# Monetary Policy Shocks in a Tri-Polar Model of Foreign Exchange*

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**Abstract**

This paper investigates effects of third-currency monetary policy shocks on exchange rates. For this purpose we setup a structural VAR model containing the exchange rates of the three major currencies – the U.S. dollar, the euro and the Japanese yen – and short-term interest rates on the three currencies. In addition, we include the medium-term interest rates and price levels as control variables. Long-run restrictions in accord with tested hypotheses and the existing literature are used to identify the structural VAR. The impulse response analysis of the co-integrated VAR reveals that third-currency monetary policy shocks not only significantly impact on the considered exchange rates but their impacts are comparable to those of MP shocks associated with the quoted currencies in terms of their magnitude.

**Keywords**: Exchange Rates, Currency Substitution, Third-Currency Effects, SVAR

**JEL Classification**: F02, F31, F36, F42,

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# 1 Introduction

One of the existing puzzles in international macroeconomics is the exchange rate behavior in response to news about interest rates adjustments – shocks to interest rates. Empirical analyses of the effects of monetary policy shocks on exchange rates commonly reveal delayed exchange rate overshooting (see e.g. Eichenbaum and Evans, 1995; Faust et al., 2002). This exchange rate behavior is inconsistent with traditional theories linking the interest rate and exchange rate movements such as Dornbusch (1976) or Obstfeld and Rogoff (1995). Although Kim (2000) finds an identification scheme for his structural vector auto-regression (VAR) model that tends to eliminate the exchange rate anomaly we look at yet another factor that might be responsible for the large deviations from uncovered interest parity (UIP).

This candidate factor is third-currency effects. In general, given a bilateral exchange rate between currency one and two, the third-currency effects are defined as effects of currency's three fundamentals on such an exchange rate. Brandt et al. (2003), Kingston and Melecky (2003), MacDonald and Marsh (2004), and Nucci (2003) find significant evidence of third-currency effects on exchange rates. Hodrick and Vassalou (2002) demonstrate third-country effects for bond yields, in addition. Brandt et al. start from an identity postulating that exchange rates depreciate by the difference between domestic and foreign marginal utility growth. They argue that marginal utility growth implied by the equity premia requires much more variation of exchange rates to what we observe. This implies significant correlation of marginal utilities across countries and indicates that third-currency effects constitute significant components of the pricing kernels for exchange rates. Kingston and Melecky also offer theoretical justification of third-currency effects based on non-separable currency preferences. Their empirical findings are in line with such a theory. MacDonald and Marsh look at currency spillovers in a setup of three major currencies similar to that introduced in this paper. They find significant spillovers from third-currencies fundamentals. Yet, they do not consider the term structure of interest rates and do not relate their results to the subject of currency substitution, as we do in this paper. Similarly, Nucci finds some evidence that the term structures of forward premiums of third currencies contain significant information for exchange rate forecasting in addition to information in the currency's own forward premium. Hodrick and Vassalou find that their multi-country models help to explain exchange rate dynamics better than their two-country counterparts and that the third-country effects appear to be significant in most cases considered.

This paper sheds light on the importance of third-currency interest rate effects upon exchange rates which are largely ignored in existing policy models. We setup a simple macro-econometric model with one common permanent component driving the system of bilateral exchange rates for the US dollar, the Japanese yen and the euro to examine responses of the three exchange rates to monetary policy (MP) shocks – including third-currency MP shocks. First, some hypotheses tests are carried out to achieve more efficient (data consistent) identification of the co-integrating vectors. The system involving EUR/USD, EUR/JPY and JPY/USD exchange rates, and the short-term interest rates on the euro, the yen and the dollar is analyzed within a co-integrated structural VAR framework. The estimated impulse responses are then interpreted according to established relationships of currency substitution and complementarity among the three currencies. The model setup in this paper is new to the literature and so are the findings and their interpretation from the viewpoint of currency substitution.

This paper is organizes as follows. Section two sets up a model for an analysis of third-currency effects. Section three describes the data. Section four adds the MP reaction functions into the model. In section five we carry out the impulse response analysis of our structural VAR model. Section six reopens the subject of currency substitution in order to put our results into some perspective. Section seven discusses the impulse responses associated with third-currency MP shocks and section eight concludes.

## 2 The Model

We start building our structural VAR model from the exchange-rate market perspective and later on add the monetary policy reaction functions to complete the system.

Consider uncovered interest parity (UIP) for each of the three currencies expressed in levels of the current spot rates:

$$\begin{bmatrix} s_{1t} \\ s_{2t} \\ s_{3t} \end{bmatrix} = E_t \begin{bmatrix} s_{1t+1} \\ s_{2t+1} \\ s_{3t+1} \end{bmatrix} + \begin{bmatrix} i_{1t}^* - i_{1t} \\ i_{2t}^* - i_{2t} \\ i_{3t}^* - i_{3t} \end{bmatrix} \tag{1}$$

where $s_t$ is the log of the spot rate defined in terms of the direct quotation, i.e. domestic currency per unit of foreign currency, and $i_t$ and $i_t^*$ are the domestic and foreign interest rates corresponding to the period over which the UIP is defined.

