also, this section describes the identification approach based on the heteroskedasticity of exchange rate shocks. Section 4 gives information about the data. Section 5 contains the empirical results and section 6 concludes.

2. Background

The exchange rate change in monetary policy rules is discussed in the theoretical and empirical literature. Ball (1999, 2002) argues that pure inflation targeting without explicit attention to the exchange rate is dangerous in an open economy, because it creates large fluctuations in exchange rates and output. In an open economy, the effects of exchange rates on inflation through import prices is the fastest channel from monetary policy to inflation, and so inflation targeting implies that it is used aggressively. Large shifts in the exchange rate, however, produce large fluctuations in output. Ball found that, holding the standard deviation of output relative to potential output constant (at 1.4 per cent), the interest-rate rule that reacts to the exchange rate as well as to output and inflation reduces the standard deviation of the inflation rate around the inflation target from 2.0 per cent to 1.9 per cent (Ball, 1999 p. 134) compared with a rule that reacts only to inflation and output. But this improvement is small. He suggests that policymakers in open economies should modify a Taylor-like reaction function to give a role to the exchange rate: Their policy instrument namely Monetary Condition Index (MCI) should base on both the exchange rate and the interest rate. As a target variable, policymakers should choose "long-run inflation" an inflation variable purged of the transitory effects of exchange rate fluctuations.

Taylor (2001) examines the exchange rate as a candidate for a monetary policy rule for the ECB in the form of Ball (1999) studies. He argues that a monetary policy rule that reacts directly to the exchange rate, as well as to inflation and output, sometimes works worse than policy rules that do not react directly to the exchange rate and thereby avoid more erratic fluctuations in the interest rate. In Taylor (2002), however, he points out that monetary policy in open economies is different from that in closed economies. Open-economy policymakers seem averse to considerable variability in exchange rate. In his view they should target a measure of inflation that filters out the transitory effects of exchange rate fluctuations and they should also include the exchange rate in their policy reaction functions. In the empirical literature there are some studies focus on the role of the exchange rate in a policy rule .The results of empirical studies are quite controversial.

Clarida et al. (1998) find the empirical evidence on the monetary policy response to the exchange rate in industrial countries. They show that monetary policy responds to the exchange rate, but the magnitude of monetary policy reaction is small. Along the same line, Osawa (2006) estimates monetary policy reaction functions to investigate whether monetary policy responds to exchange rate movements under the inflation-targeting regimes in Korea, Thailand and the Philippines using Two Stage Least Squares (TSLS) and Ordinary Least Squares (OLS). He finds no evidence that monetary policy in these countries responds to the exchange rate. Inclusion of the financial crisis period overestimates the monetary policy response to the exchange rate. For the same countries, Sek, Siok Kun (2008) apply a structural VAR and GMM approaches, this study seeks to find out the answer on the relationship of monetary policy and exchange rate. The result of GMM is consistent with the result of SVAR, i.e. the policy reaction functions in Korea and Philippines do not react significantly to exchange rate directly and there is strong response of policy reaction function in Thailand to exchange rate movements only in the pre-crisis period. These results are consistent with result of Ball (1999) and Taylor (2001).

On the other side, Filosa (2001) examines the interest rate setting behaviour of monetary authorities in a cross section of maturing emerging market economies. An important finding of this paper is that most central banks react strongly to the exchange rate, although changes in the monetary policy regime make it difficult to assess the relative importance placed by countries on inflation control and external equilibrium. Mohanty and Klau (2005) examine monetary policy responses to the exchange rate by focusing on quarterly data between the 1995 and 2002 for Asian countries and they conclude that these countries respond to the exchange rate strongly. Lastly, Frömmel and Schobert (2006) estimate the Taylor policy rule for six European countries. They find that exchange rate plays an important role in the monetary policy during the fixed exchange rate regimes periods. However, this impact disappears after having flexible regimes.

But general empirical studies ignore the endogeneity problem and eliminate numerous factors affecting interest rate and exchange rate. Therefore, empirical studies benefiting the OLS, 2SLS, VAR and IV approach cannot appropriately separate the response of monetary policy to the exchange rate. This paper aims to come up with the unbiased estimates with the heteroskedasticity based identification approach.

3. Statement of the Proble and Methodology

In the literature, in order to measure the reaction of monetary policy to the exchange rate as applicable methodologies the ordinary least squares estimation (OLS), two stage least squares estimation (Osawa, 2006; Clarida et al. 1998), VAR and GMM (Sek, Siok Kun, 2008) are used. When the endogeneity problem is ignored and biascoefficients are appeared after the estimation. Generally, addressing the endogeneity problem is through instrumental variables (IV). It is difficult to find an instrumental variable that would affect the exchange rate without correlated with interest rate movements. Thus, IV method is not an effective approach to estimate coefficients of simultaneous equations (Rigobon 2003).

