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**Abstract**

An exchange rate between two currencies can be materially affected by shocks emerging from a third country. A US demand shock, for example, can affect the exchange rate between the euro and the yen. Since positive US demand shocks have a greater positive impact on Japanese interest rates than on eurozone 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; US dollar; euro; Japanese yen.

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

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# 1 Introduction

In the era of increasing globalization when both trade and capital flows among individual economies intensify, an exchange rate between two countries' currencies can be materially affected by shocks emerging from a third country. For example, a US demand shock can influence the exchange rate between the euro and the Japanese yen. This paper investigates the transmission of third-currency shocks to bilateral exchange rates, attempts to shed light on the factors behind the possibly increasing third-currency effects on bilateral exchange rates and derive resulting implications for exchange rate volatility and monetary regimes of bilateral exchange rate targeting.

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), Brandt *et al.* (2006), and Kingston and Melecky (2007). Although some of the studies provide a theoretical justification for the existence of third-currency effects on bilateral exchange rates, as in Hodrick and Vassalou (2002), Brandt *et al.* (2006) and Kingston and Melecky (2007), in their empirical analyses the authors do not examine the actual transmission of third-currency shocks (such as demand, supply and monetary policy shocks arising in a third country), and the factors determining the intensity and direction of third-currency effects. This paper conducts such an examination, and contributes to the literature by setting the discussion on 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). Using UIP for exchange rate determination does not allow the third-currency effects to appear in the exchange rate equations explicitly, and therefore tackles a possible criticism of opponents of third-currency effects on bilateral exchange rates who could 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 those are typically set in response to output and inflation, both of which are affected by other exchange rates. Possibly to a much larger extent, the transmission of third-currency shocks works also through the expected exchange rate, which is part of the UIP condition and in the three-country model influenced by changes in third-currency fundamentals and third-currency shocks. The acquired result suggest that third-currency shocks have a higher impact on a currency of the relatively more open economy. For instance, a positive US demand shock is found to have a larger positive effect on the Japanese economy than the euro area. The interest rate in Japan thus increases more than the interest rate in the euro area due to relatively higher monetary policy tightening in Japan, and the yen appreciates against the euro in response. More specifically, the monetary policy shocks are found to have significantly positive effects on currencies of more open economies, so that e.g. the euro appreciates against the dollar 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 could vary according to the weight financial markets put on trade and financial openness when forming their expectations about the future exchange rate. 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 performs an impulse response analysis and discusses the transmission mechanism of the three-country model. Section six includes sensitivity analysis in regards to the restrictions on formation of exchange rate expectations. 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 the 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:

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

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 shock.[1] Since I am interested in building a three-country model, two exchange rates appear in the vector $\boldsymbol{q}_t$. The term hybrid relates to the fact that the Phillips curve is backward, as well as, forward looking in inflation. Allowing for an inertial effect by giving a non-zero weight to $\pi_{t-1}$ in Equation (1) was initially empirically motivated, but can also be derived from a staggered price setting mechanism, where a proportion of firms use a naïve, backward looking rule to forecast inflation. It 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 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 the CPI inflation on wage-setting. In either case, it 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 into the domestic economy.[2]

[1] 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.

[2] 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 IS equation:

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

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, the trade-off between consumption today and tomorrow is changed, making consumption today in terms of consumption tomorrow more costly, and 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 induced 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[3] and reasonably robust to different model structures (see Svensson, 2000). Also, in some circumstances the Taylor rule can describe optimizing behavior (see Benigno and Benigno, 2003). A forward-looking version of the Taylor rule is employed to emphasize a Central

[3] 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 MP 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 MP reaction function of the central bank, however, no statistical evidence was found to suggest that the MP authority reacted to exchange rate fluctuations. I thus decided to exclude foreign variables from the MP reaction function.

Bank's focus on future inflation when adjusting its MP 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.[4] The specification in (3) implies that the monetary authority responds to one period ahead expected inflation 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 a common assumption in the literature of 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 being 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 to compute the log-likelihood 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 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 towards 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) and the domestic variables, shocks and parameters of each block distinguished by superscripts. Namely, the first block variables, shocks and parameters have no superscript while the same quantities

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

The three blocks are similar in structure but their parametrization will vary as the parameters will be estimated from the data. I will use the data for the three major economies of the US, the euro area and Japan 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 will focus are therefore those between the US dollar, the euro, and the Japanese yen. Also, note that the expected signs of the elements of $\boldsymbol{\lambda}_q$ and $\boldsymbol{\delta}_q$ will 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 US while they bear negative signs in the IS and AS equations for the euro area, so that depreciation of a domestic currency increases domestic output and CPI inflation.

# 3 Data and Estimation Method

## 3.1 Data

The employed data are those for the US, the euro area and Japan, and cover the period from the first quarter of 1981 till the last quarter of 2006. I chose the starting date similar to Hodrick and Vassalou (2002) and MacDonald and Marsh (1999) who work with related model structures and start their estimations in early 80's.