Assume further that an endogenous system of the three major currencies is governed by a single common factor, $f_t$:

$$\begin{bmatrix} s_{1t} \\ s_{2t} \\ s_{3t} \end{bmatrix} = \boldsymbol{J} f_t + \begin{bmatrix} u_{1t} \\ u_{2t} \\ u_{3t} \end{bmatrix} \tag{2}$$

where $\boldsymbol{J}$ is a $3 \times (3-r)$ matrix of coefficients and $\boldsymbol{u}_t$ is a vector of shocks. The number $r$ is given as a difference between the number of the spot rate series (three) and the assumed number of common factors (one). This gives us $r$ of two co-integrating vectors we expect to find. The common factor is thus thought of as being equivalent to the common permanent component (the common trend). The common factor is assumed to be a function of a set of arbitrage conditions that eliminate any opportunities of a risk free return. The set of arbitrage conditions is the vector of UIP conditions outlined in (1).

Consider now the conditional expectation of the vector of the $t+1$ period spot rates. We assume that the conditioning information set contains variables that summarize current information in other exchange rate markets, i.e. the remaining two bilateral spot rates, the long-run equilibria given by the corresponding purchasing power parities (PPP), and information on the prospects of the economy associated with a given currency in the system. The latter is assumed to be captured by the yield curve (Soderline and Svensson, 1997; Mishkin, 1990). The three pieces of information delivered by the spot rates, the yield curve spread and PPP correspond to short-run, medium-run and long-run equilibrium rates, respectively. In an unrestricted form the conditional expectation is expressed as:

$$E_t \boldsymbol{s}_{t+1} = g\left(\boldsymbol{s}_t, \boldsymbol{yc}_t, \boldsymbol{p}_t\right) \tag{3}$$

where $\boldsymbol{p}_t$ is a vector of price levels in a given economy. $\boldsymbol{yc}_t$ is a vector of yield curve spreads defined as $\boldsymbol{yc}_t \equiv \boldsymbol{r}_t - \boldsymbol{i}_t$ with $\boldsymbol{r}_t$ being a vector of long-term interest rates, i.e. the maturity of the asset corresponding to $r_t$ is greater than the maturity of the asset corresponding to $i_t$. Assuming the function $g(\cdot)$ is linear we can write $E_t\boldsymbol{s}_{t+1}$ as:

$$E_t\boldsymbol{s}_{t+1} = \boldsymbol{\Phi}_1\boldsymbol{s}_t + \boldsymbol{\Phi}_2\left(\boldsymbol{r}_t - \boldsymbol{i}_t\right) + \boldsymbol{\Phi}_3\boldsymbol{p}_t \tag{4}$$

where the $\boldsymbol{\Phi}$'s are a $3\times 3$ coefficient matrices all elements of which are unrestricted. Putting together (1), (2) and (4) gives:

$$\begin{gathered}\left(\boldsymbol{I} - \boldsymbol{J}\boldsymbol{\Phi}_1\right)\begin{bmatrix} s_{1t} \\ s_{2t} \\ s_{3t} \end{bmatrix} = \boldsymbol{J}'\boldsymbol{\Phi}_2\begin{bmatrix} r_{1t} - i_{1t} \\ r_{2t} - i_{2t} \\ r_{3t} - i_{3t} \end{bmatrix} + \boldsymbol{J}'\boldsymbol{\Phi}_3\begin{bmatrix} p_{1t} \\ p_{2t} \\ p_{3t} \end{bmatrix} + \boldsymbol{J}\begin{bmatrix} i^*_{1t} - i_{1t} \\ i^*_{2t} - i_{2t} \\ i^*_{3t} - i_{3t} \end{bmatrix} + \begin{bmatrix} u_{1t} \\ u_{2t} \\ u_{3t} \end{bmatrix} \\ \boldsymbol{A}\begin{bmatrix} s_{1t} \\ s_{2t} \\ s_{3t} \end{bmatrix} = \boldsymbol{B}\begin{bmatrix} i_{1t} \\ i_{2t} \\ i_{3t} \end{bmatrix} + \boldsymbol{C}\begin{bmatrix} r_{1t} \\ r_{2t} \\ r_{3t} \end{bmatrix} + \boldsymbol{D}\begin{bmatrix} p_{1t} \\ p_{2t} \\ p_{3t} \end{bmatrix} + \boldsymbol{J}\begin{bmatrix} i^*_{1t} \\ i^*_{2t} \\ i^*_{3t} \end{bmatrix} + \begin{bmatrix} u_{1t} \\ u_{2t} \\ u_{3t} \end{bmatrix}\end{gathered} \tag{5}$$

where $\boldsymbol{A} = \left(\boldsymbol{I} - \boldsymbol{J}\boldsymbol{\Phi}_1\right)$, $\boldsymbol{B} = -\left(\boldsymbol{J} + \boldsymbol{J}\boldsymbol{\Phi}_1\right)$, $\boldsymbol{C} = \boldsymbol{J}\boldsymbol{\Phi}_2$ and $\boldsymbol{D} = \boldsymbol{J}\boldsymbol{\Phi}_3$.