Alternative identification approaches including long-run and sign restrictions also do not help with the identification of my paper. Obstfeld and Rogoff (1995) impose restrictions to exchange rate coefficient on monetary policy reaction function[2]. However, this restriction is not appropriate in this context. Obviously, we do not want to set the parameter of the reaction of the short-term interest rate to the exchange to zero because we are interested in estimating the interest rate response to the exchange rate. We can conclude that widely used identification methods are inappropriate in this context.

In this paper, given the shortcomings of commonly-used identification techniques, we instead use an identification method suggested by Rigobon (1999) which relies on the heteroskedasticity in interest rates and exchange rate to identify the reaction monetary policy to the exchange rate. In other words, shifts in importance of exchange shocks relative to monetary policy shocks, and the estimated changes in the covariance between the shock results, allow us to measure the reaction of interest rates to changes in exchange rate.

The data suggest that shifts in variance of shocks affect the correlation between changes in interest rates and exchange rates. Figure 1 shows the simple correlation between daily changes in exchange rate and daily changes in the three-month Treasury bill rate. Note that the correlation varies but mostly becomes negative during periods in which volatility of exchange rate are increased.

VAR model which include unobserved shocks that affect the interest rate and exchange rate is conducted. The dynamic structural equations for short-term interest rate and exchange rate are written as follows:

$$i_t = \beta e_t + \theta x_t + \gamma z_t + \varepsilon_t \tag{1}$$

[2] They equalize the parameter of the reaction of the short-term interest rate to the exchange rate to zero.

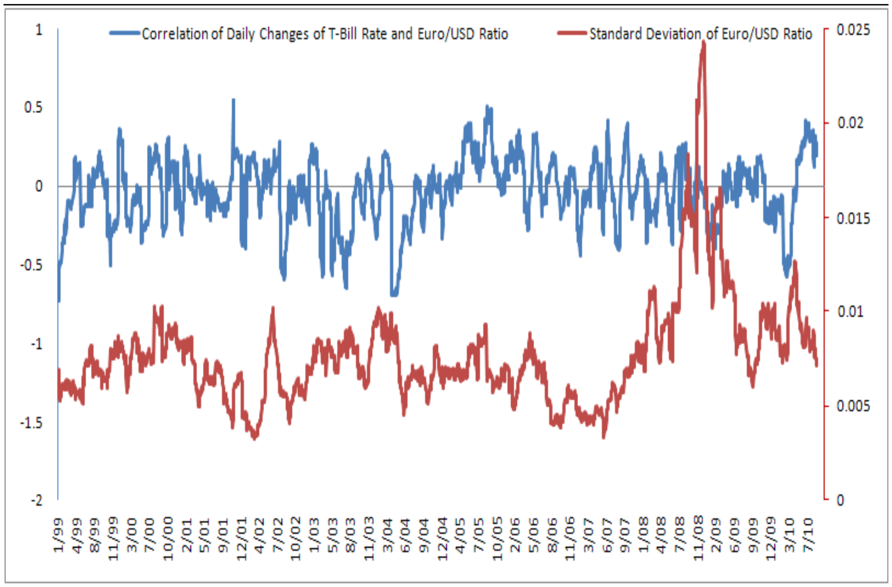

Figure 1: Comovements in Exchange Rate and Interest Rates

$$e_t = \alpha i_t + \phi x_t + z_t + \eta_t \tag{2}$$

where $i_t$is the short-term interest rate, e_t is the exchange rate and z_t is the unobserved variables (with the coefficient on z_t in the exchange rate equation normalized to 1). The variable z_t represent some unobserved shocks affecting interest rate and exchange rate such as changes in risk preference, liquidity shocks. Equation (1) is the high frequency monetary policy reaction function for ECB. Equation (2) represents the exchange rate equation, which measures the response of exchange rate to the interest rate and other shocks. ε_t is the monetary policy shock, and η_t is the exchange rate shock. The residuals ε_t and η_t and unobserved shock z_t are assumed to be serially uncorrelated and to be uncorrelated with each other.