Inflation series for the US, the euro area (EA) and Japan are constructed as annualized percentage changes in the national CPI indexes. All CPI series were taken from DataStream. The output gap was constructed as the deviation of the log of real GDP from its trend estimated using the HP filter. The deviations were 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 series of real GDPs 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 are taken from the IMF's International Financial Statistic where I used the money market rates for all three countries. The interest rate series for the euro area was extrapolated from the first quarter of 1994 back to the first quarter of 1981 using the growth rates of the short-term interest rate from the Fagan *et al.* (2001) dataset. The money market rates are used instead of the policy interest rates to maximize the data availability and consistency. 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) and demean and detrend all data so that the three economies' behavior is modeled away from a deterministic steady-state growth path. Giordani (2004) has recently pointed out that working with demeaned/detrended data significantly contributes to elimination of parameter instability and structural breaks which, he finds, largely affect the unconditional mean of the modeled variables.

## 3.2 Estimation Method

There are three estimation methods commonly used to fit New Keynesian models to empirical data in the literature. These are the Generalized Method of Moments (GMM), the full information Maximum Likelihood (ML) and Bayesian estimation. 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. However, there are drawbacks also to using ML. 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 natural 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 NKPM with nominal rigidities consists of the following steps. Firstly, 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 QZ solution algorithm of Sims (2002). The solved model has a VAR(1) 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 US, euro area and Japanese economy. The priors for the US were centered around the estimates from Cho and Moreno (2005) and Buncic and Melecky (*forthcoming*) who estimated a similar model for the US. 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 US. 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 US, to reflect the presumably higher degree of openness of the two economies. The priors are generally mild but restrict the probability mass of the priors to cover largely 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.[5] The values of the parameters at the posterior mode, together with the corresponding Hessian matrix are then used to start the random 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). Namely, the Bayesian coefficient estimates are the posterior means and the inference is based on 95% Bayesian[6] 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 from about 40% forward looking. 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 US and only marginally lower in the euro area, of 0.0034 and 0.0028, respectively. The estimate for Japan is substantially, about 7 to 8 times, smaller of 0.0004. The latter could be attributed to Japan's problems with using the traditional monetary transmission mechanism when trying to get the economy out of the conditions of deflation and low growth, the "liquidity trap".[7]

[5] Note that, as with ML estimation, it is the log of the posterior density that is maximized.

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

[7] 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.

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 and I will discuss those next. In the first row the coefficient $\delta_{q1}$ represents the elasticity of the output gap in the US, EA and Japan to changes in USD/EUR, EUR/USD and JPY/USD exchange rates, respectively.[8] One would therefore expect that the more open the economy the more positive the coefficient is going to be. This is in general reflected in the estimates as the elasticity of US output to the USD/EUR rate is the lowest of 0.0091, whereas those of EA output and Japanese output significantly higher, of 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 US, EA 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 suggest larger 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 US output gap, 0.0076 for the EA output gap, and 0.0207 for the Japanese output gap, suggesting again that Japan is the most open economy followed by the EA.

Turning now to the estimates of the Phillips curve, the forward looking behavior as characterize by $\rho_\pi$ is estimated to be significantly stronger than in the case of output gap formation. Further, the estimates for the US and EA are fairly close of 0.6624 and 0.6368, whereas the estimate of $\rho_\pi$ for Japan is much higher of 0.8182. The impact of building demand pressure and capacity utilization on prices as captured by $\lambda_y$ is the highest in the US of 0.0375, closely followed by Japan of 0.0346, and somewhat lower in the euro area for which the estimate is 0.0282. This suggest 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 the strongest in Japan and the weakest in the US, thus fairly reflecting the differences in the degrees of openness across the three economies. More specifically, the pass-through of the USD/EUR, EUR/USD and

[8] 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.

JPY/USD rate to US, EA 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, EA 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 exchange rates on CPI inflation in each country is very similar with minor exception of Japan, where again the USD/JPY exchange rate appears to be more influential than the EUR/JPY exchange rate. 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 US, EA and Japan suggest that the respective central banks smooth the paths of their interest rates, where the highest estimate of $\rho_r$ of 0.8259 is obtained for Japan. It appears that the Bank of Japan is also the most conservative in its reaction to inflation as it puts somewhat higher weight on inflation in its reaction function, of $\psi_\pi = 1.7799$, than the Fed or the ECB, of 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, in which cases the weights estimates are 1.6062 and 1.7304. One can also observe that only the ECB seems to be putting 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.[9] 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.

[9] This finding could be justified by a large use of discretionary monetary policy over the estimated period within the context of the specification of MP 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.

The relative sizes of the structural shocks however, do not tell us much about their impact on the economy, which is commonly investigated by means of impulse response functions.

