# A structural investigation of third-currency shocks to bilateral exchange rates

Melecky, Martin

Department of Economics, Technical University of Ostrava

October 2007

# A Structural Investigation of Third-Currency Shocks to Bilateral Exchange Rates*

Martin Melecky†

Department of Economics

Technical University of Ostrava

March 10, 2008

**Abstract**

An exchange rate between two currencies can be materially affected by shocks emerging from a third country. A U.S. demand shock, for example, can affect the exchange rate between the euro and the yen. Since positive U.S. demand shocks have a greater positive impact on Japanese interest rates than on euro area rates, the yen appreciates against the euro in response. Using quarterly data on the U.S., the euro area and Japan from 1981 to 2006, this paper shows that the third-currency effects are significant even when exchange rates evolve according to uncovered interest parity. This is because interest rates are typically set in response to output and inflation, which are in turn influenced by other exchange rates. More importantly, third-currency effects are also transmitted to the actual exchange rate through the expected future exchange rate which is, in a multi-country setup, influenced by third-countries' fundamentals and shocks. Third-currency effects have a stronger impact on the currency of a relatively more open economy. The analysis implies that small open economies should avoid strict forms of bilateral exchange rate targeting, since higher trade and financial openness work as a force intrinsically amplifying currency fluctuations.

**Keywords**: bilateral exchange rates; third-currency shocks; three-country model; U.S. dollar; euro; Japanese yen.

**JEL Classification**: F36, F31, F41

*I thank Cesar Calderon, Jan Libich, Connor Spreng, Dana Vorisek and Benn Steil for their comments and suggestions. All remaining errors are mine. Financial support from the Czech Science Foundation (GACR 402/08/0067) is gratefully acknowledged.

†MSN H4-400, World Bank, 1818 H Street, NW, Washington, DC 20433, U.S.A, email: mmelecky@worldbank.org, m.melecky@gmail.com.

# 1 Introduction

In an era of increasing globalization, when both trade and capital flows among individual economies are intensifying, an exchange rate between two countries' currencies can be materially affected by shocks emerging from a third country. For example, a U.S. demand shock can influence the exchange rate between the euro (EUR) and the Japanese yen (JPY). This paper investigates the transmission of third-currency shocks to bilateral exchange rates, attempts to shed light on the factors behind it, and derives implications for both exchange rate volatility and monetary policy regimes.

Recent investigations of the importance of third-currency effects on bilateral exchange rates include the work of Hodrick and Vassalou (2002), Nucci (2003), MacDonald and Marsh (2004), and Kingston and Melecky (2007). Although some of the studies – Hodrick and Vassalou (2002) and Kingston and Melecky (2007) – provide a theoretical justification for the existence of third-currency effects on bilateral exchange rates, their empirical analyses do not examine the actual transmission of third-currency shocks (such as demand, supply, and monetary policy shocks arising in a third country), or the factors determining the intensity and direction of third-currency effects. This paper conducts such an examination, and contributes to the literature by discussing the importance of third-currency effects for explaining exchange rate fluctuations in a structural framework, while postulating that the exchange rate evolves according to uncovered interest parity (UIP). Because the study uses UIP for exchange rate determination, it does not allow the third-currency effects to appear in the exchange rate equations explicitly, therefore tackling a possible criticism of skeptics of third-currency effects on bilateral exchange rates, who may argue that all third-currency effects should be arbitraged away.

The paper uses quarterly data on the U.S., the euro area, and Japan over the period 1981-2006 to estimate the three-country structural model that is used for analysis of third-currency effects and the transmission of third-currency shocks. The third-currency shocks are transmitted to a bilateral exchange rate through interest rates, since the latter are typically set in response to output and inflation, both of which are affected by other exchange rates. The transmission of third-currency shocks also works through the expected exchange rate, which is part of the

UIP condition, and, in the three-country model, is influenced by changes in third-currency fundamentals and shocks. The results suggest that third-currency shocks have a higher impact on the currency of a relatively more open economy. For instance, a positive U.S. demand shock is found to have a larger positive effect on the Japanese economy than the euro area economy. As such, the interest rate in Japan increases more than the interest rate in the euro area due to relatively greater monetary policy tightening in Japan. In response, the JPY appreciates against the EUR. Additionally, third-currency monetary policy shocks are found to have significantly positive effects on currencies of relatively more open economies, so that the euro, for example, appreciates against the U.S. dollar (USD) in response to a positive monetary policy shock in Japan. On the other hand, the direction of the impact of third-currency demand and supply shocks varies according to the weight financial markets put on trade and financial openness when forming their expectations about future exchange rates. The analysis thus implies that it can be costly for a small open economy to adopt strict bilateral exchange rate targeting as its monetary policy regime because increasing trade and financial flows among economies intrinsically amplify currency fluctuations.

The remainder of the paper is organized as follows: section two explains the three-country model employed for the investigation of third-currency shocks to bilateral exchange rates; section three describes the data and the estimation method; section four discusses the baseline estimation results; section five reports the result of an impulse response analysis and discusses the transmission mechanism of the three-country model; section six presents a sensitivity analysis in regards to the restrictions on formation of exchange rate expectations; and section seven concludes.

# 2 Model of an Economy

This section describes the open-economy model that constitutes a single building block of the three-country system in which third-currency shocks to bilateral exchange rates are analyzed. Let $E_t x_{t+1}$ denote the rational expectation forecast of $x_{t+1}$ conditional on the information set available to the forecasting agent at time $t$. The equation describing inflation dynamics is modelled by the following "hybrid" Phillips curve[1]:

$$\pi_t = \rho_\pi E_t \pi_{t+1} + (1 - \rho_\pi) \pi_{t-1} + \lambda_y y_t + \boldsymbol{\lambda}_q \begin{bmatrix} q_{1,t} \\ q_{2,t} \end{bmatrix} + \epsilon_{AS,t} \tag{1}$$

where $\pi_t$ is CPI inflation, $y_t$ is the output gap, $\boldsymbol{q}_t$ is a vector of real exchange rates, and $\epsilon_{AS,t}$ is a white-noise aggregate supply (AS) shock.[2] Since I am interested in building a three-country model, two exchange rates appear in the vector $\boldsymbol{q}_t$. Although allowing for an inertial effect by giving a non-zero weight to $\pi_{t-1}$ in Equation (1) was initially empirically motivated, the effect can be derived from a staggered price-setting mechanism, where a proportion of firms use a naïve, backward-looking rule to forecast inflation. The inertial effect also arises as a consequence of a Calvo-type price setting mechanism, with partial indexation to last period's inflation. For explicit derivation of the hybrid Phillips curve, see e.g. Christiano *et al.* (2005) and Smets and Wouters (2003). The empirical usefulness of the hybrid specification has been advocated in Fuhrer and Moore (1995), Rudd and Whelan (2005), and Linde (2005), among others. Further, CPI inflation increases in response to a positive output gap and an increasing marginal cost of production. The effect of the exchange rate on CPI inflation is exercised directly through the domestic currency price of imported final goods, and the domestic currency price of the imported intermediate inputs. Eventually, the exchange rate will also affect nominal wages via the effect of CPI inflation on wage setting. In either case, the exchange rate will affect the cost of domestically produced goods and inflation in the prices of domestically produced goods (see e.g. Svensson, 2000). Notice also that the impact of the real exchange rate $\boldsymbol{q}_t$ on domestic inflation represents the first transmission channel of foreign shocks to the domestic economy.[3]

[1] The term hybrid relates to the fact that the Phillips curve is backwards, as well as forward-looking in inflation.

[2] All the structural shocks in the three-country model are represented by white-noise processes to economize on the number of parameters that need to be estimated. This is aimed at alleviating the computational burden of the estimation and ensuring satisfactory performance of the optimizer.

[3] A levels real exchange rate specification is chosen here, as opposed to changes as employed in Giordani (2004, pp. 717), which is more in line with the derivation advocated in Svensson (2000).

The output gap dynamics is described by the following aggregate demand (IS[4]) equation:

$$y_t = \rho_y E_t y_{t+1} + (1-\rho_y) y_{t-1} - \delta_r \left(r_t - E_t \pi_{t+1}\right) + \boldsymbol{\delta}_q \begin{bmatrix} q_{1,t} \\ q_{2,t} \end{bmatrix} + \epsilon_{IS,t} \tag{2}$$

where $r_t$ is the monetary policy instrument and $\epsilon_{IS,t}$ a white-noise aggregate demand shock. One can see from Equation (2) that the output gap depends on its expected value one period ahead and its lagged value, where the relative impact is determined by the size of $\rho_y$. The forward-looking term is due to households' inter-temporal optimizing behavior and the lagged term arises as a result of consumption habit formation, or a costly adjustment of the capital stock under inter-temporal optimization, see Clarida *et al.* (2002), Christiano *et al.* (2005), and Smets and Wouters (2003) for further details. When the interest rate increases, consumption today in terms of consumption tomorrow becomes more costly, leading to a reduction in current domestic demand. Moreover, the interest rate affects the user cost of capital, influencing investment demand. Aggregate demand is thus influenced through intertemporal substitution effects (by the real interest rate), and through intratemporal price effects (by changes in the real exchange rate). The presence of the vector of real exchange rates $\boldsymbol{q}_t$ in (2) denotes the second transmission channel of foreign shocks into the domestic economy. The motivation for the open-economy IS equation can be found in Monacelli (2005), Clarida *et al.* (2001), and Svensson (2000).

For the specification of the monetary policy (MP) reaction function, I use a Taylor-type rule that considers only the domestic output gap and domestic inflation, which has been found empirically plausible[5] and reasonably robust to different model structures (see Svensson, 2000). In some circumstances, the Taylor rule can also be used to describe optimizing behavior (see Benigno and Benigno, 2003). A forward-looking version of the Taylor rule is employed to emphasize a

[4] The IS (Investment/Saving) curve can represent the equilibria where total private investment equals total saving.