Equations (1) and (2) cannot be estimated directly, because of the endogeneity problem discussed above and because z_t is an unobservable variable. Only the following reduced form of equations (1) and (2) can be estimated:

$$\begin{pmatrix} i_t \\ e_t \end{pmatrix} = \Phi x_t + \begin{pmatrix} \nu_t^i \\ \nu_t^e \end{pmatrix} \tag{3}$$

where the reduced form residuals are given by

$$\nu_t^i = \frac{1}{1-\alpha\beta}\left[(\beta+\gamma)\, z_t + \beta\eta_t + \varepsilon_t\right] \tag{4}$$

$$\nu_t^e = \frac{1}{1-\alpha\beta}\left[\left(1+\alpha\gamma\right)z_t + \eta_t + \alpha\varepsilon_t\right] \tag{5}$$

The covariance matrix of the reduced form residuals is

$$\Omega = E\left[\left[i_t e_t\right]'\left[i_t e_t\right]\right]$$

$$\Omega = \frac{1}{\left(1-\alpha\beta\right)^2}\begin{bmatrix} \left(\beta+\gamma\right)^2\sigma_z^2 + \beta^2\sigma_\eta^2 + \sigma_\varepsilon^2 & \left(1+\alpha\gamma\right)\left(\beta+\gamma\right)\sigma_z^2 + \beta\sigma_\eta^2 + \alpha\sigma_\varepsilon^2 \\ . & \left(1+\alpha\gamma\right)^2\sigma_z^2 + \sigma_\eta^2 + \alpha^2\sigma_\varepsilon^2 \end{bmatrix} \tag{6}$$

The covariance matrix only provides three moments-two variances and a covariance while in matrix Ω there are six unknown: α, β, γ, σ_z^2, σ_η^2 and σ_ε^2. Hence, these restrictions are not enough to achieve identification and recover the structural form parameters.

The presence of conditional heteroskesdasticity in the reduced form residuals provides additional restrictions to the system represented by (4). Consider the impact of a shift to a regime with different covariance matrix. The additional regime provides three new equations and also the new regime adds three unknown parameters σ_z^2, σ_η^2 and σ_ε^2.

Within this framework, assuming that the monetary policy shocks ε_t are homoscedastic to ensure an identification. As is well known, general characteristic of macroeconomic data is heteroskedastic and monetary policy shocks are heteroskedastic as well. Since our subsample stands for the non-policy dates (days immediately preceding the monetary policy committee meeting days), We assume that monetary policy shocks ε_t are homoscedastic.The assumption of constant monetary policy shock is not very restrictive, because fact that the variance of the interest rate is consist of $\sigma_{i,\eta}^2$ and $\sigma_{i,z}^2$ which depends on unobserved shocks and exchange rate shocks.

Under the assumption of homoskedastic policy shocks, a shift in the covariance matrix provides three new equations but only two new unknown parameters. In that case, the parameter of interest is β-the reaction of the short-term to the exchange rate- is identified as long as there are at least three different regimes for the covariance matrix. For each new regime indexed by the subscript i, the covariance matrix can be written as

$$\Omega_i = \frac{1}{\left(1-\alpha\beta\right)^2}\begin{bmatrix} \left(\beta+\gamma\right)^2\sigma_{i,z}^2 + \beta^2\sigma_{i,\eta}^2 + \sigma_\varepsilon^2 & \left(1+\alpha\gamma\right)\left(\beta+\gamma\right)\sigma_{i,z}^2 + \beta\sigma_{i,\eta}^2 + \alpha\sigma_\varepsilon^2 \\ . & \left(1+\alpha\gamma\right)^2\sigma_{i,z}^2 + \sigma_{i,\eta}^2 + \alpha^2\sigma_\varepsilon^2 \end{bmatrix} \tag{7}$$

Two important assumptions in equation (5) are as follows:i) α, β and γ are stable across the covariance regimes.[3]ii) The variance of the ECB reaction function remains constant across the regime.Under these assumptions, there are nine equations and ten unknown parameters but it is enough for partial identification and in particular the parameter β can be estimated.

The parameter β is identified as long as there are at least three different regimes for the covariance matrix. The covariance matrix under each regime, i = 1; 2; 3 can be written as follows;

$$\Omega_i = \frac{1}{(1-\alpha\beta)^2}\begin{bmatrix} (\beta+\gamma)^2\sigma_{i,z}^2 + \beta^2\sigma_{i,\eta}^2 + \sigma_\varepsilon^2 & (1+\alpha\gamma)(\beta+\gamma)\sigma_{i,z}^2 + \beta\sigma_{i,\eta}^2 + \alpha\sigma_\varepsilon^2 \\ . & (1+\alpha\gamma)^2\sigma_{i,z}^2 + \sigma_{i,\eta}^2 + \alpha^2\sigma_\varepsilon^2 \end{bmatrix} \tag{8}$$