# 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 is inspected first. This is to make sure that the transmission mechanism is clearly identified and consistent with the theoretical foundations of the model. Since the reduced-form coefficients are non-linear functions of the structural coefficients the obtained impulse responses are not guaranteed to be well-behaved and without "puzzles" for all values of structural coefficients. Hence, the impulse response analysis of domestic variables to domestic shocks and exchange rate shocks is carried out first to inspect the basic transmission mechanism of the model, and before proceeding to the discussion of the impulse responses of interest. 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, i.e. the output gap, inflation and the interest rate to the domestic shocks. Namely, the first row of the panels shows responses of the domestic output gap, inflation and interest rate to the domestic IS shock for each economy, i.e. of the US output gap, inflation and the interest rate to the US demand (IS) shock, and analogously for the EA and Japan. The second row shows the responses to AS shocks and the third row the responses to MP shocks for each economy in a similar manner. The impulse responses are not accompanied by confidence intervals for the sake of good readability, but I will comment on their significance in the text.

Consider the first row of Figure (1). 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 of the output gap to the IS shock is estimated for

Japan and reflects its largest estimated standard deviation, where US and the euro area follow. The correction of the deviation from the steady state is the fastest for Japan due to the strongest response of MP to the output gap and expected inflation. Inflation increases in response to an IS shock significantly only in the case of the US and EA while for Japan the response is insignificant 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 strong reaction of inflation to appreciation of JPY exchange rates due to the increasing Japanese interest rate. Both the US and EA responses of inflation to an IS shock are long-lasting, however, the US response peaks much sooner than the EA response. Also, the responses of interest rates to IS shocks in each economy are 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 its interest rate more than one-to-one. The most pronounced response is that in the US mainly due to the significantly weakest reaction of the US output gap to exchange rate appreciation.

The second row of panels presents the responses to AS (supply) shocks. The AS shock increases inflation significantly at impact where the largest impact is seen in Japan due to the largest estimated standard deviation of the AS shock. The output gap responses to an AS shock are mildly negative in all three economies with the most negative response taking place in the euro area. As positive AS shocks raise inflation and inflation expectations the central bank strongly increases its interest rate so that the real interest rate goes up and the output gap declines as a result of the intertemporal substitution and rising user cost of capital, and intratemporal price effect of appreciating real exchange rates. The combination of the size of the AS shock, the strength of the MP 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. All three central banks increase significantly their interest rates in response to a supply shock where the responses of the Fed and ECB appear to be much stronger than that of the Bank of Japan, which can be explained by heavier reliance of the ECB and the Fed on the interest rate (credit) channel rather than the exchange rate channel, as it is likely the case for the Bank of Japan.

The third row of panels plot the impulse responses to monetary policy shocks. Output gaps in all three economies decline in response to a positive MP shock where the response of the Japanese output gap is the strongest. This can be attributed to the relatively large standard deviation of the MP shock for Japan, and much stronger impact of the exchange rate appreciation, as a result of the increased interest rate, on the output gap in Japan relative to the US and the euro area. The responses of inflation to a positive MP shock are also negative and mild where only for Japan the maximum effect appears at impact and is about twice as big as the maximum impacts of the MP shock on inflation in the US and EA, which arrive with about a two-quarter lag. This is mainly due to the finding that the transmission of the interest rate effect on inflation works largely through the exchange rate channel in Japan, where as in the euro area and the US the exchange rate channel is more subdued and the direct interest rate (credit) channel is more effective. Given the faster response of inflation to the MP shock in Japan the exchange rate channel is delivering its maximum effect at impact whereas the interest rate channel takes longer to kick in. The responses of interest rates to corresponding MP shocks are significantly positive with the largest effect at their impacts and relatively short duration. The largest response is estimated for Japan consistently with the largest, estimated standard deviation of Japanese MP shocks.

## 5.2 Responses of Domestic Variables to Exchange Rate Shocks

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. 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 to the two exchange rate shocks in the three-country system for the US, EA and Japan. These shocks are namely those to the USD/EUR and USD/JPY exchange rates. Recall at this point that the EUR/JPY exchange rate is constructed as the cross-exchange rate of the USD/EUR and USD/JPY rates and has thus no shock attached to it.