[5] Empirical validation of this can be sought in, for example, Giordani (2004), who includes $r_t^*$, $\pi_t^*$ and $y_t^*$, but nevertheless finds that only $r_t^*$ receives a non-zero weight in the monetary policy reaction function in his model for Canada. In the models estimated by Lubik and Schorfheide (2007) and Lubik (2005), changes in the nominal exchange rate were included in the monetary policy reaction function of the central bank, however, no statistical evidence was found to suggest that the monetary policy authority reacted to exchange rate fluctuations. I thus decided to exclude foreign variables from the monetary policy reaction function.

central bank's focus on future inflation when adjusting its monetary policy instrument

$$r_t = \rho_r r_{t-1} + (1 - \rho_r)\left(\psi_\pi E_t \pi_{t+1} + \psi_y y_t\right) + \epsilon_{MP,t} \tag{3}$$

where $\epsilon_{MP,t}$ is again assumed to be a white-noise process.[6] The specification in (3) implies that the monetary authority responds to expected inflation one period ahead and the current output gap, while at the same time adhering to a certain degree of inertia in $r_t$.

Finally, the real exchange rate, $q_t$, needs to be described to close the model. The real exchange rate in logs is defined as $q_t \equiv s_t + p_t^* - p_t$, where $s_t$ is the log of the nominal exchange rate, and $p_t^*$ and $p_t$ are the foreign and domestic price levels in logs. I adopt an assumption common in the literature of the exchange rate evolving according to real UIP. The UIP condition is generally stated as an identity over the log of the exchange rate and interest rates, with the exchange rate expressed as the ratio of domestic to foreign currency units. Since the model becomes stochastically singular if UIP is left as an identity in (4), it is necessary to either add a shock or evaluate the log-likelihood function excluding the exchange rate equation. I follow the former approach, similar to Justiniano and Preston (2004) and McCallum and Nelson (2001)

$$E_t \Delta q_{t+1} = (r_t - E_t \pi_{t+1}) - \left(r_t^* - E_t \pi_{t+1}^*\right) + \epsilon_{RER,t} \tag{4}$$

Again, $\epsilon_{RER,t}$ is assumed to be a white-noise process. For more details regarding the empirical properties of UIP, see the studies by Ferreira and Leon-Ledesma (2007), Chinn and Meredith (2004), and Mark and Moh (2001). When investigating the real UIP condition, Ferreira and Leon-Ledesma find support for the hypothesis of a rapid reversion of exchange rates toward a zero-yield differential for developed countries.

The three-country model for investigation of third-currency shocks to bilateral exchange rates will thus consist of three identical blocks. Each block is described by equations (1)-(4); the domestic variables, shocks, and parameters of each block are distinguished by superscripts. Namely, the first block variables, shocks and parameters have no superscript while the same variables

[6] An *i.i.d* specification of the monetary policy shock is a common assumption in the literature, see Smets and Wouters (2003) and Del Negro *et al.* (2005).

belonging to the second and third blocks bear superscripts $*$ and $**$, respectively. The only difference across the three blocks is that the first two exchange rates are determined using the UIP condition, while the third, is a cross-exchange rate of the former two rates, i.e. the ratio of the other two exchange rates. Hence, there are only two exchange rate shocks, $\epsilon_{RER,t}$ and $\epsilon^*_{RER,t}$.

Although the three blocks are similar in structure their parametrization varies, as the parameters are estimated from the data. Data for the U.S., the euro area and Japan is used to estimate the parameters of the three blocks, so that superscripts $*$ and $**$ indicate variables associated with the euro area and Japan, respectively. The bilateral exchange rates on which I focus are therefore those between the USD, the EUR, and the JPY. Note that the expected signs of the elements of $\boldsymbol{\lambda}_q$ and $\boldsymbol{\delta}_q$ differ according to the quotation of the exchange rates. For instance, the coefficients attached to the USD/EUR exchange rate bear positive signs in the IS and AS equations for the U.S. but negative signs in the IS and AS equations for the euro area. In both cases, depreciation of a domestic currency increases domestic output and CPI inflation.

# 3 Data and Estimation Method

## 3.1 Data

The data employed are for the U.S., the euro area and Japan for the period from the first quarter of 1981 to the last quarter of 2006. I chose the starting date similar to Hodrick and Vassalou (2002) and MacDonald and Marsh (1999), as they work with related model structures and start their estimations in the early 1980s.

The inflation series for the three economies are constructed as annualized percentage changes in the national CPI indexes. All CPI series were taken from Datastream. The output gap is constructed as the deviation of the log of real GDP from its trend, estimated using the Hodrick-Prescott filter. The deviations are multiplied by 100 to scale up the variance of the series in accord with that of inflation and the interest rate (see also Buncic and Melecky, *forthcoming*; and Cho and Moreno, 2006). The real GDP series for the three countries were obtained from Datastream, where the real GDP for the euro area was extrapolated back to the first quarter of

1981 using the growth rates of the real GDP series from the Fagan *et al.* (2001) dataset. The interest rate series were taken from the IMF's International Financial Statistics. For all three countries, the money market rates are used instead of the policy interest rates to maximize data availability and consistency. The interest rate series for the euro area is extrapolated from the first quarter of 1994 back to the first quarter of 1981 using the growth rates of the short-term interest rate given in the Fagan *et al.* (2001) dataset. The observable series of exchange rates that enter the estimation are the logs of USD/EUR and USD/JPY exchange rates. The series of synthetic USD/EUR and JPY/USD were obtained from Datastream.

Further, I follow the approach undertaken in Smets and Wouters (2003), demeaning and detrending all data so that the three economies' behavior is modeled away from a deterministic steady-state growth path. Giordani (2004) has shown that working with demeaned/detrended data significantly reduces parameter instability and structural breaks, which, he finds, affect the unconditional mean of the modeled variables.

## 3.2 Estimation Method

Three estimation methods are commonly used to fit New Keynesian models to empirical data in the literature: the generalized method of moments (GMM), the full information maximum likelihood (ML) and the Bayesian estimation. However, there are some drawbacks to using the first two methods. Linde (2005) showed recently that GMM estimates of the parameters of a simple New Keynesian model are likely to be estimated imprecisely and with a bias. When using ML the estimated parameters can take on corner solutions or theoretically implausible values. In addition, it is often the case that the log-likelihood function is flat in certain directions of the parameter space and extremely hilly overall, so that without careful constraints on the parameters space it is difficult to numerically maximize the log-likelihood function (see An and Schorfheide, 2005).

Rather than imposing constraints on the parameter space and using ML estimation, it is more effective to add a probabilistic statement, or a prior belief, on the parameter space of the estimated model. This can be done easily within a Bayesian estimation approach which combines theoretical constraints and prior beliefs on the parameter space with the information contained in the data (see Adolfson *et al.*, 2005). I therefore use the Bayesian approach to obtain parameter estimates and draw inferences on the model. The Bayesian estimation of a New Keynesian policy model with nominal rigidities consists of several steps. First, the linearized rational expectations model consisting of three blocks (economies), each described by equations (1) to (4), is put into state-space form and solved using the solution algorithm of Sims (2002). The solved model has a VAR(1)[7] structure and thus allows one to readily compute the likelihood function. Combining the likelihood function of the solved model with the prior densities on the parameters then defines the posterior density. That is, given the priors $p(\theta)$, where $\theta$ is a vector containing the model parameters, the posterior density is proportional to the product of the likelihood function of the solved model and the priors:

$$p(\theta|\mathbf{Y}) \propto L(\theta|\mathbf{Y})\, p(\theta) \tag{5}$$

where $L(\theta|\mathbf{Y})$ is the likelihood function conditional on data $\mathbf{Y}$. Note that the priors that I use are mutually independent, so that $p(\theta)$ is constructed as the product of the individual priors on the structural parameters given in the first column of Table (1) for the U.S., euro area and Japanese economies. The priors for the U.S. are centered around the estimates from similar models in Cho and Moreno (2005) and Buncic and Melecky (*forthcoming*). Since I am not aware of any studies that estimated a similar New Keynesian model for the euro area or Japan, the priors for the latter two countries are centered at the same values as the ones for the U.S.. An exception are the priors for the parameters attached to exchange rates which are centered at marginally higher values in the case of Japan and the euro area than in the case of the U.S., to reflect the presumably higher degree of openness of the former two economies. The priors are generally mild, however, concentrate the probability mass over the range of theoretically plausible parameter values.

The posterior in (5) is generally a non-linear function of the structural parameters $\theta$ and is maximized using a numerical optimization algorithm.[8] The values of the parameters at the posterior mode, together with the corresponding Hessian matrix, are then used to start the random

[7]VAR(1) stands for a vector auto regression including first lag of all endogenous variables.
[8]Note that, as with ML estimation, it is the log of the posterior density that is maximized.

walk Metropolis-Hastings sampling algorithm to obtain draws from the entire posterior distribution. Proposals in the sampling algorithm are drawn from a multivariate normal distribution, where a scaling factor is used to achieve the desired acceptance rate. See An and Schorfheide (2005) for the Metropolis-Hastings sampling algorithm and the role of the scaling factor in the sampler. I ran two chains of $20,000$ draws, where the first 50% of each chain were discarded as a burn-in sample.

# 4 Estimation Results

The estimation results for the three-country model, including economies of the US, the euro area and Japan, are reported in Table (1). The Bayesian coefficient estimates are the posterior means and the inference is based on 95% Bayesian[9] confidence intervals.