Define $\Delta\Omega_{21} = \Delta\Omega_2 - \Delta\Omega_1$ and $\Delta\Omega_{31} = \Delta\Omega_3 - \Delta\Omega_1$.Equation (8) implies that

$$\Omega_{j1} = \frac{1}{(1-\alpha\beta)^2}\begin{bmatrix} (\beta+\gamma)^2\Delta\sigma_{j1,z}^2 + \beta^2\Delta\sigma_{j1,\eta}^2 & (1+\alpha\gamma)(\beta+\gamma)\Delta\sigma_{j1,z}^2 + \beta\Delta\sigma_{j1,\eta}^2 \\ . & (1+\alpha\gamma)^2\Delta\sigma_{j1,z}^2 + \Delta\sigma_{j1,\eta}^2 \end{bmatrix}$$

where $\Delta\sigma_{j1,z}^2 = \Delta\sigma_{j,z}^2 - \Delta\sigma_{1,z}^2$ and $\Delta\sigma_{j1,\eta}^2 = \Delta\sigma_{j,\eta}^2 - \Delta\sigma_{1,\eta}^2$ for $j = \{2,3\}$. Since the σ_ε^2 is homoskedastic and α, β and γ parameters are stable, the change in covariance matrix does not depend on the variance of monetary policy shocks.

These two changes in the covariance matrices, $\Delta\Omega_{21}$ and $\Delta\Omega_{31}$, form a system of six nonlinear equations with seven unknowns, but in which β is just identified. To see this, rewrite the covariance matrix as:

$$\Omega_{j1} = \frac{1}{(1-\alpha\beta)^2}\begin{bmatrix} \omega_{z,j} + \beta^2\Delta\sigma_{j1,\eta}^2 & \theta\omega_{z,2} + \beta\Delta\sigma_{j1,\eta}^2 \\ . & \theta^2\omega_{z,2} + \Delta\sigma_{j1,\eta}^2 \end{bmatrix}$$

$$\theta = \frac{1+\alpha\gamma}{\beta+\gamma}$$

$$\omega_{z,j} = (\beta+\gamma)^2\Delta\sigma_{j1,z}^2.$$

[3]In the macroeconomics literature, VARs are often estimated across samples that surely exhibit heteroskedasticity, without allowing shifts in parameters. Similarly, in the finance literature, many studies that even explicitly allow for variation in volatility, including GARCH models, often impose that the parameters of the underlying equation are fixed (Rigobon, 2004).

The six equations that result can be written as follows:

$$
\begin{aligned}
\omega_{z,2} + \beta^2 \Delta\sigma^2_{21,\eta} &= (1-\alpha\beta)^2 . \Delta\Omega_{21,11} \\
\theta\omega_{z,2} + \beta \Delta\sigma^2_{21,\eta} &= (1-\alpha\beta)^2 . \Delta\Omega_{21,12} \\
\theta^2\omega_{z,2} + \Delta\sigma^2_{21,\eta} &= (1-\alpha\beta)^2 . \Delta\Omega_{21,22}
\end{aligned}
$$

$$
\begin{aligned}
\omega_{z,3} + \beta^2 \Delta\sigma^2_{31,\eta} &= (1-\alpha\beta)^2 . \Delta\Omega_{31,11} \\
\theta\omega_{z,3} + \beta \Delta\sigma^2_{31,\eta} &= (1-\alpha\beta)^2 . \Delta\Omega_{31,12} \\
\theta^2\omega_{z,3} + \Delta\sigma^2_{31,\eta} &= (1-\alpha\beta)^2 . \Delta\Omega_{31,22}
\end{aligned}
$$

where $\Delta\Omega_{j1,kl}$ is the k and l element of the j matrix. If $\theta\beta \neq 1$, which assures finite variance, then the three equations for each covariance matrix collapse to

$$\theta = \frac{\Delta\Omega_{21,12} - \Delta\Omega_{21,22}}{\Delta\Omega_{21,11} - \Delta\Omega_{21,12}} \tag{9}$$

$$\theta = \frac{\Delta\Omega_{31,12} - \Delta\Omega_{31,22}}{\Delta\Omega_{31,11} - \Delta\Omega_{31,12}} \tag{10}$$

which is a system of two equations with two unknowns (θ,β). Finally, equations (9) and (10) imply a quadratic equation for β :

$$\alpha\beta^2 - b\beta + c = 0$$

where

$$
\begin{aligned}
a &= \Delta\Omega_{31,22}\Delta\Omega_{21,12} - \Delta\Omega_{21,22}\Delta\Omega_{31,12} \\
b &= \Delta\Omega_{31,22}\Delta\Omega_{21,11} - \Delta\Omega_{21,22}\Delta\Omega_{31,11} \\
c &= \Delta\Omega_{31,12}\Delta\Omega_{21,11} - \Delta\Omega_{21,12}\Delta\Omega_{31,11}.
\end{aligned}
$$

Because the covariance matrices are positive definite, there should be always a real solution to the quadratic equation[4]. When there are more than three regimes for variance-covariance matrix, any three can be used to arrive at a solution to equations (9) and (10). If the model is correctly specified, the estimates

[4]See the Appendix A for showing the solution of the system gives true values.

of β should be same for any three regimes. We implement the standard test of the overidentifying restrictions of the model. A rejection of the overidentifying restrictions, imply that the parameters of equations are not stable across the regimes or the assumption of homoskedasticity for the monetary policy shock is violated. Also, if the parameter β is not constant the formulation of Rigobon and Sack (2003) may not capture the nonlinearities.