The first row of plots in Figure (2) shows the impulse responses of output gaps, inflation and interest rates in the US, EA and Japan to a USD/EUR exchange rate shock. Starting with the first panel we can observe that relative depreciation of USD versus EUR increases the US output gap at impact and output returns slowly back to the equilibrium in about 20 quarters. Since depreciation of USD with respect to EUR, represents equally relative appreciation of EUR relative to USD the euro area output gap decreases at impact and returns back to the steady state within 15 quarters. *Ceteris paribus*, the Japanese yen depreciates with respect to USD and appreciates with respect to EUR. Due to the relatively high openness of the Japanese economy and a higher impact of USD/JPY exchange rate, compared to the JPY/EUR rate, on exports (see the estimation results in Table (1)) the Japanese output gap increases in response to the positive USD/EUR rate shock and returns to the steady state in 10 quarters. The response of inflation in the US and Japan to a positive USD/EUR rate shock is only marginally positive and very short-lived, lasting for about one quarter. The impact of the shock on CPI inflation is likely propagated through the effect of the output gap on inflation rather than the direct pass-through to prices. The impact of relative appreciation of EUR with respect to USD has a negative effect at impact, however, the effect becomes positive in about three quarters and lasts for another 12 quarters. One may expect that the positive effect is brought about by the reaction of the monetary policy to a decrease in inflation, where the MP easening results in an increasing output gap and inflation. This hypothesis is supported by the next plot in which the response of the EA interest rate to a positive shock to the USD/EUR rate is negative - the interest rate declines significantly at impact and further in the second quarter. The reaction of the US monetary policy to the same shock is much smaller and can be likely 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, of about 18 quarters, than the interest rate increase in the US.

The second row of panels starts with the plot of output gap impulse responses to an USD/JPY exchange rate shock. Since relative depreciation of USD with respect to JPY induces, under unchanged conditions, also relative depreciation of EUR with respect to JPY, both the US and EA output gaps respond positively to the shock and return to the steady state in about 6 quarters. On the other hand, the response of the Japanese output gap is much sharper as a result of relatively higher openness of the Japanese economy, significantly negative, as JPY appreciates with respect to USD and EUR, and lasting for about 9 quarters. The reaction of the US and EA inflation to a positive USD/JPY shocks is positive and could be attributed mainly to the increasing output gap in both countries at impact, while later on the response reflects the reaction of the monetary policy. The response of Japanese inflation to the USD/JPY rate shock is similar to that of EA inflation to the USD/EUR shock. Namely, it is significantly negative at impact, after about two quarters becomes positive, as the interest rate decreases, and remains positive for about another 10 quarters. As indicated, the interest rate response to a positive USD/JPY rate shock is mildly positive in the US and EA and significantly negative in Japan. The Japanese interest rate response peaks after three quarters and returns back to the steady state in 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 focuses on the main subject of interest, namely, investigation of third-currency shocks to bilateral exchange rates within the theoretical structure of the three-country model with estimated coefficients. It further compares the impact of third-currency shocks to the impact of the fundamental shocks on the exchange rates. Therefore, I compare 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 from the US, EA 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, in which case the last panel summarizes the effects of third-currency shocks from the euro area. And finally, the third column does the same for the EUR/JPY exchange rate where the third-currency shocks plotted in the last panel come from the US.

### 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 US induces appreciation of the USD/EUR exchange rate. The positive IS shock results in a positive output gap and increased inflation expectations so that the Fed raises the interest rate. Under the UIP restriction this results in an appreciation of the current exchange rate. A mirror-image scenario takes place on the EUR side where the euro appreciates against the dollar as a result of a positive IS shock in the euro area. The USD appreciation in response to a positive IS shock in the US seems to be somewhat stronger than the analogous response to an IS shock in the EA. The response of the USD/EUR rate to a third-currency IS shock, i.e. the Japanese IS shock in this case, is about ten times smaller than the responses to the IS shocks in the US or EA. However, as shown in Figure (4) the third-currency effect is significantly negative, i.e. resulting in USD appreciation relative to EUR. It thus appears that depreciation of both USD and EUR with respect to JPY as a result of a positive IS shock in Japan (see panels (1,2) and (1,3)[10] of Figure (3)) has a stronger positive effect on the US economy, i.e. the output gap and inflation, so that the USD interest rate increases relatively more than the EUR interest rate and USD appreciates against EUR.

On the other hand, the responses of the USD/EUR rate to AS shocks in the US and EA are entirely opposite to what we observed in the case of the corresponding IS shocks. Namely, since inflation expectations increase as a result of an AS shock the relevant currency depreciates relative to its counterpart in accord with the relative PPP incorporated within the real UIP condition. Hence, USD depreciates against EUR as a result of a positive AS shock in the US, and similarly EUR depreciates against 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 magnitudes of the USD/EUR responses to AS shocks in the US and the EA. The statistical significance of this shock could be explained by recognizing that as a result of a Japanese AS shock JPY depreciates against USD and EUR, and that the

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

cumulative easening of the US monetary policy in response to USD appreciation against JPY is larger than the cumulative easening of MP in the EA in response to EUR appreciation against JPY (see panel (2,3) of Figure (2)).