Starting with the IS curve and the estimate of $\rho_y$ for the three economies, it appears that the process of output formation is more backward than forward looking in all three countries. The estimates happen to be very similar across the three economies and suggest that the output formation is forward looking from about 40%. The estimate of output-gap elasticity to changes in real interest rates, $\delta_r$, however, varies across the three economies. The elasticity is estimated to be the highest in the U.S. and only marginally lower in the euro area: 0.0034 and 0.0028, respectively. At 0.0004, the estimate for Japan is substantially (7 to 8 times) smaller. The latter could be attributed to Japan's problems with using the traditional monetary transmission mechanism in attempt to get the economy out of the "liquidity trap" conditions of deflation and low growth.[10]

Elasticities of the output gap to exchange rate movements are very important for dissemination of foreign shocks, including third-currency shocks, through the three-country system. In the first row of Table (1), the coefficient $\delta_{q1}$ represents the elasticity of the output gap in the U.S.,

[9] These are the minimum-distance confidence intervals computed from the posterior distribution of the coefficient iterates.

[10] The liquidity trap arises in circumstances when the zero lower bound on the central bank's instrument rate is strictly binding. Monetary policy in Japan has essentially consisted of a very low interest rate since 1995, a zero interest rate since 1999, and quantitative easening since 2001. During 2006 the money market interest rate increased marginally but is still below one percent at the end of 2007.

euro area and Japan to changes in USD/EUR, EUR/USD and JPY/USD exchange rates, respectively.[11] It is expected that the coefficient is more positive for a relatively more open economy. This is generally reflected in the estimates, as the elasticity of U.S. output to the USD/EUR rate is the lowest of 0.0091, whereas those of euro area output and Japanese output are significantly higher: 0.0134 and 0.0248, respectively. In all three cases a depreciation of the domestic currency increases the output gap through higher net exports. Similarly, the $\delta_{q2}$ coefficient represents the elasticity of the U.S., euro area and Japanese output gap to changes in USD/JPY, EUR/JPY and JPY/EUR exchange rates. First, note that the magnitudes of the estimated $\delta_{q2}$ coefficients are somewhat lower than the predominately dollar-based exchange rate elasticities approximated by the $\delta_{q1}$ estimates. This suggests greater importance of dollar exchange rates within the three-country system, and possibly the world economy as well. The three respective estimates are 0.0067 for the U.S. output gap, 0.0076 for the euro area output gap, and 0.0207 for the Japanese output gap, suggesting again that Japan is the most open economy, followed by the euro area.

Turning now to the estimates of the Phillips curve, the forward looking behavior as characterized by $\rho_\pi$ is estimated to be significantly stronger than in the case of output gap formation. Further, the estimates for the U.S. and euro area are fairly close, 0.6624 and 0.6368, whereas the estimate of $\rho_\pi$ for Japan is much higher, 0.8182. The impact of growing demand pressure and capacity utilization on prices, as captured by $\lambda_y$, is the highest in the U.S., 0.0375, closely followed by Japan, 0.0346, and somewhat lower in the euro area, for which the estimate is 0.0282. This suggests that nominal rigidity is more prevalent in the euro area than in the U.S. and Japan.

The exchange rate pass-through to CPI inflation is estimated to be strongest in Japan and weakest in the U.S., thus reflecting the differences in the degrees of openness across the three economies. More specifically, the pass-through of the USD/EUR, EUR/USD and JPY/USD rates to U.S., euro area and Japanese CPI inflation, characterized by $\lambda_{q1}$, appears to be 0.0107, 0.0173 and 0.0265, respectively. Similarly, the pass-through of USD/JPY, EUR/JPY and JPY/EUR exchange rates to US, euro area and Japanese CPI inflation, respectively, as captured by $\lambda_{q2}$, is estimated to be 0.0104, 0.0180, and 0.0209. Unlike for the IS curve, the impact of the different

[11] The equations involving $\boldsymbol{\delta}_q$ and $\boldsymbol{\lambda}_q$ are set up in such a way that the coefficients are expected to be always positive.

exchange rates on CPI inflation in each country is very similar, with the minor exception of Japan, where again the USD/JPY exchange rate appears to be more influential than the EUR/JPY exchange rate. The significance of this result is supported by the estimated 95% confidence intervals, which do not overlap in this case.

The estimated monetary policy reaction functions for the three economies suggest that the respective central banks smooth the paths of their interest rates. The highest estimate of $\rho_r$, 0.8259, is obtained for Japan. It appears that the Bank of Japan is the most conservative in its reaction to inflation, as it puts somewhat higher weight on inflation in its reaction function, $\psi_\pi = 1.7799$, than the Fed or the ECB (1.6268 and 1.3798, respectively). The Fed is estimated to put the least weight on the output gap in its reaction function, of $\psi_y = 1.4306$, relative to the ECB or the Bank of Japan, where the weights' estimates are 1.6062 and 1.7304. One can also observe that only the ECB seems to put more weight on the output gap than inflation in its reaction function.

The estimates of the standard deviations of structural shocks imply that the IS (demand) shock is the smallest disturbance for each economy, and that the IS curves fit the data best. Although the forward-looking Taylor rules show the second best fit in each economy, the size of the monetary policy shocks is generally ten times larger than that of the IS shocks.[12] The empirical literature estimating New Keynesian policy models commonly finds that the Phillips curve does not fit the data as well as the IS curve or the Taylor rule, and similarly, that the exchange rate equation produces the poorest fit to data across the equations of an open economy model (see e.g. Dennis *et al.*, 2007). These findings are also reflected in the estimates of the standard deviations of the shocks within the presented three-country model.

The relative sizes of the structural shocks however, do not tell us much about their relative impacts on the economy, which are commonly analyzed using impulse response functions.

[12] This finding could be justified by a large use of discretionary monetary policy over the estimated period within the context of the specification of monetary policy reaction function in the presented model. Or, by the fact that the monetary policy makers take into account other variables such as significant disequilibria (bubbles) in assets markets when deciding on the appropriate stance of monetary policy.

# 5 Impulse Response Analysis

Although I am interested in analyzing the impact of third-currency shocks on bilateral exchange rates, it is important that the impulse responses to domestic shocks and their transmission within the three economies are inspected first, in order to ensure that the basic transmission mechanism is clearly identified and consistent with the theoretical foundations of the model. This is because the reduced-form coefficients are non-linear functions of the structural coefficients, and the obtained impulse responses are not guaranteed to be well-behaved and without "puzzles" for all values of structural coefficients. All impulse responses in this paper are to shocks of one standard deviation.

## 5.1 Responses of Domestic Variables to Domestic Shocks

Figure (1) shows the impulse responses of domestic variables – the output gap, inflation and the interest rate – to the domestic shocks in each of the three economies. The first row of the panels shows the responses to a domestic IS shock in each economy, the second row shows the responses to AS shocks, and the third row the responses to monetary policy shocks.[13]

Consider the first row of Figure (1). Although the output gap significantly increases in response to an IS shock in all three economies, with the strongest response at the impact and a slow return to the steady state, the strongest response to the IS shock occurs in Japan, reflecting its larger estimated standard deviation relative to the U.S. and the euro area. Due to the strongest response of monetary policy to the output gap and expected inflation, however, the correction of the response deviation from the steady state is also the fastest in Japan. Inflation increases in response to an IS shock significantly only in the case of the U.S. and euro area, while for Japan the response is insignificantly different from zero. Since $\lambda_y$, the effect of output gap on inflation, is not significantly different across the three countries, the insignificant response in Japan arises as a result of the strong reaction of inflation to appreciation of the JPY following an increase in the Japanese interest rate. Though the response of inflation to an IS shock is long-lasting in both

[13] For the sake of readability, the impulse responses are not accompanied by confidence intervals, but I will comment on their significance in the text.

the U.S. and euro area, the U.S. response peaks much sooner. The response of the interest rate to a IS shock in each of the three economies is clearly identified and significantly positive. As the output gap opens due to a positive IS shock, inflation expectations increase and the monetary policy reacts to both positive output gap and inflation expectations by increasing interest rates more than one-to-one. The most pronounced response is in the U.S., mainly due to the U.S. having the weakest reaction of the output gap to exchange rate appreciation.

The second row of panels presents impulse responses to AS (supply) shocks. The AS shock increases inflation most significantly at its impact, where the largest inflation response is seen in Japan, which has the largest estimated standard deviation of the AS shock. The output gap responses to an AS shock, however, are mildly negative in all three economies. This is due to the fact that as positive AS shocks raise inflation and inflation expectations, central banks strongly increase nominal interest rates. The real interest rate then goes up, and the output gap declines as a result of intertemporal substitution, the rising user cost of capital, and the intratemporal price effect of appreciating real exchange rates. The combination of the size of the AS shock, the strength of the monetary policy reaction to inflation expectations, and the strength of the interest rate and exchange rate channels produces the most negative response of the output gap to a domestic AS shock in the euro area. Though the central banks of all three countries significantly increase interest rates in response to a supply shock, the responses of the Fed and ECB appear to be much stronger than that of the Bank of Japan. This result can be explained by heavier reliance of the ECB and the Fed on the interest rate (credit) channel of monetary policy rather than the exchange rate channel.

The third row of panels shows the impulse responses to monetary policy shocks. Although the output gap in all three economies declines in response to a positive MP shock, the largest decline occurs in Japan. This can be explained by the strongest second-round effect of an interest rate increase as a result a positive MP shock in Japan on the output gap, which occurs as the result of the subsequent JPY appreciation relative to other currencies. In all three economies, the response of inflation to a positive MP shock is also mildly negative. In the case of Japan, the response is at a maximum at the impact of the shock, and is about twice as large as the maximum response in the US or the euro area, where the maximums occur with a two-period lag. This is mainly due to the fact that in Japan, the transmission of the interest rate change to inflation works largely through the exchange rate channel, whereas in the euro area and the U.S. it works largely through the interest rate (credit) channel. Given the faster response of inflation to the MP shock in Japan, the exchange rate channel is delivering its maximum effect at impact, whereas transmission through the interest rate channel is longer lasting. The responses of interest rates to corresponding MP shocks in all three economies are significantly positive, peak at the impact of the monetary policy shocks, and last for about ten quarters. The largest response, however, is estimated for Japan. This is consistent with Japan having the largest estimated standard deviation of the MP shocks, which implies relatively higher discretion applied by the Bank of Japan within the context of the estimated reaction function.