4. Data

In this study we use three-month Treasury bill rate of Germany as short-term interest rate and exchange rate (euro-dollar). Treasury bill rates are not available for European Central Bank. Therefore, we use three-month Treasury bill rate of Deutsche Bundesbank as short-term interest rate. One could argue that instead Treasury bill rate, the ECB marginal lending rate or euro overnight index average (EONIA) would be more appropriate instrument for short-term interest rate. Treasury bill rate is the one of the most liquid security at short maturities and it adjust daily according to changes in expectation of monetary policy over the following term, where ECB marginal lending rate is adjusted approximately once a month. The reason of using three-month Treasury bill rate versus EONIA is that volatility in interest rate is an important factor for our identification approach and volatility of EONIA rate may be relatively poor to define the heteroskedasticity of the shocks.

Our empirical investigation relies on daily and monthly data covering the period from April 1999 to September 2010. The daily data are used for following reasons. Firstly, the daily data allows us to more accurately define the heteroskedasticity of the shocks. Secondly, the liquidity in the money market rate can be affected at the daily frequency by central banks. Lastly, Treasury bill rates tend to anticipate monetary policy decisions, monetary policy can affect daily movements of Treasury bill rate even if interest rate decisions take place on lower frequency (Bohl et al., 2007).

In this framework, we assume that monetary policy shocks are homoscedastic. Therefore, the related sample stands for the non-policy dates (days immediately preceding the monetary policy committee meeting days) and the holidays and weekends are removed. As Rigobon and Sack (2003) point out, control for observable macroeconomic shocks is required. We add lags in exchange rate as an exogenous variable, as wells as lags in short term interest rate. Euro-dollar exchange rates obtained from ECB website and Bundesbank staff provided the three-month Treasury bill rate.

The data are plotted in levels in Figures 2. As can be seen in the graph, there is a negative relationship between the short term interest rate and exchange rate.

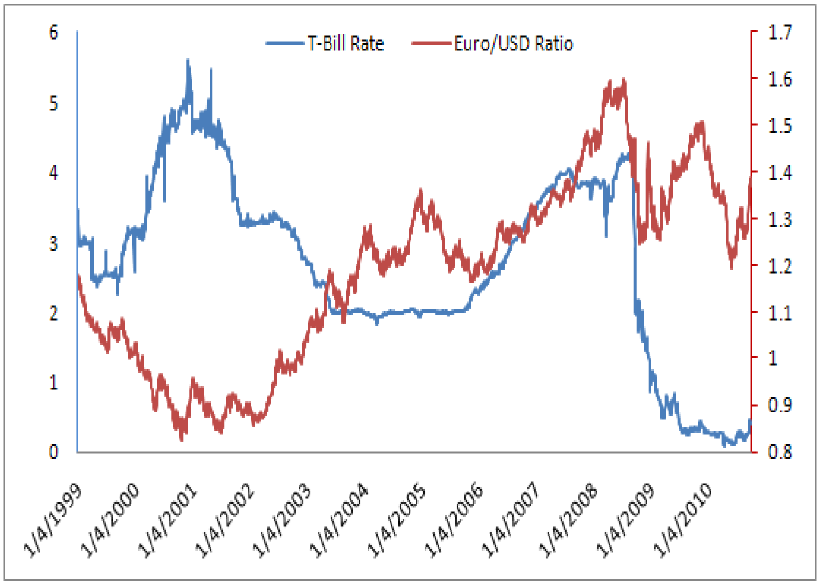

Figure 2: Treasury Bill Rate and Exchange Rate

5.Results

5.1 OLS Estimates

Formally, the dynamics of the short-term interest rate and the exchange rate are written as follows:

$$\Delta i_t = \beta \Delta e_t + \varphi x_t + \varepsilon_t \tag{11}$$

$$\Delta e_t = \alpha \Delta i_t + \phi x_t + \eta_t \tag{12}$$

where i_t is the three-month Treasury bill rate and e_t is the daily change exchange rate. The data are daily, and the sample runs from January 1999 to October 2010. The variable x_t is a vector containing 5 lags of the exchange rate and the interest rate, as well as other observable macroeconomic shocks. The lag lengths of the interest rate and exchange rate are chosen with the Akaike Information Criterion (AIC).