The second last panel of the first column shows the responses of the USD/EUR rate to MP shocks. As postulated by the UIP condition a positive MP shock, which results in an interest rate increase, will induce appreciation of the corresponding currency. Therefore, USD appreciates against EUR in response to a positive MP shock in the US, and similarly, EUR appreciates relative to USD in response to a positive MP shock in the EA. 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 yen against both the dollar and the euro, the increase in the USD/EUR rate as a result of a Japanese MP shock could be justified by a larger positive impact of the euro depreciation on the EA economy than the dollar depreciation on the US economy.

As could be seen in the last panel of column one, the strongest third-currency shock to 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 the 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 USD appreciates relative to JPY in response to a positive IS shock in the US. And similarly, JPY appreciates against USD in response to a positive Japanese IS shock. As the central bank increases its interest rate in response to a positive output gap the UIP condition then implies contemporaneous appreciation of the currency with the positive interest rate differential. The response of the USD/JPY exchange rate to a third-currency IS shock, which originated in the euro area, is estimated to be significantly positive. The depreciation of both the dollar and the yen with respect to the euro in response to a positive IS shock in the EA has a larger positive effect on the Japanese economy, due to its higher degree of openness, and thus results in appreciation of the yen against the dollar. Also, the Bank of Japan is estimated to react somewhat stronger to opening output gap and expected inflation than the Fed.

One can see in the second panel of column two that USD depreciates against JPY in response to a positive AS shock in the US, and analogously, JPY depreciates against 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 dollar depreciates against the yen. Since the euro depreciates against the dollar and the yen as a result of a positive euro area AS shock, the higher openness and thus relatively stronger MP policy easening in Japan would imply contemporaneous depreciation of JPY against USD. Nevertheless, I find the opposite, i.e. that USD depreciates contemporaneously against JPY. If the impact of exchange rate expectations is much higher than the impact of the positive interest rate differential the USD/JPY exchange rate can start increasing in the current period if the expected USD/JPY exchange rate increased significantly as a result of the third-currency (euro area) AS shock. 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 implies that both USD and JPY appreciate contemporaneously relative to their counterparts as a result of a positive US monetary policy and Japanese MP shock, respectively. The third-currency (euro area) shock to the USD/JPY exchange rate induces depreciation of USD against JPY as the positive effect of JPY depreciation against EUR on the Japanese economy is higher than the positive effect of USD depreciation on the US economy, due to the higher degree of openness of the Japanese economy.

The last panel of column two shows that the monetary and AS shocks originating in the euro area 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 in the order of magnitude of 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 shows the plots of the impulse responses of the EUR/JPY exchange rate to IS, AS and MP shocks originating in the euro area, Japan and the US. The shocks originating in the US are then the third-currency shocks. The euro appreciates at impact relative to the yen in response to an IS shock occurring in the euro area. Analogously, JPY appreciates relative to 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 appreciation of the domestic currency as postulated by UIP. The response of the EUR/JPY rate to an IS shock originating in the US is positive so that JPY appreciates at impact relative to EUR. This could be due to a larger positive impact of the USD/JPY rate increase on Japanese exports, relative to the positive impact of the USD/EUR rate increase on the euro area exports, and thus the 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 euro depreciates at impact in response to a positive AS shock in the EA in line with the underlying relative PPP hypothesis. Similarly, the yen depreciates in response to a positive AS shock in Japan. The EUR/JPY rate response to a positive AS shock originating in the US is mildly positive. This response can be explained by an expected depreciation of the euro relative to the yen in response to an AS shock in the US. The second-round effect through 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. The latter is based on a larger degree of openness of the Japanese economy.

Finally, 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 US. According to those, the euro appreciates relative to the yen at impact as a result of an euro area MP shock, after two quarters the response shows a small euro depreciation relative to the yen before it fades out. The yen appreciates in response to a Japanese MP shock relative to the euro, after two quarters the response implies depreciation of the yen and then returns to the steady state. The third-currency shock, in this instance the US monetary policy shock, has a mild positive impact on the

EUR/JPY rate. This means that the Japanese interest rate and JPY's currency value increase more than the euro area interest rate and currency value in response to USD depreciation relative to EUR and JPY. Again, the higher openness of Japan is behind this result.

The last plot summarizes the responses of the EUR/JPY exchange rate to the third-currency shocks coming from the US. One can observe in the plot that the exchange rate response to an IS shock from the US is the strongest, and that those to AS and MP shocks from the US are very similar in magnitude and shape. Overall, only the response to the US 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 not only realized 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. This may require that the trade and financial openness play more substantial role in the model and particularly in exchange rate determination. Therefore, I will focus on relaxing the restrictions on state variables and shocks in the reduced-form equations for the expected future exchange rates, and thus account for the possibly more substantial role of trade and financial openness in formation of exchange rate expectations.

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 will 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) while relaxing the 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 are in general not statistically different.[11] What is more interesting is to look at the difference between the coefficients attached to the state variables in the equations describing the formation of exchange rate expectations. Such comparison is presented in Table (3). As one can see 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. These impulse responses are plotted in Figure (4).