In sum, the responses of domestic variables to domestic shocks do not show any "puzzles", and the directions of those responses are in line with economic theory.

## 5.2 Responses of Domestic Variables to Exchange Rate Shocks

To complete the inspection of the basic transmission mechanism of the model, the responses of domestic variables to exchange rate shocks are discussed in this section. Figure (2) shows the impulse responses of the output gap, inflation and the interest rate, in the US, the euro area and Japan to shocks to two exchange rates of the three-country system, USD/EUR and USD/JPY. Recall at this point that the EUR/JPY exchange rate is constructed as the cross-exchange rate using the USD/EUR and USD/JPY rates and thus has no shock attached to it.

The first row of panels in Figure (2) shows the impulse responses of output gaps, inflation and interest rates in the U.S., euro area and Japan to a USD/EUR exchange rate shock. In the first panel, we can observe that a relative depreciation of the USD versus the EUR increases the U.S. output gap at impact, and that output returns slowly back to its equilibrium in about 20 quarters. Since depreciation of the USD vis-a-vis the EUR mirrors a relative appreciation of the EUR vis-a-vis the USD, the euro area output gap decreases at impact and returns back to its steady state within 15 quarters. *Ceteris paribus*, the JPY depreciates with respect to the USD and appreciates with respect to the EUR. Due to the relatively greater openness of the Japanese economy and a higher impact on exports of the USD/JPY exchange rate compared with the JPY/EUR rate (see the estimation results in Table (1)), the Japanese output gap increases in response to the positive USD/EUR rate shock and returns to its steady state in 10 quarters. The responses of inflation in the U.S. and Japan to a positive USD/EUR rate shock are only marginally positive and very short-lived, lasting for about one quarter. In both countries, the impact of an exchange rate shock on CPI inflation is likely propagated through the effect of the output gap on inflation rather than through the direct exchange rate pass-through to prices. In the euro area, the idiosyncratic appreciation of the EUR against the USD has a negative effect on CPI inflation at impact. However, the inflation response becomes positive in about three quarters and lasts for another 12 quarters. One may expect that the positive effect is brought about by the easing of monetary policy in response to a decrease in inflation, which subsequently results in an increase in output gap and inflation. This hypothesis is supported by the next plot, in which the response of the euro area interest rate to a positive USD/EUR rate shock is negative – the interest rate declines significantly at impact and further in the second quarter. The reaction of U.S. monetary policy to the same shock is much smaller, and can likely be attributed to the effort to offset the effect on the output gap. A similar reaction seems to be applied by the Bank of Japan. However, the increase in the Japanese interest rate is stronger and longer lasting (about 18 quarters) than the U.S. interest rate increase.

The second row of panels starts with the plot of output gap responses to the USD/JPY exchange rate shock. Since relative depreciation of the USD against the JPY also induces, *ceteris paribus,* relative depreciation of the EUR against the JPY, both the U.S. and euro area output gaps respond positively to the shock and return to their steady states in about six quarters. On the other hand, the response of the Japanese output gap is significantly negative and much sharper as a result of the relatively greater openness of the Japanese economy. The JPY appreciation with respect to the USD and the EUR lasts for about nine quarters. The response of the U.S. and euro area inflation to a positive USD/JPY shock is positive and can be attributed, at impact, mainly to the increasing output gap in both countries. Later, however, the responses decline as monetary policy tightens. The response of Japanese inflation to the USD/JPY rate shock is similar to that of euro area inflation to the USD/EUR shock. Namely, it is significantly negative at impact, becomes positive after about two quarters (as the interest rate decreases) and remains positive for another 10 quarters. As indicated, the interest rate response to a positive USD/JPY rate shock is mildly positive in the U.S. and the euro area, and significantly negative in Japan. The Japanese interest rate response peaks after three quarters, returning to its steady state after about 20 quarters. The reaction of the Bank of Japan to the shock again demonstrates the relatively higher sensitivity of the Japanese economy to external shocks.

## 5.3 Fundamental and Third-Currency Shocks to Bilateral Exchange Rates

This section investigates third-currency shocks to bilateral exchange rates within the structure of the three-country model with estimated coefficients. It also compares the impacts of two classes of shocks: (i) third-currency shocks, as defined earlier, and (ii) fundamental shocks, i.e. shocks originating in countries whose currencies are related by a given exchange rate. The first column of Figure (3) shows plots of the impulse responses of the USD/EUR exchange rate to IS, AS and MP shocks originating in the U.S., the euro area and Japan, where the last panel in the first column summarizes the third-currency shocks to the USD/EUR rate originating in Japan. Similarly, the second column of plots shows the responses of the USD/JPY exchange rate, with the last panel summarizing the effects of third-currency shocks from the euro area. Finally, the third column does the same for the EUR/JPY exchange rate; the third-currency shocks plotted in the last panel come from the U.S..

### 5.3.1 Impulse Responses of the USD/EUR Exchange Rate

Consider now the first column of Figure (3). A positive IS shock in the U.S. induces appreciation of the USD/EUR exchange rate. The positive IS shock results in a positive output gap and increased inflation expectations, making the Fed raise the interest rate. Under the UIP restriction, this results in an appreciation of the USD against the EUR. A mirror-image scenario takes place on the EUR side, where the EUR appreciates against the USD as a result of a positive IS shock in the euro area. The USD appreciation in response to a positive IS shock in the U.S. seems to be somewhat stronger than the response to an IS shock in the euro area. The response of the USD/EUR rate to a third-currency IS shock, however – in this case a positive IS shock from Japan – is about ten times smaller than the responses to an IS shock in the U.S. or the euro area. The confidence intervals associated with the response (see Figure (4)) suggest that the third-currency effect is significantly negative, i.e. that it results in USD appreciation vis-a-vis the EUR. Hence, while both the USD and the EUR depreciate against the JPY as a result of a positive IS shock in Japan (see panels (1,2) and (1,3)[14] of Figure (3)) there appears to be a stronger positive effect on the U.S. economy (i.e. the output gap and inflation), such that the USD interest rate increases relatively more than the EUR interest rate, thus leading the USD to appreciate against the EUR.

Consider next the responses of the USD/EUR rate to AS shocks in the U.S. and the euro area, and the third-currency AS shock originating in Japan. Because inflation expectations increase as a result of an AS shock, a currency depreciates relative to its counterpart in accord with the relative PPP incorporated within the assumed real UIP condition for the exchange rate dynamics. Hence, following a positive AS shock in the U.S., the USD depreciates against the EUR. Similarly, the EUR depreciates against the USD as a result of a positive AS shock in the euro area. The response of the USD/EUR exchange rate to a third-currency (Japanese) AS shock appears to be economically insignificant given the magnitude of the USD/EUR responses to AS shocks in the U.S. and the euro area. The statistical significance of this shock can be explained by recognizing that the JPY depreciates against the USD and the EUR as a result of a Japanese AS shock, and that the cumulative easing of U.S. monetary policy in response to USD appreciation against the JPY is larger than the cumulative easing of monetary policy in the euro area in response to EUR appreciation against the JPY (see panel (2,3) of Figure (2)).

The second to last panel of the first column shows the responses of the USD/EUR rate to monetary policy shocks. As postulated by the UIP condition, a positive monetary policy shock, which results in an interest rate increase, will induce appreciation of the corresponding currency.

[14] Panel (1,2) meaning, first row and second column of a figure.

Therefore, the USD appreciates against the EUR in response to a positive monetary policy shock in the U.S., and likewise the EUR appreciates relative to the USD in response to a positive monetary policy shock in the euro area. The third-currency (Japanese) MP shock appears to have a positive impact on the USD/EUR exchange rate. Since a MP shock in Japan results in appreciation of the JPY against both the USD and the EUR, the increase in the USD/EUR rate as a result of a Japanese MP shock can be justified by a larger positive impact of the EUR depreciation on the euro area economy than that of the USD depreciation on the U.S. economy.

As displayed in the last panel of column one, the strongest third-currency shock to the USD/EUR exchange rate appears to be the Japanese IS shock, while the impact of the Japanese AS shock appears to be the weakest. Although all three responses of the USD/EUR rate to Japanese structural shocks are estimated to be statistically significant (see Figure (4)), their economic significance is rather marginal, with possible exception of the response to a Japanese IS shock.

### 5.3.2 Impulse Responses of the USD/JPY Exchange Rate

Consider next the second column of Figure (3). The plotted responses suggest that the USD appreciates relative to the JPY in response to a positive U.S. IS shock. Similarly, the JPY appreciates against the USD in response to a positive Japanese IS shock. As a central bank increases its interest rate in response to a positive output gap, the UIP condition implies contemporaneous appreciation of the currency with the positive interest rate differential. Therefore, the response of the USD/JPY exchange rate to a third-currency IS shock originating in the euro area is estimated to be significantly positive. Due to the Japanese economy being relatively more open than the U.S. or euro area economies, the depreciation of both the USD and the JPY against the EUR in response to a positive IS shock in the euro area has a larger positive effect on the Japanese interest rate, thus resulting in appreciation of the JPY against the USD. Also, the Bank of Japan is estimated to react more strongly to changes in the output gap and expected inflation than the Fed.