Given our assumption that the system in (5) is driven by a single permanent component we expect the $\left(\boldsymbol{I} - \boldsymbol{J}\boldsymbol{\Phi}_1\right)$ matrix of coefficients to have a deficient rank. More specifically, we expect to find two co-integrating vectors for the variables in the system. This raises questions of how to identify this model and what currency should be selected as a common denominator. In accord with the existing literature we choose the U.S. dollar to be the unifying currency so that $s_{1t} = \left(eur / usd\right)_t$, $s_{2t} = \left(jpy / usd\right)_t$ and $s_{3t} = \left(eur / jpy\right)_t$.

For the purpose of estimation we assume that the variables on the RHS of equation (5) are all weakly exogenous and thus uncorrelated with the vector of shocks, $\boldsymbol{u}_t$. We claim that the pass-through effect of the exchange rates on the price levels in the big economies considered here, i.e. the United States, the European Union and Japan, is negligible and thus assumed to be zero. Similarly, we argue that the monetary policy rules in those big economies are of a Taylor rule type and do not involve exchange rates. Furthermore, we assume that the interest rates are not influenced implicitly either, since the effect of the exchange rate on the output gap, i.e. its coefficient in the familiar IS equation, is close to zero. Finally, the exchange rate does not enter in any way the relationship describing the term structure of the interest rates[1].

## 3 Data Description and Unit Root Tests

The vector of the spot exchange rates, $\boldsymbol{s}_t$, contains logs of the EUR/USD, JPY/USD and EUR/JPY bilateral exchange rates. However, preceding the introduction of the euro in January 1999, the euro bilateral exchange rates are approximated by their DEM counterparts. The vector of prices in the three countries, $\boldsymbol{p}_t$, is approximated by logs of the consumption price indexes (CPIs). The two vectors of interest rates $\boldsymbol{i}_t$ and $\boldsymbol{r}_t$, which are deemed to characterize the shorter and longer ends of the yield curve, respectively, are approximated by three-month and six-month LIBOR rates for the corresponding currencies. One-month LIBOR is not used here to approximate the shorter end of the yield curve due to problems with its availability. The LIBOR rates are used here as they are likely to be more market determined than corresponding national interest rates.

[1] Some support for the above assumptions can be found in Kim (2001), Kim and Roubini (2000), McCarthy 2000, Valderama (2004) and Hufner and Schroder (2002). A further discussion is provided in Section 4.

The data spans the period from January 1983 to February 2004 and are obtained from the IMF's International Financial Statistic.

We test the order of integration of the series by employing the ADF-GLS test proposed by Elliott, Rothenberg, and Stock (1996). This test improves on the low power of the conventional ADF test in finite samples by estimating the coefficients on deterministic variables in the test specification prior to the estimation of the coefficient of interest. The results are reported in table 1:

******* Table 1 Here *******

All the variables appear to be integrated to order one, I(1). Although there are good theoretical grounds suggesting that the interest rates should be stationary we should treat them as I(1) if they appear to behave as such. The only difficulty in determining the order of integration is experienced when dealing with the U.S. *cpi* series which is found to be integrated to an order even higher than I(2). When applying other tests, e.g. ADF, KPSS, Ng-Perron, PP, the results are mixed as well. Since ADF test strongly rejects the hypothesis that the U.S. *cpi* series is integrated to order higher than I(1), the series is regarded as I(1) further on.

The lag length $p$ for the system in equation (5) is determined in encompassing manner by applying Hannan and Quinn's log iterated criterion (HQC). Paulsen (1984) shows that HQC along with the Schwartz information criterion (SIC) is a weakly consistent measure for determining the true lag order in the presence of unit roots (stochastic trends). Jacobson's (1990) Monte-Carlo study suggests that HQC shows greater accuracy in choosing the true lag compared to SIC. We thus use HQC to determine the lag order for the system in (5) considering a maximum of nine lags. The results are reported in table 2:

******* Table 2 Here *******

## 4 Preliminary Estimation and Hypotheses Tests

The system of equations described in (5) is estimated using the autoregressive distributed lag approach (ARDL) to co-integration due to Pesaran and Shin (1995) and Pesaran et al. (1996). The error correction form of the ARDL model is given by equation where the dependent variable in first differences is regressed on the lagged values of the dependent and independent variables in levels and first differences.

$$\triangle \boldsymbol{y}_t = \phi \boldsymbol{y}_{t-1} + \beta \boldsymbol{x}_{t-1} + \sum_{j=1}^{p} \delta_j \triangle \boldsymbol{y}_{t-j} + \sum_{j=0}^{q} \gamma_{i,j} \triangle \boldsymbol{x}_{i,t-j} + \xi_t \tag{6}$$

where $\boldsymbol{y}_t$ is a $T \times n$ matrix of endogenous variables, $\boldsymbol{x}_t$ is a $T \times k$ matrix of observations on the weakly exogenous variables and deterministic variables. The latter include a constant and a shift dummy variable corresponding to the introduction of the euro in January 1999. $\triangle \boldsymbol{y}_{t-j}$ and $\triangle \boldsymbol{x}_{t-j}$ are the $j$-period lagged values of $\triangle \boldsymbol{y}_t \equiv \boldsymbol{y}_t - \boldsymbol{y}_{t-1}$ and $\triangle \boldsymbol{x}_t \equiv \boldsymbol{x}_t - \boldsymbol{x}_{t-1}$, respectively, and $\xi_t \equiv (\xi_1, ..., \xi_T)'$ is a $T \times 1$ vector of residuals. The disturbances $\xi_t$ are assumed to be independently distributed and independent of the regressors, i.e. $E(\xi_t \mid \boldsymbol{x}_t) = 0$. The lag length $p$ is chosen as described in section 3 and $q$ is set to zero. Further, the underlying $ARDL(p,q)$ model is assumed to be stable, which ensures that $\phi < 0$, and thus there exists a long-run relationship between $\boldsymbol{y}_t$ and $\boldsymbol{x}_t$ defined as:

$$y_t = -(\boldsymbol{\beta}' / \phi) \boldsymbol{x}_t + \eta_t \tag{7}$$

where $\eta_t$ is a stationary process. The coefficient standard errors are then obtained using the familiar *delta method*.

Applying the ARDL model to the system in (5) produces results presented in table 3. We report the parsimonious version of the estimations, i.e. all the insignificant variables are eliminated. At this stage we merely normalize on the spot rates before proceeding to full identification of the system.

******* Table 3 Here *******

At this point, we test some hypothesis that might increase efficiency of the estimation and introduce some well-established theoretical patterns. Namely, we test for whether PPP can be imposed on the data, whether UIP holds, whether there is significant information coming from other markets (market efficiency) and over all significance of the third-currencies' effects on a given bilateral exchange rate. We apply these tests to the parsimonious versions of the estimates following the general-to-specific approach. Market efficiency is tested by making the coefficients of the other two bilateral quotes equal and opposite. Third-currency effects are tested by setting all the coefficients of the variables related to the third currency to zero. Outcomes of the tests are reported in table 4:

******* Table 4 Here *******

The test of the PPP hypothesis is applicable only to jpy/usd. When PPP is tested in the jpy/usd equation $s_{2t} = (\text{jpy/usd})_t$ and the null hypothesis (H0) is $d_{21} = -d_{22}$ where the latter two are the corresponding elements of the matrix $\boldsymbol{D}$ in equation (5). When the strict PPP is tested H0 is set to be $d_{11} = 1 \wedge d_{12} = -1$. Both hypotheses are rejected for jpy/usd.

Testing of UIP is applicable to both eur/usd and jpy/usd equations. When UIP is tested $s_{1t} = (\text{eur/usd})_t$ and H0 is $b_{11} = -j_{11}$. When the strict UIP is put to a test H0 is $b_{11} = -1 \wedge j_{11} = 1$. Both UIP versions are rejected for eur/usd and the strict UIP is rejected for jpy/usd.

The market efficiency is tested for both pairs. When $s_{1t} = (\text{eur/usd})_t$ the H0 of market efficiency is formulated as $a_{12} = -a_{13}$. When the strict version of market efficiency is tested H0 is set to $a_{12} = 1 \wedge a_{13} = -1$. If H0 is not rejected one can write

$$\begin{aligned} eur_t - usd_t &= a_{12}\left(jpy_t - usd_t\right) + a_{12}\left(eur_t - jpy_t\right) \\ &= a_{12}\left(eur_t - usd_t\right) \end{aligned} \tag{8}$$

and in this case the two other pairs, i.e. jpy/usd and eur/jpy cancel out. One may think of this test as revealing some kind of a measurement error and there is no significant information coming from the other exchange rate markets. The case when $a_{12} = 1$ is then analogous and one gets

$$eur_t - usd_t = \left(jpy_t - usd_t\right) + \left(eur_t - jpy_t\right) = eur_t - usd_t \tag{9}$$

producing a true statement that postulates efficiency of the associated exchange rate market. The strict version of market efficiency is rejected in both cases, however, the weaker version is accepted for the pair eur/usd. Hence the latter can be regarded as having more efficient market than jpy/usd.

Finally, significance of third-currency effects for each exchange rate is tested as follows. For instance, when $s_{1t} = (\text{eur/jpy})_t$ H0 becomes $a_{13} = b_{13} = c_{13} = d_{13} = 0$. H0 is rejected for all pairs so that the third-currency effects are indeed important for the development of each of the exchange rates.

In line with the accepted hypotheses we impose following restrictions upon the matrix $\boldsymbol{A}$ using the dollar as the unifying currency:

$$\boldsymbol{A} = \begin{bmatrix} \beta_3 & 1 & \beta_3 \\ \beta_4 & 0 & 1 \end{bmatrix} \tag{10}$$

## 5 Monetary Policy Shocks

At this point, we add MP reaction functions to complete the system so that we can examine the relative impacts of MP shocks. The MP shock is represented here as the *transitory* short-term interest rate shock[2]. Consider therefore a monetary policy rule of the following form:

$$i_t = \delta_0 i_{t-1} + \delta_1 g_t + \delta_2 E_t\left(\pi_{t+h} - \pi^*\right) + \nu_t^{MP} \tag{11}$$

where $\delta_0 > 0$, $\delta_1 > 0$ and $\delta_2 > 0$ so that the central bank (the policymaker) increases the short-term interest rate (its instrument) in response to a positive output gap, $g_t$, or a positive deviation of expected inflation $E_t\pi_{t+h}$ from the target $\pi^*$ while adhering to a certain degree of inertia. We work with an alternative representation of the MP rule in (11) of the form:

$$i_t = \lambda_0 i_{t-1} + \lambda_1 \pi_t + \lambda_2 yc_t - \lambda_1 \pi^* + v_t^{MP} \tag{12}$$

where it is assumed that the current price dynamics (inflation) contains information about the output gap (see e.g. Mishkin, 1990) and the yield curve spread provides information on expected future monetary policy and expected inflation (see e.g. Soderlind and Svensson, 1997; Soderlind, 1995). Equation (12) can thus be rewritten as:

[2] Other variables used to approximate monetary policy instruments are e.g. non-borrowed reserves or narrow monetary aggregates, see e.g. Kim and Roubini (2000) or Eichenbaum and Evans (1995).

$$
\begin{aligned}
i_t &= \frac{\lambda_0}{1-\lambda_2} i_{t-1} + \frac{\lambda_1}{1-\lambda_2} \pi_t + \frac{\lambda_2}{1-\lambda_2} r_t - \frac{\lambda_1}{1-\lambda_2} \pi^* + v_t^{MP} \\
&= \frac{\lambda_0}{1-\lambda_2} i_{t-1} + \frac{\lambda_1}{1-\lambda_2} p_t - + \frac{\lambda_1}{1-\lambda_2} p_{t-1} + \frac{\lambda_2}{1-\lambda_2} r_t - \frac{\lambda_1}{1-\lambda_2} \pi^* + v_t^{MP} \\
&= \gamma_1 i_{t-1} + \gamma_2 p_t - \gamma_2 p_{t-1} + \gamma_4 r_t - \gamma_2 \pi^* + v_t^{MP}
\end{aligned}
\tag{13}
$$

where we allow the coefficients attached to the current and lagged price level, and the inflation target to differ:

$$
i_t = \gamma_1 i_{t-1} + \gamma_2 p_t - \gamma_3 p_{t-1} + \gamma_4 r_t + c + v_t^{MP} \tag{14}
$$

Consider now the monetary policy rule in (14) from a system perspective. Assume that each central bank is unaffected by the decision of the other central banks. This is consistent with Kim's (2001) finding that nominal interest rates of non-US G-6 countries are not significantly affected by changes in US monetary policy. Also Kim and Roubini (2000) find small reaction of German and Japanese monetary policy to changes in US monetary policy. Further, the exchange rate pass-through effect on prices and the effect of the exchange rate on the output gap are assumed to be negligible for the three economies. Some support for this assumption can be found in McCarthy (2000) and Valderrama (2004) for the US and Hufner and Schroder (2002) for the EU. Since we do not model prices and long-term interest rates explicitly here only lags of those variables appear in the interest rate equations due to their possible endogeneity with respect to the modeled policy instrument. Hence, we have now six endogenous variables and we stack them into the vector, $\boldsymbol{z_t}$:

$$
\boldsymbol{z_t} = \left[ (\text{eur/jpy})_t \quad (\text{eur/usd})_t \quad (\text{jpy/usd})_t \quad i_t^{EU} \quad i_t^{JAP} \quad i_t^{US} \right] \tag{15}
$$

Since only one common permanent component is driving the system we have to identify the resulting five co-integrating vectors. The vectors describing the MP rules in each country are easily identified using the assumptions listed above.

However, we have to impose some restrictions on the behavior of the short-term interest rates in the exchange rate equations.

The first restriction that we apply is consistent with the tested weak version of UIP and follows the quotation of the exchange rate upon which we normalized. In a similar manner we impose a restriction on the third-currency interest rate. Consistently with the UIP, the relevant coefficient is restricted to be the same or opposite to that on the associated RHS exchange rate. For instance, the first row of the $\boldsymbol{A}$ matrix in (16)reads as follows. We normalize on eur/usd and in accord with UIP set the coefficients on $i_t^{EU}$ and $i_t^{USD}$, i.e. elements (2,4) and (2,6), to -1 and 1, respectively. The third-currency interest effect is restricted to $\beta_1$ in line with UIP for the eur/jpy and jpy/usd exchange rates. The latter two bear coefficients $\beta_1$ and $-\beta_1$ in the first row vector. Hence, given the coefficients and the quotations the required restriction on the JPY interest rate is indeed $\beta_1$.

Given the ordering of variables in $\boldsymbol{z}_t$ the coefficient matrix $\boldsymbol{A}$ identifying the co-integrating vectors – matrix of long-run restrictions - is:

$$\boldsymbol{A} = \begin{bmatrix} \beta_1 & 1 & -\beta_1 & -1 & \beta_1 & 1 \\ \beta_2 & 0 & 1 & -\beta_2 & -1 & 1 \\ 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix} \tag{16}$$

Consider now the underlying VAR:

$$E(L)\boldsymbol{z}_t = \rho_0 + \rho^* D_t + \varepsilon_t \tag{17}$$

where $E(L) = I_n - \sum_{j=1}^{q} E_j L^j$ and $\varepsilon_t$ is a white noise process with a zero mean and finite variance. $D_t$ contains the exogenous (forcing) variables. After some manipulation (17) can be written as:

$$E^*(L)\triangle \boldsymbol{z}_t = \rho_0 + \rho^* D_t - E(1)\boldsymbol{z}_{t-1} + \varepsilon_t \tag{18}$$