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 an 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 an US demand shock goes in the opposite direction to that of the EUR/JPY response in the baseline model, and in addition the response is about four times stronger. This can be to some degree explained by looking at the effect of third-currency IS shocks on exchange rates in the reduced-form solution of the estimated model. The coefficient on the third-currency IS shock in the reduced-form equations for USD/EUR, USD/JPY and

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

EUR/JPY changes its sign once the exchange rate expectations are unrestricted. The coefficient signs also 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 rather empirical than theoretical. Intuitively, the changed formation of exchange rate expectations resulted 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 for 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 it returns to the steady state. The response of the USD/JPY rate to an euro area AS shock is significantly different from the analogous response in the baseline model. At impact it is negative and after about two quarters becomes positive and then returns to its steady state. The same can be said about the EUR/JPY response to an US 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 directions of impulse responses of exchange rates to third-currency AS shocks at impact can be read off again from the reduced-form exchange rate equation where the reduced-form coefficients on third-currency AS shocks change in the case of the USD/JPY and EUR/JPY rates. 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 similarly 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 an 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 an US monetary policy shock is positive at impact consistently with the baseline case but about two to three times larger. The response remains positive with a hump before it returns to the steady state. The reduced-form coefficients attached to the third-currency MP shocks thus did not change. Hence, the changed formation of exchange rate expectations magnified the exchange rate impulse responses to third-currency monetary policy shock 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, 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, and to the 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 in regards to their type, 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 directions of impacts of third-currency supply and demand shocks vary, on the other hand, depending on the weight financial market agents attach to the state variables and shocks when forming their expectation about future exchange rates.

# 7 Conclusion

This paper investigated the impact of third-currency shocks on bilateral exchange rates in terms of the 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 is given by uncovered interest parity so that third-currency effects do not appear in the exchange rate equations explicitly. The transmission of the third-currency shocks was found to work through the interest rate that is typically set in response to output and inflation which, in turn, are affected by other exchange rates. More importantly, the 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 the third-currency effects, the 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 conducted analysis suggests that the importance of third-currency effects rises with growing trade and financial openness which inherently increases exchange rate fluctuations. Therefore, from the point of view of sustainability and cost effectiveness, small open economies should restrain themselves from adopting monetary policy regimes of 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 opening output gap and expected inflation relative to its counterparts in other countries. It is predicted that for a given degree of trade and financial openness 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, to explain more explicitly the directions of third-currency effects and 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] Brandt, M.W., Chochrane, J.H., Santa-Clara, P. (2006). International Risk Sharing is Better Than You Think, or Exchange Rates are Too Smooth. *Journal of Monetary Economics* 4, vol. 53, 671-698.

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

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

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

[7] 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.

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

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

[10] 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.

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

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

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

[14] 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.

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

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

[17] 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.

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

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

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

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

[22] 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.

[23] 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.

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

[25] 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.

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

[27] 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.

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

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

[30] 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.

[31] 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

| | | $E_t(q_{t+1}) - E_t(q_{t+1}^{UR})$ | |
|---|---|---|---|
| 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