One can see in the second panel of column two that the USD depreciates against the JPY in response to a positive AS shock in the U.S., and analogously that the JPY depreciates against the USD in response to a positive Japanese AS shock. The responses are consistent with the relative PPP incorporated in the real UIP condition, which postulates that the currency with a positive inflation differential is expected to depreciate. The response of the USD/JPY rate to a third-currency (euro area) AS shock is positive, so that the USD depreciates against the JPY. Since the EUR depreciates vis-a-vis the USD and the JPY as a result of a positive euro area AS shock, the greater openness and thus relatively stronger monetary policy easing in Japan, should imply contemporaneous depreciation of the JPY against the USD. Nevertheless, I find the opposite, i.e. that the USD depreciates contemporaneously against the JPY. This could arise if the third-currency (euro area) AS shock induces an expected future depreciation of the USD against the JPY that more than offsets the impact of the emerging positive differential between the dollar and yen interest rates. Note that the rational exchange rate expectations in this model are functions of all state variables appearing in the model, including those of the third countries (currencies).

The third panel of column two shows that the USD appreciates contemporaneously relative to the JPY as a result of a positive U.S. MP shock, and that the JPY appreciates relative to the USD in response to a positive Japanese MP shock. The third-currency (euro area) shock to the USD/JPY exchange rate induces depreciation of the USD against the JPY, as the positive effect of the JPY depreciation against the EUR on the Japanese economy is higher than the positive effect of the USD depreciation on the U.S. economy. This is due to the higher degree of trade and financial openness of Japan.

The last panel of column two shows that the euro area MP and AS shocks are the most influential third-currency shocks to the USD/JPY exchange rate. In this case, the intensity of the responses seems to be economically significant and on the same order of magnitude as the impulse responses associated with domestic fundamentals (see Figure (1) and (2)).

### 5.3.3 Impulse Responses of the EUR/JPY Exchange Rate

Consider the third column of Table (3), which plots the impulse responses of the EUR/JPY exchange rate to IS, AS and MP shocks originating in the euro area, Japan and the U.S.. The shocks originating in the U.S. are then the third-currency shocks. The EUR appreciates at impact relative to the JPY in response to an IS shock occurring in the euro area. Analogously, the JPY appreciates relative to the EUR in response to an IS shock occurring in Japan. An IS shock results, *ceteris paribus,* in an interest rate increase in the domestic economy and, as postulated by UIP, in an appreciation of the domestic currency. The response of the EUR/JPY rate to an IS shock originating in the U.S. is positive, so that the JPY appreciates relative to the EUR at impact. This could be due to a larger positive impact of JPY depreciation against the USD on Japanese exports relative to the positive impact of EUR depreciation against the USD on the euro area exports, output gap, and possibly inflation.

The second panel in the third column shows responses of the EUR/JPY exchange rate to AS shocks. It appears that the EUR depreciates upon impact of a positive AS shock in the euro area, in line with the underlying relative PPP hypothesis. Similarly, the JPY depreciates in response to a positive AS shock in Japan. The EUR/JPY rate response to a positive AS shock originating in the U.S. is mildly positive, i.e. the EUR mildly depreciates against the JPY. This response can be explained by an expected depreciation of the EUR relative to the JPY in response to an AS shock in the U.S.. The second-round effect, arising due to the increasing interest rate differential as interest rates respond to the opening output gaps and inflation in the two countries, is thus larger in Japan. This larger second-round effect in Japan is due to the greater degree of openness of the Japanese economy.

The third panel in the second column presents impulse responses of the EUR/JPY exchange rate to MP shocks originating in the euro area, Japan and the U.S.. According to these, the EUR appreciates relative to the JPY at impact of an euro area MP shock. After two quarters the EUR begins to depreciate relative to the JPY. Concurrently, the JPY appreciates relative to the EUR in response to a Japanese MP shock. After two quarters, however, the JPY depreciates and returns to the steady state. A positive third-currency MP shock, in this instance from the

U.S., causes depreciation of the EUR vis-a-vis the JPY. This means that the JPY interest rate and currency value increase more than the EUR interest rate and currency value in response to USD depreciation relative to the EUR and the JPY. Again, the greater openness of Japan is behind this result.

The last panel summarizes the responses of the EUR/JPY exchange rate to the third-currency shocks coming from the U.S.. As shown, the exchange rate response to an IS shock from the U.S. is the strongest. The exchange rate responses to AS and MP shocks from the U.S. are very similar in magnitude and shape. Overall, however, only the response to the U.S. demand shock appears to be economically significant.

# 6 Sensitivity Analysis

Consider again equation (4), and note that the transmission of third-currency shocks to the exchange rate is realized not only through the interest rates (due to the impact of exchange rates on the output gap and inflation), but also through the expected future exchange rate, which is, in the three-country model, a function of the third-country's state variables and shocks. Given the forward looking nature of exchange rate dynamics (see e.g. Engel and West, 2005), financial (exchange rate) markets could be processing the news about changes in macroeconomic variables differently than the model restrictions imply. Such behavior may require that trade and financial openness play more substantial roles in the model, particularly in exchange rate determination. Therefore, I focus on relaxing the restrictions on state variables and shocks in the reduced-form equations for the expected future exchange rates.

More explicitly, note that in the three-country model the exchange rate expectation is a function of state variables, $S_t$, model coefficients, $\boldsymbol{\theta}$, and structural shocks, $\boldsymbol{\epsilon}_t$,

$$E_t s_t = \mathbf{f}\left(S_t, \boldsymbol{\theta}, \boldsymbol{\epsilon}_t\right) \tag{6}$$

where

$$S_t \equiv \left[y_{t-1}, \pi_{t-1}, r_{t-1}, y^*_{t-1}, \pi^*_{t-1}, r^*_{t-1}, y^{**}_{t-1}, \pi^{**}_{t-1}, r^{**}_{t-1}, (\text{usd/eur})_{t-1}, (\text{usd/jpy})_{t-1}, (\text{eur/jpy})_{t-1}\right]'$$

I relax the coefficient restrictions on the state variables, and therefore also on the structural shocks in the exchange rate equations, such that the coefficients attached to the variables in $S_t$ are no longer restricted to be functions of $\boldsymbol{\theta}$, but are estimated freely from the data. I reestimate the three-country model described in (1)-(4) with the relaxed restrictions and present the resulting coefficient estimates in Table (2) together with the coefficient estimates of the baseline estimation. The coefficient estimates differ somewhat from those of the baseline model, but in general are not statistically different.[15] It is more interesting to look at the difference between the coefficients attached to the state variables in the equations describing the formation of exchange rate expectations. Such a comparison is presented in Table (3). As shown, the differences in the estimated coefficients under restricted and unrestricted exchange rate expectations are significant, and the deviations from the estimated coefficients of the baseline model are both positive and negative. However, what we are interested in most is the impact of the coefficient estimates from the three-country model with unrestricted exchange rate expectations on the size and shape of the resulting exchange rate impulse responses to third-currency shocks.

Consider the first column of Figure (4), which shows the exchange rate impulse responses to third-currency IS shocks. The responses of USD/EUR and USD/JPY exchange rates to a Japanese IS shock and a euro area IS shock, respectively, appear to be of the same magnitude as in the baseline model, but their direction at impact is exactly the opposite. Similarly, the EUR/JPY response to a U.S. demand shock goes in the opposite direction to that of the EUR/JPY response in the baseline model, although in addition the response is about four times stronger. This can be to some degree explained by inspecting the effect of third-currency IS shocks on exchange rates in the reduced-form solution of the estimated model. This coefficient on the third-currency IS shock changes its sign in the reduced-form equations for USD/EUR, USD/JPY and EUR/JPY exchange rates, once the exchange rate expectations are unrestricted. The coefficient signs also

[15] I do not report the corresponding confidence intervals here to save space.

switch if one looks at the effects of the lagged third-currency output gap in the reduced-form equations for the exchange rates, i.e. the variable with the strongest second round impact. Recall at this point that the reduced-form coefficients are non-linear functions of the structural coefficients, so that the underlying explanation for the changes in the reduced-form coefficients' magnitudes and signs is empirical rather than theoretical. The changed formation of exchange rate expectations results in a larger effect of the expected future exchange rate on the current exchange rate relative to the effect of the interest differential, so that the shocks are likely to induce a decrease in the values of currencies of relatively more open economies.

The exchange rate impulse responses to third-currency AS shocks are shown in the second column of Figure (4). The response of the USD/EUR rate to a Japanese AS shock moves in the same direction as the analogous response in the baseline model, but is about five times stronger at impact. Furthermore, after about four quarters the response changes from a positive to a negative one before returning to the steady state. The response of the USD/JPY rate to a euro area AS shock, however, is significantly different from the analogous response in the baseline model. It is negative at impact, and becomes positive after about two quarters, and then returns to the steady state. The same can be said about the EUR/JPY response to a U.S. supply shock, which is negative at impact and about ten times larger than the positive EUR/JPY response in the baseline model. After two quarters the response becomes positive and then returns to the steady state. The direction of the immediate exchange rate response to a third-currency AS shock is determined by the sign of the coefficient on the third-currency AS shock in the reduced-form equation for a given exchange rate. The signing of this coefficient changed in the case of the USD/JPY and EUR/JPY rates, as one can see from the plotted responses of the USD/JPY and EUR/JPY rates to the corresponding third-currency AS shocks. Broadly, the impulse responses of the USD/JPY and EUR/JPY rates imply that at impact the effect of expected exchange rate depreciation dominates, while the peaks of the responses occur in the opposite direction and are induced by the prevailing interest rate differentials.