As mentioned before, due to the endogeneity problem equations (8) and (9) cannot be estimated and only reduced form of these equations can be estimated. We interest in impact of change in exchange rate on short term interest rate. Under assumption of exchange rate has no simultaneous response to the interest rate, ECB policy reaction function can be estimated. The results of policy reaction function (equation 11) are summarized in Table 1.

Table 1: Response of Daily Changes in Short-Term Interest Rate to Changes in Exchange Rate (Ignoring Endogeneity)

Variable	*Coefficient*	*Std. Error*	*t-Statistic*
Exchange Rate	-0.258	0.155	-1.668

Sample: 1999:1 to 2010:4	Included obs.: 2808
R-Squared: 0.99	Durbin-Watson stat.: 2.00
S.D.dependent var.: 1.28	S.E.of regression: 0.067

Regression includes a constant and five lags of the interest rate and exchange rate.

The changes in the exchange rate do not have a large impact on the interest rate. The estimated coefficient (β) is significant and negative which means that there is negative correlation between exchange rate and interest rate. Because of endogeneity problem, heteroskedasticity and unobservability of a common shock, in that case (OLS) the estimated policy reaction is strongly biased[5].

In order to describe the movements in interest rate, a large literature has developed on estimating monetary policy rules. But most studies ignore the endogeneity problem. Monetary policy can be described by a rule depending on both inflation and output gap developments, but adjusts slowly from interest rate lagged level as follows:

$$i_t = \rho \left(\beta_0 + \beta_y y_t + \beta_\pi \pi_t \right) + \rho i_{t-1} \tag{13}$$

where π_t is the inflation rate, y_t is the output gap, and i_t is the policy rate. Consumer price inflation in the euro area is measured by the Harmonised Index of Consumer Prices (HICP). In line with e.g. Clarida et al. (1998), we take the industrial production index for the euroarea and apply a standard Hodrick-Prescott filter and calculate the measure of the output gap as the deviation from its trend. Table 2 shows the estimated parameters from this rule (using least squares). This table indicates that the ECB react weakly to variations in the inflation rate to output. Suppose that exchange rate, denoted e_t, has taken into account in formulating monetary policy as in:

$$i_t = \rho \left(\beta_0 + \beta_y \left(Y_t - Y^* \right) + \beta_\pi \pi_t + \beta_e \Delta e_t \right) + \rho i_{t-1} \tag{14}$$

The exchange rate is an important part of transmission mechanism in many policy-evaluation models (Taylor, 2001). Because of the exchange rate has impacts on the future path of output and inflation, it is entered the rule. Estimation of the equation (14) indicates that measured reaction of interest rate to the exchange rate is significant and increased the inflation coefficient very slight. Lastly, we use lag of macroeconomic variables and exchange rates as instrument

[5] See the Appendix B for showing bias coefficient.

for addressing endogeneity problem but it is unlikely that these are not effective instruments. The results in Table 2 show that there is significant response to the exchange rate.

Table 2: Quarterly Monetary Policy Rule (Ignoring Endogeneity)

Coefficient	*Without Exchange Rate (OLS)*	*Including Exchange Rate (OLS)*	*Including Exchange Rate (IV)*
β_0	0.025 (0.05)	1.249 (0.58)	2.175 (0.95)
β_y	0.001 (0.00)	0.006 (0.00)	0.010 (0.00)
β_π	0.022 (0.02)	0.040 (0.04)	0.042 (0.08)
β_e	-	-0.696 (0.31)	-1.185 (0.5)
ρ	0.829 (0.07)	0.561 (0.09)	0.433 (0.12)

Standard errors shown in parenthesis.

Overall, using exclusion or sign restrictions and instrumental variables cannot solve the simultaneous equation and omitted variable bias problem effectively. Instead of commonly-used identification techniques, we use a methodology based on heteroskedasticity of the error terms to identify the monetary policy reaction to the exchange rate.

5.2 Identification through heteroskedasticity Estimates

The initial step is determining the different regimes for the variance-covariance matrix of the reduced form shocks to monetary policy and exchange rate. Firstly, equation (3) is estimated by VAR and computes the residuals. We define four regimes: one is that both interest rates and exchange rates shocks have high volatility, one is that both shocks have low volatility, and rest two regimes in which one has low and the other high volatility. Periods of high volatility are defined as when the thirty-day rolling variance of the residual from VAR is more than one standard deviation above its average as identified in Rigobon and Sack (2003). The four variance-covariance regimes are illustrated in Table 3.