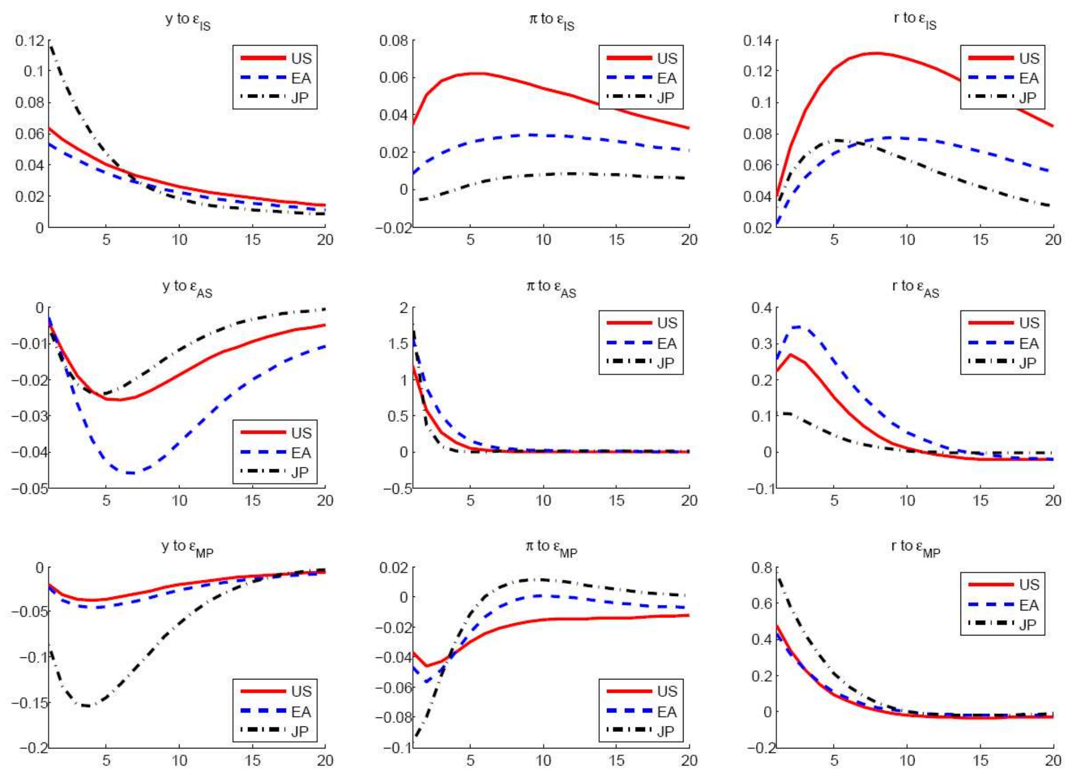


Figure 1: Impulse responses of domestic variables to domestic shocks for the US, euro area and Japan.

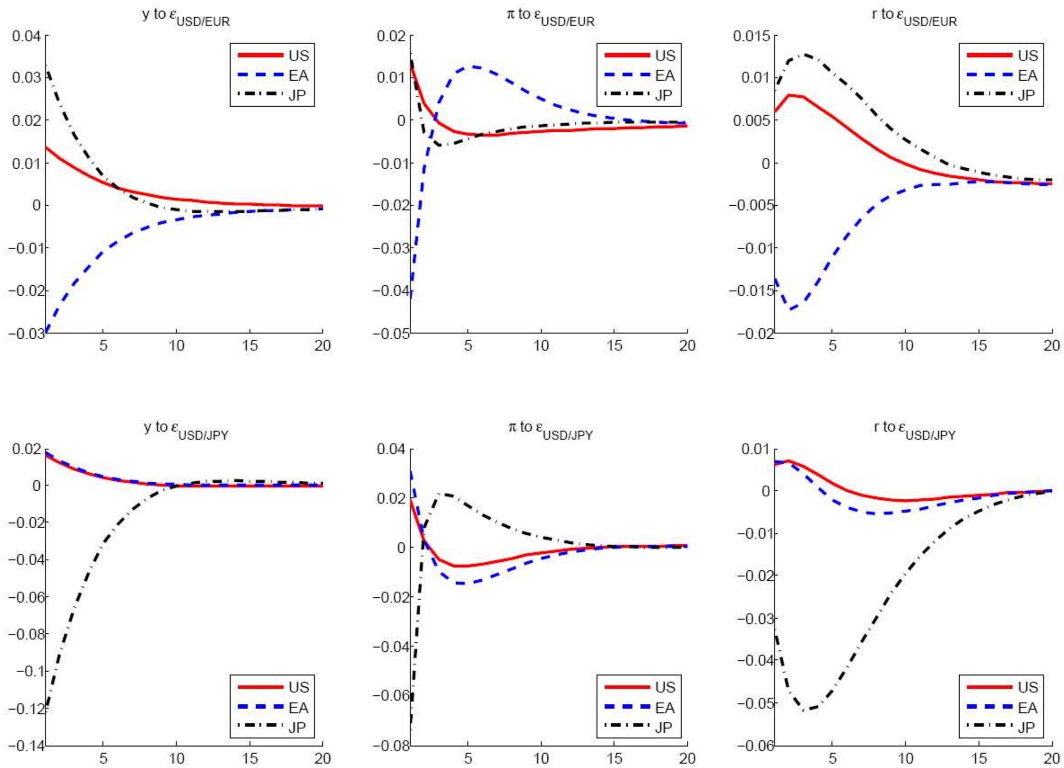


Figure 2: Impulse responses of domestic variables to USD/EUR and USD/JPY exchange rate shocks for the US, euro area and Japan