The last column of Figure (4) plots the exchange rate impulse responses to third-currency MP shocks. The response of the EUR/USD rate to a Japanese MP shock is positive at impact, as in the baseline model but about ten times larger. Further, the response becomes negative after two quarters, unlike in the baseline case where it is always positive, before it returns to zero. The USD/JPY response to a euro area MP shock is positive, as in the baseline case, but about two times stronger. After two quarters it becomes negative and then returns to the steady state. Similarly, the response of the EUR/JPY rate to a U.S. MP shock is positive at impact, consistent with the baseline case, but about two to three times larger. The response remains positive, with a hump, before returning to the steady state. The reduced-form coefficients attached to the third-currency monetary policy shocks thus did not change. Hence, the changed formation of exchange rate expectations magnified the exchange rate impulse responses to third-currency MP shocks several times but did not change their directions.

In general, relaxing the coefficient restrictions on the state variables and shocks determining the future expected exchange rate can significantly change the estimates of exchange rate impulse responses to third-currency shocks. The significant change in the impulse response estimates can manifest itself in larger responses at impact, and changing directions of the responses and their shapes. More importantly, in an environment of unrestricted, more empirically-driven exchange rate expectations, the importance of third-currency shocks to exchange rates rises significantly, to a level similar to the response of exchange rates to fundamental shocks associated with the currencies of the exchange rate (see Figure (3)). Concerning the directions of the third-currency shocks' impacts, monetary policy shocks are found to have a consistently positive effect on currencies of economies with a higher degree of trade and financial openness. The direction of impact of third-currency supply and demand shocks varies, on the other hand, depending on the weight financial market agents attach to the state variables and shocks when forming their expectations about future exchange rates.

# 7 Conclusion

This paper investigated the impact of third-currency shocks on bilateral exchange rates in terms of transmission, potential size and direction. For this purpose, a structural three-country model was used and its parameters estimated using quarterly data for the U.S., the euro area and

Japan from 1981 to 2006. An assumption was made that the exchange rate dynamics are given by uncovered interest parity so that third-currency effects do not appear in the exchange rate equations explicitly. The transmission of third-currency shocks was found to work through the interest rate that is typically set in response to output and inflation, both of which are, in turn, affected by a variety of exchange rates. More importantly, third-currency shocks are found to be transmitted through the expected exchange rate which is, in a multi-country set up, influenced by changes in third-countries' fundamentals and third-country shocks. The third-currency shocks have a larger impact on currencies of relatively more open economies. Concerning the direction of third-currency effects, monetary policy shocks appeared to have consistently positive effects on currencies of more open economies, while the direction of the effects of third-currency demand and supply shocks varied according to the weight financial market agents put on trade and financial openness when forming their expectations about the future exchange rate.

The analysis suggests that the importance of third-currency effects rises with growing trade and financial openness, which inherently amplifies exchange rate fluctuations. Therefore, from the point of view of sustainability and cost effectiveness, small open economies should avoid adopting monetary policy regimes involving strict bilateral exchange rate targeting. Although not reflected strongly in the model parametrization in this paper, the strength of third-currency effects also depends on how strongly a monetary authority responds to an increasing output gap and expected inflation relative to its counterparts in other countries. For a given degree of trade and financial openness, it is predicted that a relatively stronger stabilization of output and inflation through the use of the interest rate will result in larger exchange rate fluctuations for a given country. Future research should focus on incorporating the concepts of currency substitution and complementarity into the multi-country setup in order to explain more explicitly the directions of third-currency effects and to analyze why some exchange rates could be more volatile than others.

# References


[1] Adolfson, M., Laseen, S. ,Linde, J., Villani, M. (2005). Empirical Properties of Closed and Open Economy DSGE Models of the Euro Area. Manuscript, Sveriges Riksbank.

[2] An, S., Schorfheide, F. (2005). Bayesian Analysis of DSGE Models. CEPR Discussion Paper 5207.

[3] Buncic, D., Melecky, M. (*forthcoming*). An Estimated New Keynesian Policy Model for Australia. *Economic Record*.

[4] Chinn, M.D., Meredith, G. (2004). Monetary Policy and Long-Horizon Uncovered Interest Parity. *IMF Staff Papers* 51, 409–430.

[5] Cho, S., Moreno, A. (2006). A Small-Sample Study of the New-Keynesian Macro Model. *Journal of Money, Credit and Banking* 38, 1461–1481.

[6] Christiano, L. J., Eichenbaum, M., Evans, C. (2001). Nominal Rigidities and the Dynamic Effects of a Shock to Monetary Policy. Working Paper 01-07, Federal Reserve Bank of Cleveland.

[7] Clarida, R., Gali, J., Gertler, M. (2001). Optimal Monetary Policy in Open versus Closed Economies: An Integrated Approach. *American Economic Review* 91, 248–252.

[8] Clarida, R., Gali, J., Gertler, M. (2002). A Simple Framework for International Monetary Policy Analysis. *Journal of Monetary Economics* 49, 879–904.

[9] Del Negro, M., Schorfheide, F., Smets, F., Wouters, R. (2005). On the fit and Forecasting Performance of New-keynesian Models. ECB Working Paper 491. Frankfurt am Main.

[10] Dennis, R., Leitemo, K., Soderstrom, U. (2007). Monetary Policy in a Small Open Economy with a Preference for Robustness. CEPR Discussion Paper 6067.

[11] Engel, C., West, K.D. (2005). Exchange Rate and Fundamentals. *Journal of Political Economy* 3, vol. 113, 485-517.

[12] Fagan, G., Henry, J., Mestre, R. (2001). An Area-Wide Model (AWM) for the Euro Area. ECB Working Paper 42. Frankfurt am Main.

[13] Ferreiraa, A.L., León-Ledesma, M.A. (2007). Does the Real Interest Parity Hypothesis Hold? Evidence for Developed and Emerging Markets. *Journal of International Money and Finance* 3, Vol. 26, 364-382.

[14] Fuhrer, J., Moore, G. (1995). Inflation Persistence. *Quarterly Journal of Economics* 110 (1), 127–159.

[15] Giordani, P. (2004). Evaluating New-Keynesan Models of a Small Open Economy. *Oxford Bulletin of Economics and Statistics* 66, 713–733.

[16] Hodrick, R., Vassalou, M. (2002). Do we need multi-country models to explain exchange rate and interest rate and bond return dynamics? *Journal of Economic Dynamics & Control* 26, 1275–1299.

[17] Justiniano, A., Preston, B. (2004). Small Open Economy DSGE Models: Specification, Estimation and Model Fit. Manuscript, Columbia University.

[18] Linde, J. (2005). Estimating New-Keynesian Phillips Curves: A Full Information Maximum Likelihood Approach. *Journal of Monetary Economics* 52, 1135–1149.

[19] Kingston, G., Melecky, M. (2007). Currency Preferences and the Autralian Dollar. *Journal of International Money and Finance* 26(3), 454-467.

[20] Lubik, T.A. (2005). A Simple, Structural, and Empirical Model of the Antipodean Transmission Mechanism. Manuscript, Johns Hopkins University.

[21] Lubik, T.A., Schorfheide F. (2007). Do Central Banks Respond to Exchange Rate Movements? A Structural Investigation. *Journal of Monetary Economics* 54(4), 1069-1087.

[22] MacDonald, R., Marsh, I.W., (1999). Currency Spillovers and Tri-Polarity: a Simultaneous Model of the US Dollar, German Mark and Japanese Yen. *Journal of International Money and Finance* 23, 99–111.

[23] Mark, N.C., Moh, Y.K. (2001). What do Interest-Rate Differentials Tell us about the Exchange Rate? Manuscript, Ohio State University.

[24] McCallum, B.T., Nelson, E. (2001). Monetary Policy for an Open Economy: An Alternative Framework with Optimizing Agents and Sticky Prices. CEPR Discussion Paper 2756.

[25] Monacelli, T. (2005). Monetary Policy in a Low Pass-Through Environment. *Journal of Money, Credit and Banking* 37, 1047–1066.

[26] Nucci, F. (2003). Cross-Currency, Cross-Maturity Forward Exchange Premiums as Predictors of Spot Rate Changes: Theory and Evidence. *Journal of Banking and Finance* 27, 183-200.

[27] Rudd, J., Whelan, K. (2005). New Tests of the New-Keynesian Phillips Curve. *Journal of Monetary Economics* 52, 1167–1181.

[28] Sims, C.A. (2002). Solving Linear Rational Expectations Models. *Computational Economics* 20, 1–20.

[29] Smets, F., Wouters, R. (2003). An Estimated Dynamic Stochastic General Equilibrium Model of the Euro Area. *Journal of the European Economic Association* 1, 1123–1175.