As $\boldsymbol{z}_t$ is integrated to order one (18) implies that $E(1)\boldsymbol{z}_{t-1}$ must be stationary and $E(1)$ can be written as a product of two matrices $E(1) = \boldsymbol{\alpha\beta'}$ where $\boldsymbol{\alpha}$ is a $n \times r$ matrix of rank $r$. So that (18) can be written in an error-correction form:

$$E^*(L)\triangle \boldsymbol{z}_t = \rho_0 + \rho^* D_t - \boldsymbol{\alpha\beta'}\boldsymbol{z}_{t-1} + \varepsilon_t \tag{19}$$

Since the domestic price level and the long-term interest rate, appearing in $D_t$, are likely to be correlated with the domestic MP shock, we further restrict the contemporaneous coefficients on these variables to zero, where appropriate.

Following Mellander et al. (1992), (see also Johansen, 1995) the process described by (19) can be expressed in a moving-average form:

$$\triangle \boldsymbol{z}_t = F(1)\rho_0 + F(L)\left[\rho^* D_t + \varepsilon_t\right] \tag{20}$$

The impulse responses can thus be easily derived. Solving for levels we get:

$$\boldsymbol{z}_t = \boldsymbol{z}_0 + F(1)\rho_0 t + F(1)\sum_{i=1}^{t}\left[\rho^* D_i + \varepsilon_i\right] + F^*(L)\left[\rho^* D_t + \varepsilon_t\right] \tag{21}$$

where $F(1)$ is the long-run impact matrix of reduced rank $n-r$ and $F^*(L) = [1-L]^{-1}\left[F(L) - F(1)\right]$. We thus have $n-r$ permanent shocks affecting the system. Since we have assumed that the MP shocks are transitory we have one permanent shock here. This theoretical assumption is supported by the *trace* and *maximum eigenvalue* statistics reported in table A1 in the Appendix.

In the next figure we present the orthogonalized impulse responses for the levels of the bilateral exchange rates. Although the restrictions imposed let us identify (see Wickens and Motto, 2001) and estimate the VAR at hand we choose to make the covariance matrix of the shocks diagonal so that we can label the shocks. The main interest here is in the effects of MP shocks on the bilateral exchange rates. Figure 1 shows the plot of the impulse responses we are interested in:

******* Figure 1 Here *******

The monetary policy shocks are temporary (transitional) as is apparent from figure 1. It is not a surprise as we have identified them as such. The first two rows of figure 1 describe MP shocks related to currencies in a given bilateral quote and the third row captures the third-currencies' MP shocks. Looking at the first two rows, the exchange rates seem to react to the MP shocks in accord with the imposed UIP, i.e. the domestic currency depreciates in reaction to the positive shock to the domestic short-term interest rate. We thus do not find any evidence of delayed overshooting, as e.g. Eichenbaum and Evans (1995). This pattern is however somewhat different when the jpy/usd exchange rate is hit by the US MP shock. We can observe only minor downswing in accord with UIP that is followed by a dominating upswing in the opposite direction. Some explanation for this might be obtained by looking into the associated term structure of interest rates, however, this is not attempted here. In addition, we detect a small initial appreciation followed by a dominating depreciation for eur/usd and eur/jpy pairs which may imply some exchange rate overshooting in these cases. This is however not inconsistent with UIP as the impact appreciation in response to positive MP shock is dominated by subsequent depreciation. Our findings are thus similar to those of Kim and Roubini (2000) and Faust et al. (2002).

The speed with which such shocks are eliminated tells us something about efficiency of the markets trading the currencies at hand. In this respect, the jpy/usd and eur/jpy markets seem to be much more efficient then the eur/jpy market suggesting that MP shocks are more sustained in the case of currency complements (see below). On the other hand, there is weak evidence that the MP shocks although relatively short-lived are more pronounced when currency substitutes (see below) appear in the quote.

Before we proceed to an interpretation of the responses of exchange rates to third-currency MP shocks we investigate possible currency substitution and complementarity relationships among the three currencies. The subject of currency substitution is reopened here in order to put the third-currency effects into some perspective.

## 6 Currency Substitution and Complementarity

Brittain (1981) introduced an informal graphical test for currency substitution. Such a graphical tool has been recently augmented by Kingston and Melecky (2004) to inspect both currency substitution and complementarity. A comparison of velocities of monetary aggregates associated with the currencies of interest is the focal point here. Currencies should be considered elements of internationally diversified portfolios. *Ceteris paribus*, an increase in demand for (velocity of) one currency would induce portfolio reallocation according to relative characteristics of its individual elements: the velocity of currency substitutes falls and the velocity of currency complements rises. Considering e.g. the euro and the US dollar, rising velocity of US quasi money contrasted with falling velocity of EU quasi money suggests that there is substitution between the euro and the dollar. In the same manner, significant co-movements of specified velocities would suggest currency complementarity between the two currencies.

Money velocity is calculated as $v_t = gdp_t - mq_t$ where $gdp$ is the log of nominal GDP and $mq$ is the log of the quasi money supply in a given country. We chose quasi money since this type of money is more related to the speculative demand that we believe has major influence on the exchange rate development. A plot of the calculated money velocities for the three currencies is available in figure A.1 in the Appendix.