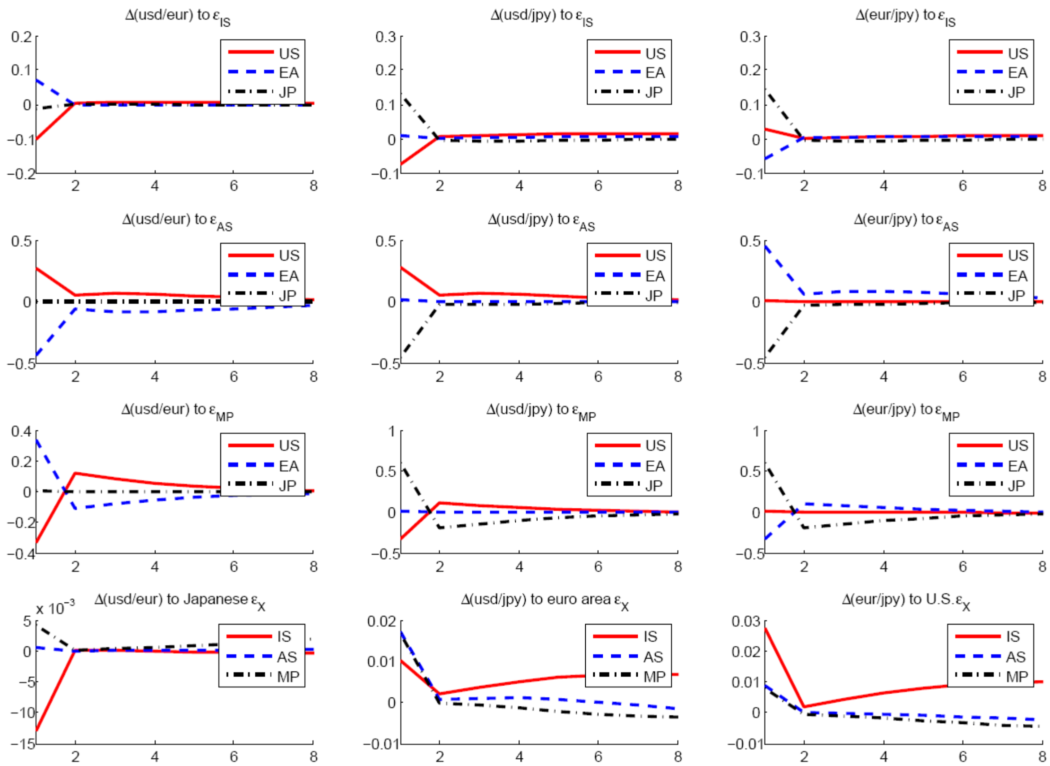


Figure 3: Impulse Responses of Bilateral Exchange Rates to Fundametal and Third-Currency Shocks

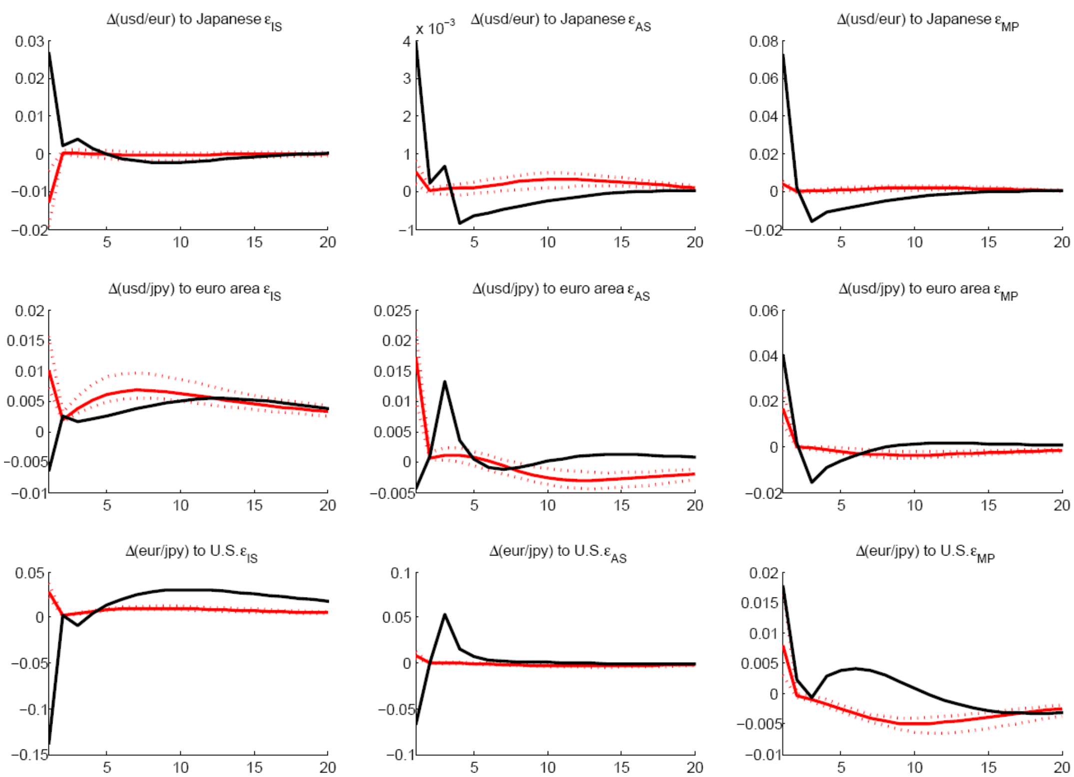


Figure 4: Comparison of exchange rate impulse responses to third-currency shocks from three-country models with restricted and unrestricted exchange rate expectations