[30] Svensson, L.E.O. (2000). Open-Economy Inflation Targeting. *Journal of International Economics* 50, 155–183.

| | | US | | Euro Area | | Japan | |
|---|---|---|---|---|---|---|---|
| param | prior | post.m | conf.interval | post.m | conf.interval | post.m | conf.interval |
| $\rho_y$ | $\mathcal{B}(0.5, 0.2)$ | 0.4235 | $[0.4061; 0.4324]$ | 0.4136 | $[0.4048; 0.4229]$ | 0.4251 | $[0.4218; 0.4291]$ |
| $\delta_r$ | $\mathcal{N}(0.003, 003)$ | 0.0034 | $[0.0030; 0.0036]$ | 0.0028 | $[0.0025; 0.0030]$ | 0.0004 | $[0.0003; 0.0004]$ |
| $\delta_{q1}$ | $\mathcal{N}(0.01, 0.01)$ | 0.0091 | $[0.0086; 0.0094]$ | 0.0139 | $[0.0134; 0.0143]$ | 0.0248 | $[0.0221; 0.0267]$ |
| $\delta_{q2}$ | $\mathcal{N}(0.01, 0.01)$ | 0.0067 | $[0.0065; 0.0070]$ | 0.0076 | $[0.0074; 0.0079]$ | 0.0207 | $[0.0167; 0.0237]$ |
| $\rho_\pi$ | $\mathcal{B}(0.6, 0.2)$ | 0.6624 | $[0.6507; 0.6763]$ | 0.6368 | $[0.6232; 0.6479]$ | 0.8182 | $[0.8020; 0.8346]$ |
| $\lambda_y$ | $\mathcal{N}(0.03, 0.03)$ | 0.0375 | $[0.0370; 0.0383]$ | 0.0282 | $[0.0250; 0.0312]$ | 0.0346 | $[0.0325; 0.0364]$ |
| $\lambda_{q1}$ | $\mathcal{N}(0.01, 0.01)$ | 0.0107 | $[0.0087; 0.0129]$ | 0.0173 | $[0.0141; 0.0206]$ | 0.0265 | $[0.0247; 0.0281]$ |
| $\lambda_{q2}$ | $\mathcal{N}(0.01, 0.01)$ | 0.0104 | $[0.0092; 0.0114]$ | 0.0180 | $[0.0158; 0.0205]$ | 0.0209 | $[0.0187; 0.0233]$ |
| $\rho_r$ | $\mathcal{B}(0.8, 0.2)$ | 0.7664 | $[0.7503; 0.7830]$ | 0.7887 | $[0.7787; 0.7970]$ | 0.8259 | $[0.8240; 0.8279]$ |
| $\psi_\pi$ | $\mathcal{N}(1.6, 0.5)$ | 1.6268 | $[1.5699; 1.6829]$ | 1.3798 | $[1.2653; 1.5661]$ | 1.7799 | $[1.7353; 1.8253]$ |
| $\psi_y$ | $\mathcal{N}(1.3, 0.5)$ | 1.4306 | $[1.3197; 1.5466]$ | 1.6062 | $[1.4975; 1.6691]$ | 1.7304 | $[1.6925; 1.7903]$ |
| $\sigma_{\epsilon_{IS}}$ | $\mathcal{IG}(0.2, 1.0)$ | 0.0403 | $[0.0396; 0.0411]$ | 0.0344 | $[0.0323; 0.0362]$ | 0.0793 | $[0.0643; 0.0928]$ |
| $\sigma_{\epsilon_{AS}}$ | $\mathcal{IG}(0.8, 1.0)$ | 0.8157 | $[0.7289; 0.9081]$ | 1.0531 | $[1.0182; 1.0970]$ | 1.4227 | $[1.3154; 1.5338]$ |
| $\sigma_{\epsilon_{MP}}$ | $\mathcal{IG}(0.4, 1.0)$ | 0.4924 | $[0.4428; 0.5371]$ | 0.4494 | $[0.3792; 0.5014]$ | 0.8465 | $[0.7738; 0.9045]$ |
| $\sigma_{\epsilon_{q1}}$ | $\mathcal{IG}(1.5, 2.0)$ | 1.0555 | $[0.9165; 1.1962]$ | – | – | – | – |
| $\sigma_{\epsilon_{q2}}$ | $\mathcal{IG}(1.5, 2.0)$ | 1.8417 | $[1.7806; 1.8812]$ | – | – | – | – |

Table 1: Estimation Results for the Three-Country Model

| | | US post.m. | | Euro Area post.m. | | Japan post.m. | |
|---|---|---|---|---|---|---|---|
| param | prior | restr. | unrestr. | restr. | unrestr. | restr. | unrestr. |
| $\rho_y$ | $\mathcal{B}(0.5, 0.2)$ | 0.4235 | 0.4769 | 0.4136 | 0.5226 | 0.4251 | 0.5228 |
| $\delta_r$ | $\mathcal{N}(0.003, 003)$ | 0.0034 | 0.0030 | 0.0028 | 0.0031 | 0.0004 | 0.0007 |
| $\delta_{q1}$ | $\mathcal{N}(0.01, 0.01)$ | 0.0091 | 0.0079 | 0.0139 | 0.0213 | 0.0248 | 0.0295 |
| $\delta_{q2}$ | $\mathcal{N}(0.01, 0.01)$ | 0.0067 | 0.0075 | 0.0076 | 0.0194 | 0.0207 | 0.0298 |
| $\rho_\pi$ | $\mathcal{B}(0.6, 0.2)$ | 0.6624 | 0.7105 | 0.6368 | 0.5956 | 0.8182 | 0.8464 |
| $\lambda_y$ | $\mathcal{N}(0.03, 0.03)$ | 0.0375 | 0.0343 | 0.0282 | 0.0336 | 0.0346 | 0.0352 |
| $\lambda_{q1}$ | $\mathcal{N}(0.01, 0.01)$ | 0.0107 | 0.0116 | 0.0173 | 0.0111 | 0.0265 | 0.0174 |
| $\lambda_{q2}$ | $\mathcal{N}(0.01, 0.01)$ | 0.0104 | 0.0111 | 0.0180 | 0.0121 | 0.0209 | 0.0177 |
| $\rho_r$ | $\mathcal{B}(0.8, 0.2)$ | 0.7664 | 0.8000 | 0.7887 | 0.8473 | 0.8259 | 0.9381 |
| $\psi_\pi$ | $\mathcal{N}(1.6, 0.5)$ | 1.6268 | 1.5652 | 1.3798 | 1.4508 | 1.7799 | 1.6226 |
| $\psi_y$ | $\mathcal{N}(1.3, 0.5)$ | 1.4306 | 1.2647 | 1.6062 | 1.3919 | 1.7304 | 1.3332 |
| $\sigma_{\epsilon_{IS}}$ | $\mathcal{IG}(0.2, 1.0)$ | 0.0403 | 0.2919 | 0.0344 | 0.2339 | 0.0793 | 0.3931 |
| $\sigma_{\epsilon_{AS}}$ | $\mathcal{IG}(0.8, 1.0)$ | 0.8157 | 1.0815 | 1.0531 | 0.6525 | 1.4227 | 1.3454 |
| $\sigma_{\epsilon_{MP}}$ | $\mathcal{IG}(0.4, 1.0)$ | 0.4924 | 0.6677 | 0.4494 | 0.4433 | 0.8465 | 0.4605 |
| $\sigma_{\epsilon_{q1}}$ | $\mathcal{IG}(1.5, 2.0)$ | 1.0555 | 1.4988 | – | – | – | – |
| $\sigma_{\epsilon_{q2}}$ | $\mathcal{IG}(1.5, 2.0)$ | 1.8417 | 1.6106 | – | – | – | – |

Table 2: Estimation Results for the Three-Country Model with Unrestricted Exchange Rate Expectations

| | | $E_t\left(q_{t+1}\right) - E_t\left(q_{t+1}^{UR}\right)$ | |
|---|---|---|---|
| state variable | prior | $q$ =usd/eur | $q$ =usd/jpy |
| $r_{t-1}^{US}$ | $\mathcal{N}(0.0, 0.2)$ | 0.0278 | 0.0041 |
| $r_{t-1}^{EA}$ | $\mathcal{N}(0.0, 0.2)$ | $-0.0033$ | 0.0128 |
| $r_{t-1}^{JP}$ | $\mathcal{N}(0.0, 0.2)$ | 0.0242 | $-0.0923$ |
| $\pi_{t-1}^{US}$ | $\mathcal{N}(0.0, 0.2)$ | 0.0084 | $-0.0296$ |
| $\pi_{t-1}^{EA}$ | $\mathcal{N}(0.0, 0.2)$ | 0.0099 | $-0.0098$ |
| $\pi_{t-1}^{JP}$ | $\mathcal{N}(0.0, 0.2)$ | 0.0001 | 0.0039 |
| $y_{t-1}^{US}$ | $\mathcal{N}(0.0, 0.2)$ | $-0.0029$ | $-0.0153$ |
| $y_{t-1}^{EA}$ | $\mathcal{N}(0.0, 0.2)$ | 0.0115 | $-0.0188$ |
| $y_{t-1}^{JP}$ | $\mathcal{N}(0.0, 0.2)$ | $-0.0095$ | 0.0289 |
| $(\text{usd/eur})_{t-1}$ | $\mathcal{N}(0.0, 0.2)$ | $-0.0191$ | $-0.0148$ |
| $(\text{usd/jpy})_{t-1}$ | $\mathcal{N}(0.0, 0.2)$ | 0.0059 | $-0.0393$ |
| $(\text{eur/jpy})_{t-1}$ | $\mathcal{N}(0.0, 0.2)$ | 0.0191 | $-0.0577$ |

Table 3: Estimated Deviations from Model Implied Restrictions on Exchange Rate Expectations

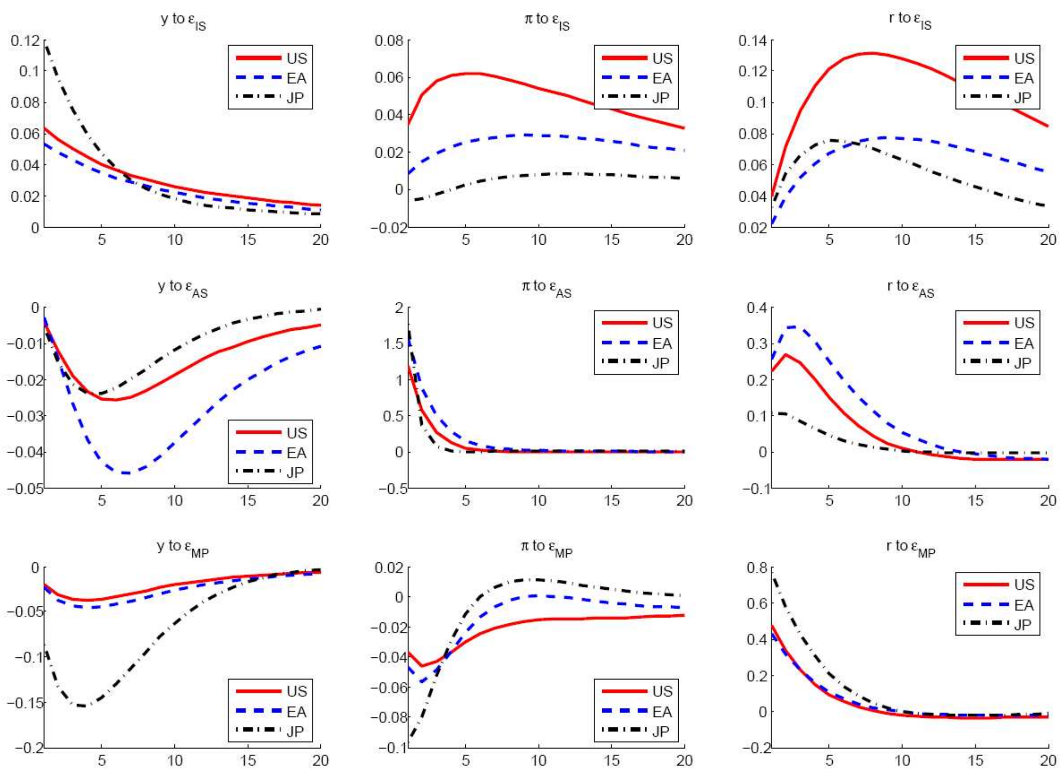


Figure 1: Impulse responses of domestic variables to domestic shocks for the US, euro area and Japan.