Table 3: Variance-Covariance Matrix of Regimes

	Variance of Monetary Policy	*Variance of Exchange Rate*	*Covariance*
Daily data			
Regime 1	0.0012094	**0.0001233**	-0.0000071
Regime 2	0.0000824	0.0000140	0.0000012
Regime 3	**0.0022764**	**0.0000667**	-0.0000675
Regime 4	**0.0101133**	0.0000536	0.0001615
Monthly data			
Regime 1	0.002135	**0.000087**	-0.000088
Regime 2	0.000488	0.000017	0.000009
Regime 3		**0.000074**	-0.000106
Regime 4		0.000043	0.000024

High variance regimes are in bold.

Table 3 reveals that the covariance between the interest rate and exchange rate varies with shifts in their variances and becomes negative when volatility of exchange rate elevates. These different regimes of the variance-covariance matrix are chosen arbitrary. As described in previous sections, the monetary policy reaction to the exchange rate could be identified with at least three regimes. I treat equations (9) and (10) as moment conditions and solve for the parameters using GMM. Estimates of the monetary policy reaction coefficient β for daily and monthly data listed in Table 4.

Table 4: Estimates of ECB's Reaction to Exchange Rate Under Alternative Regimes

Daily Data	*Regimes 1, 2, 3*	*Regimes 1, 2, 4*	*Regimes 1, 3, 4*	*Regimes 2, 3, 4*
Coefficient	-0.19999	-0.27327	-0.27117	-0.15588
Std. deviation	0.00901	0.00615	0.02328	0.01639
Monthly Data	*Regimes 1, 2, 3*	*Regimes 1, 2, 4*	*Regimes 1,3, 4*	*Regimes 2, 3, 4*
Coefficient	-0.32621	-0.29742	-0.51676	-0.28575
Std. deviation	0.00014	0.00113	0.02471	0.00007

For the daily time series the results indicate a negative policy response to the exchange rate, with an estimated coefficient β of -0.199. By employing a more appropriate identification approach based on heteroskedasticity, a significant negative reaction of monetary policy to the exchange rate is found as the major result of the paper. The point estimate for the response coefficient β shows that a 1 point rise in the exchange rate tends to decrease the three-month interest rate by around 20 basis points. Similar results are obtained when the other regimes are used to estimate the parameter. As can be seen, the estimates of monetary policy reaction resulting from other regimes summarized in Table 4 are consistently low and close to another.

In order to test that whether the central bank's reaction to exchange rate movements depends on the frequency of the data, monthly (lower frequency) data is used in analyze. The results, shown in Table 4, indicate that the estimated response of monetary policy is negative and larger than high frequency data. In addition, we consider a case of random 3-month regimes instead the thirty-day rolling regimes and the results are largely similar. Even so, the resulting estimates for low frequency and different identification regimes are still small in magnitude and support the hypothesis that the ECB does not react to exchange rate movements too much.

We also test whether the β parameter is stable across different regimes and the homoscedasticity assumption of the policy shocks. Since there are four regimes and only three regimes are sufficient for identification, the parameter is overidentified . The result of overidentification test shows that all assumptions of heteroscedasticity based identification approach are valid hypothesis cannot be rejected for both daily and monthly time series[6]. Only in two cases (i.e., estimates under regimes 1, 3, 4 for daily data and regimes 1, 2, 4 for monthly data) the hypothesis of parameter constancy can be rejected.

The empirical exercise in this paper is concerned only with measuring the policy reaction to the exchange rate, and not with determining whether such a reaction is optimal. ECB may respond to the movements in exchange rate only to the extent warranted by their impact on the macroeconomy, since it affects the expected inflation and future output path (Taylor, 2001). In 2002, Governor Jean-Claude Trichet said that " it is clearly not opportune to introduce asset prices into a monetary policy rule the central bank should commit to or in the central bank‘s reaction function." at the Federal Reserve Bank of Chicago conference[7]. According to his opinion, a wide range of economic and financial indicators: stock prices, housing prices, exchange rates are also analyzed in depth and their assessment is made in the context of maintaining price stability over the medium term, and the ECB does not react to their signals unless price stability is endangered. He summarized that if monetary policy does not react directly to asset price developments; it has clearly to take under consideration all the consequences of these developments on aggregate demand and aggregate supply, on economic agents' confidence and expectations, since they may at some point affect price developments. Conversely, we find that

[6] Many different overidentification tests could be performed and I have applied GMM-overidentification test. The overidentifying restrictions are tested with the following test statistic: $\hat{q} = \bar{m}(\beta)' V^{-1} \bar{m}(\beta)$ where V^{-1} is the variance of the difference of the estimators. Note, however, that this approach does not test the assumption that the three shocks are uncorrelated. For a general treatment, see Harris and Matyas (1999) and Newey and McFadden (1994).