We regress the velocities against each other in accord with the bilateral quotes using the fully modified OLS (FMOLS) due to Phillips and Hansen (1990) to correct for the bias that emerges when two (possibly endogenous) variables with a unit root are consistently estimated by OLS. The results are summarized below:

$$
\begin{aligned}
v_t^{EU} &= \underset{(0.193)}{0.792}\, v_t^{JAP} - \underset{(0.615)}{2.197} \\
v_t^{EU} &= -\underset{(0.353)}{0.538}\, v_t^{US} - \underset{(0.140)}{0.535} \\
v_t^{JAP} &= -\underset{(0.291)}{0.936}\, v_t^{US} - \underset{(0.116)}{3.550}
\end{aligned}
\tag{22}
$$

These results suggest that the Japanese yen and the euro are currency complements and that the US dollar acts as a substitute for both the Japanese yen and the euro.

## 7 Dissemination of the Third-Currency MP shocks

Consider now the third row of figure 1 containing the effects of third currencies' MP shocks. On average, the magnitude of the exchange rate responses to the third-currencies' MP shocks appears to be within the range of the responses of the ER to the quoted currencies' MP shocks. This finding emphasizes the role of third-currency effects in exchange rate and policy modeling. Consider now the implications of currency substitution and complementarity for the ER impulse responses. The first two impulse responses from the left describe the case when the MP shock is associated with a third currency which is a complement to the domestic currency. The third plot then describes the case when the currency associated with the MP shock is a substitute for the domestic currency. Although it is hard to interpret the third-currency effects, the results point to a significant difference between the MP-shock effects of complementary and substituting third currencies. It seems that the third-currency effect of a currency complement is more predicable than the effect of a currency substitute which shows considerable swings in both directions over time. This is consistent with the conclusion proposed by Boyer and Kingston (1987) that in the case of perfect substitutes the exchange rate follows a random walk.

## 8 Conclusion

This paper examined the importance of third-currency monetary policy shocks for exchange rates and policy modeling. For this purpose we setup a structural VAR model comprising exchange rates of the three major currencies – the U.S. dollar, the euro and the Japanese yen – and short-term interest rates on the three currencies. In addition, we have included medium-term interest rates and price levels as control variables. The structural VAR was identified using long-run restriction in accord with the tested hypotheses and the existing literature. The impulse-response analysis of the co-integrated structural VAR revealed that the third-currency MP shocks not only significantly impact on the considered exchange rates but their impacts are comparable to those of the MP shocks associated with the quoted currencies in terms of their magnitude. These findings lay emphasis on inclusion of third-currency effects in forecasting models of exchange rates and policy models of open economies.

## Appendix

******* Table A1 Here *******

******* Figure A1 Here *******

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# Tables

**Table 1** Unit Root Tests

| Variable | Unit root test: **ADF-GLS** | |
|---|---|---|
| | Levels | 1st differences |
| eur/usd | C,T,0[-1.4102] | C,0[-16.6871]*** |
| jpy/usd | 0[-1.4627] | 0[-15.4114]*** |
| eur/jpy | C[0.2355] | C[-12.3874]*** |
| p_eu | C,T,1 [-0.3495] | C,0[-13.0747]*** |
| p_jap | C,12[-0.1252 ] | 11[-1.9855]** |
| p_us | C,T,12[-1.5212] | C,11[-0.2542]<br>C,1[-7.0513]*** |
| i_eu | C,2[-0.4318] | 1[-9.1717]*** |
| i_jap | C,3[-0.2509] | 2[-8.1040]*** |
| i_us | C,8[-0.7128] | 7[-5.8260]*** |
| r_eu | C,2[-0.5511] | 1[-8.8249]*** |
| r_jap | C,0[0.3223] | 0[-16.7137]*** |
| r_us | C,8[-0.6070] | 7[-5.9078]*** |

**Table 2** Lag Length Selection for Exchange Rates

| Variable | Selected Lag Length in Equation | |
|---|---|---|
| | **eur/usd** | **jpy/usd** |
| eur/usd | 1 | 1 |
| jpy/usd | 2 | 1 |
| eur/jpy | 1 | 1 |

The numbers state the chosen lag length. The maximum lag length considered is 9.

**Table 3** Estimation of the Under-Identified System in (5)

| Variable | eur/usd | jpy/usd |
|---|---|---|
| eur/jpy | 0.6175 (0.1194)*** | 1.1536 (0.1747)*** |
| eur/usd | -1 | ------- |
| jpy/usd | -0.68139 (0.1137)*** | -1 |
| i *currency 1* | 0.4001 (0.1621)*** | ------- |
| i *currency 2* | -0.3326 (0.1189)*** | ------- |
| i *currency 3* | 0.0571 (0.0226)*** | ------- |
| r *currency 1* | -0.4482 (0.1685)*** | ------- |
| r *currency 2* | 0.3167 (0.1212)*** | ------- |
| r *currency 3* | ------- | 0.0221 (0.0121)* |
| p *currency 1* | ------- | -3.2952 (1.4424)** |
| p *currency 2* | 1.4898 (0.5848)*** | 1.2960 (0.6886)* |
| p *currency 3* | -2.6474 (1.2642)** | ------- |
| D99 | ------- | 0.5120 (0.0935)*** |
| constant | 8.8053 (3.9633)** | 13.2786 (3.8550)*** |

*currency 1* is the currency quoted in the numerator of the relevant bilateral exchange rate, *currency 2* is the currency quoted in the denominator and *currency 3* is the currency that does not appear in the bilateral quote. Standard errors are in the parentheses. *, ** , *** - stands for the significance at the 10 %, 5 % and 1 % level, respectively. ----- shows that a given variable is insignificant and was eliminated from the regression.