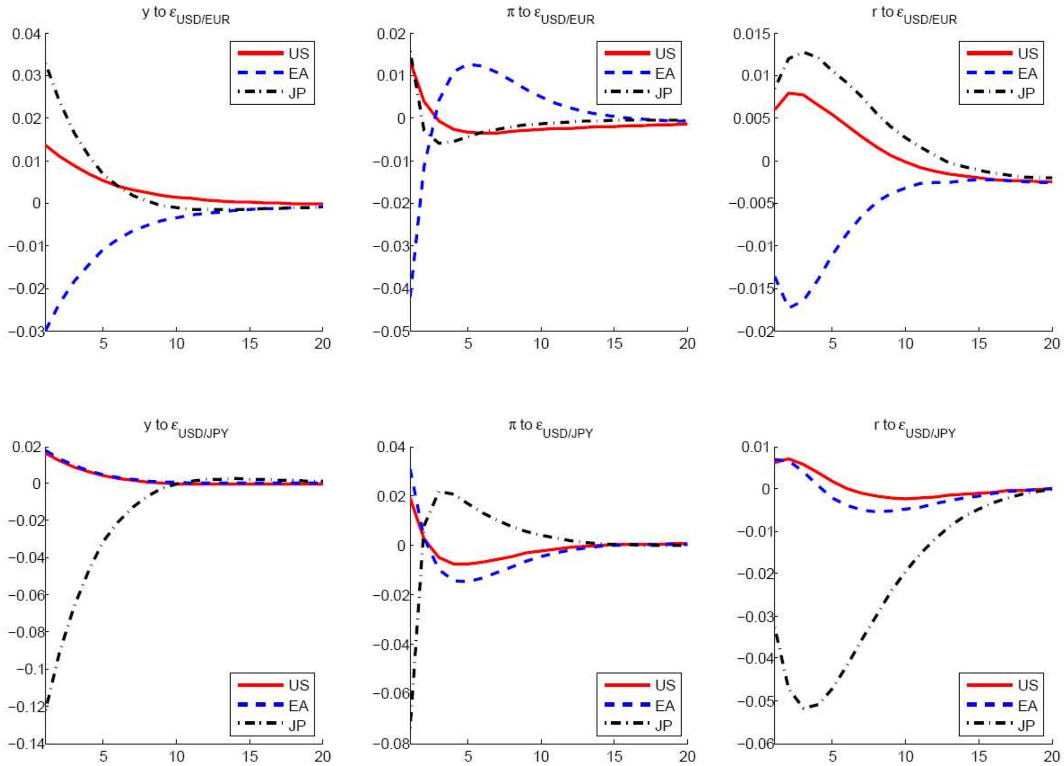


Figure 2: Impulse responses of domestic variables to USD/EUR and USD/JPY exchange rate shocks for the US, euro area and Japan

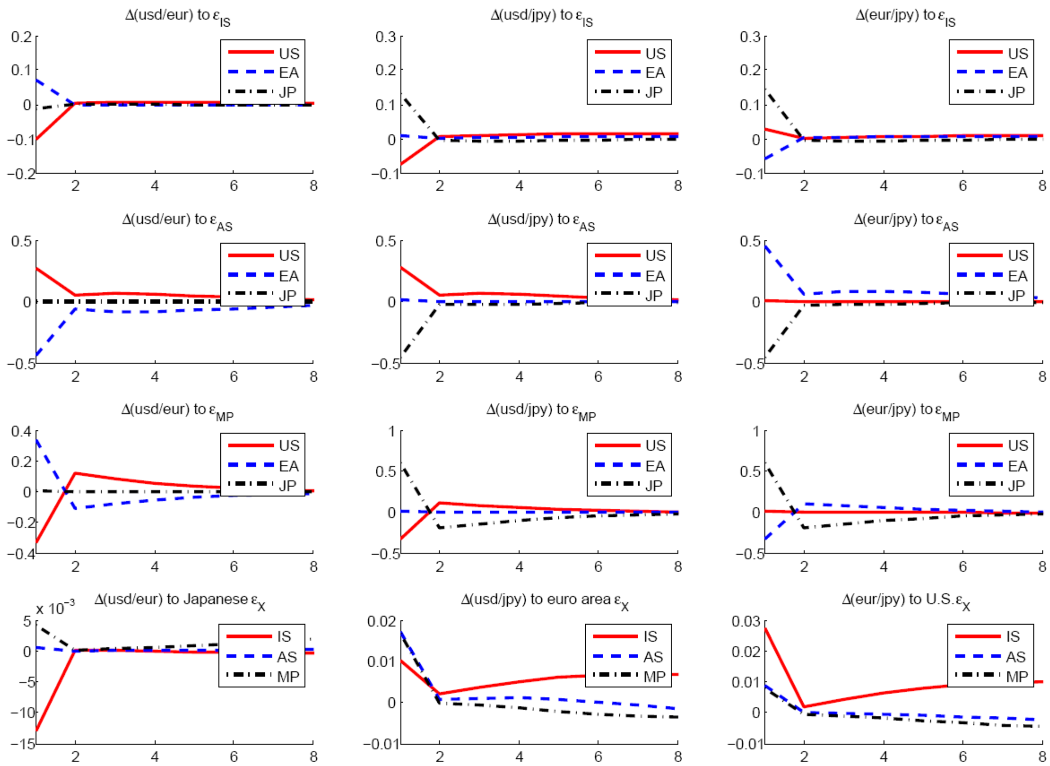


Figure 3: Impulse Responses of Bilateral Exchange Rates to Fundametal and Third-Currency Shocks

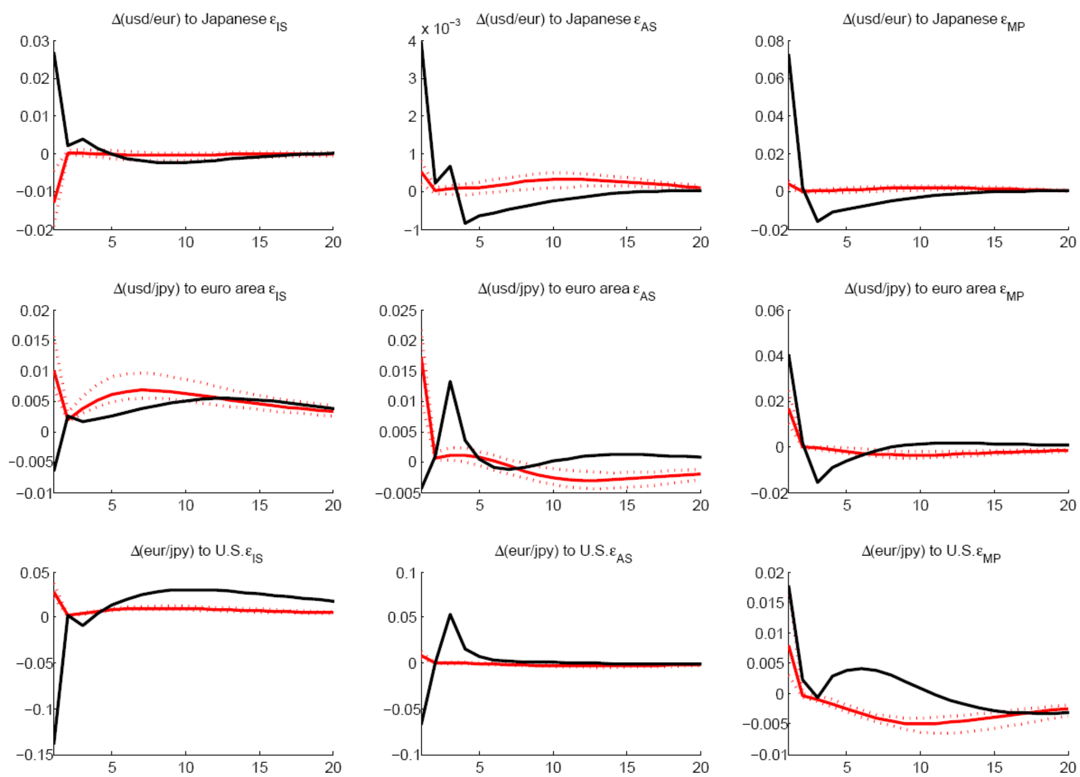


Figure 4: Comparison of exchange rate impulse responses to third-currency shocks from three-country models with restricted and unrestricted exchange rate expectations