[7] The full speech is available at http://www.bis.org/review/r020426a.pdf

there is a significant, negative and small response of policy reaction coefficient for ECB. But, because the estimated policy reaction coefficient is within reasonable range of the magnitude, it appears that ECB responds to exchange rate movements only to offset the expected pass-through of exchange rate shocks to inflation and output.

6. Conclusion

Relatively little empirical evidence is available that estimates the impact of exchange rates on conduct monetary policy. Estimating the response of monetary policy to changes in exchange rate is complicated by the endogeneity problem and the fact that both interest rates and exchange rate react to many other variables. This paper provides new empirical findings on the role of exchange rate movements on interest rates using daily and monthly data from ECB over the 1999-2010 periods.

Using identification through heteroskedasticity developed by Rigobon (1999), the reaction of policy to the exchange rate can be measured effectively, when the variance of exchange rate shocks shift. We use anticipated macroeconomic shocks in specification and also include unobserved shocks that appear to capture changes in risk preferences.

The empirical results indicate that monetary policy reacts significantly to exchange rate movements, with a 1 point rise (fall) in the exchange rate increase the interest rate 20 basis points. For daily and monthly time series, the exchange rate has a negative but small impact on interest rate of ECB over the 1999-2010 periods. Small and negative monetary policy reaction coefficient implies that ECB may respond to the movements in exchange rate only to the extent warranted by their impact on the macroeconomy, since it affect the expected inflation and future output path (Taylor, 2001). The findings are fairly robust with a large number of various model specifications.

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APPENDIX A

Solving this system of equation (9) and (10), the parameter of interest β, and an estimate for combining θ are obtained. Rigobon and Sack (2003) selection criteria which is also applied in this study is as follows: if the two roots have different signs, they select the positive one. If they have the same sign, they choose the smaller in absolute value.

Substitute the equation (9) in (10) the below quadratic equation obtained in terms of β

$$a\beta^2 + b\beta + c = 0$$

where

$$\begin{aligned} a &= \Delta\Omega_{31,22}\Delta\Omega_{21,12} - \Delta\Omega_{21,22}\Delta\Omega_{31,12} \\ b &= \Delta\Omega_{31,22}\Delta\Omega_{21,11} - \Delta\Omega_{21,22}\Delta\Omega_{31,11} \\ c &= \Delta\Omega_{31,12}\Delta\Omega_{21,11} - \Delta\Omega_{21,12}\Delta\Omega_{31,11}. \end{aligned}$$

The quadratic equation has a real solution and after some algebra it can be written as follows:

$$(1+\alpha\gamma)d\beta^2 - (2\beta + \alpha\gamma\beta + \gamma)d\beta + \beta(\beta+\gamma)d$$

where

$$d = \sigma^2_{z,3}\sigma^2_{\eta,2} - \sigma^2_{z,3}\sigma^2_{\eta,1} - \sigma^2_{z,1}\sigma^2_{\eta,2} - \sigma^2_{z,2}\sigma^2_{\eta,3} + \sigma^2_{z,1}\sigma^2_{\eta,3} + \sigma^2_{z,2}$$

On condition that $d \neq 0$, the equation has two solutions:

$$\beta_1 = \beta$$

$$\beta_2 = \frac{\beta+\gamma}{\alpha\gamma+1} = \frac{1}{\theta}$$

Hence, we are able to estimate consistently β as long as we choose the right solution of the quadratic form and we have at least three regimes for the covariance matrix.

APPENDIX B

This appendix shows the bias estimation. Suppose that, the parameter of interest is α , which measures a change in the short-term interest rate i_t on the impact of the exchange e_t on the short-term interest rate i_t . The OLS estimate of is as follows:

$$\hat{\alpha} = (i_t^{'} i_t)^{-1}(i_t^{'} e_t)$$

The mean of $\hat{\alpha}$ is:

$$E(\hat{\alpha}) = \alpha + (1 - \alpha\beta)\frac{\beta\delta_\varepsilon + (\beta + \gamma)\delta_z}{\delta_\varepsilon + \beta^2\delta_\eta + (\beta + \gamma)^2\delta_\varepsilon}$$

where E(.) is the expectatiton operator and x represents yhe variance shock x.According to above equation the OLS estimate would be biased away from its true value due to both simultaneity bias (if $\beta = 0$ and $\delta_\eta > 0$) and omitted variables bias (if $\beta = 0$ and $\delta_z > 0$)