**Table 4** Hypotheses Tests

| Hypothesis | eur/usd | jpy/usd |
|---|---|---|
| PPP | na | 10.8748 [0.004] |
| Strict PPP | na | 5.6712 [0.017] |
| UIP | 0.2128 [0.645] | na |
| Strict UIP | 138.3199 [0.000] | na |
| Market Efficiency | 0.29548 [0.587] | 43.5782 [0.000] |
| Strict Market Efficiency | 270.7667 [0.000] | 43.5782 [0.000] |
| Third-currency Effect | 47.5558 [0.000] | 43.6181 [0.000] |

**Table A1** Co-integration Rank Tests

| Eigenvalue | H0 | Trace Statistic | Max-Eigenvalue Statistic |
|---|---|---|---|
| 0.37075 | r==0 | 286.86 [0.000]* | 92.65 [0.000]* |
| 0.23531 | p <= 1 | 194.21 [0.000]* | 53.66 [0.000]* |
| 0.21926 | p <= 2 | 140.55 [0.000]* | 49.50 [0.000]* |
| 0.19229 | p <= 3 | 91.05 [0.000]* | 42.71 [0.000]* |
| 0.16600 | p <= 4 | 48.34 [0.000]* | 36.31 [0.000]* |
| 0.058402 | p <= 5 | 12.04 [0.013] | 12.04 [0.013] |

* denotes rejection of the hypothesis at the 1 % significance level. The trace and max statistics are adjusted for the number of lags (9) and endogenous variables (6) in the VAR.

# Figures

**Figure 1** Impulse Responses of Exchange Rates to Monetary Policy Shocks

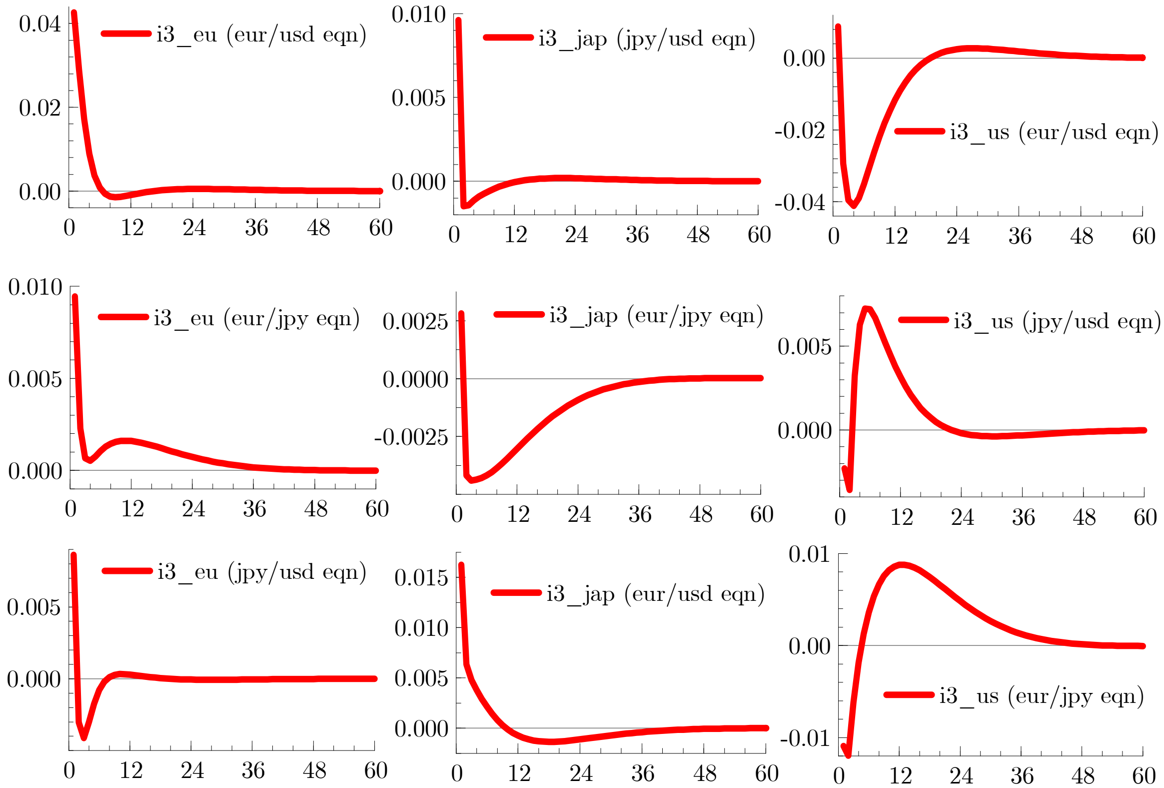


**Figure A.1** Velocity Correlations – a Comparison