"Official central bank interventions in the foreign exchange markets: a DCC approach with exogenous variables"

NUMBER OF REFERENCES

0

NUMBER OF FIGURES

0

NUMBER OF TABLES

0

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Abstract

This paper assesses the impact of official central bank interventions (CBIs) on exchange rate returns, their volatility and bilateral correlations. By exploiting the publication of intervention data by the Bank of England, this study is able to investigate official interventions by a total number of four central banks, while the previous studies have been limited to three banks, namely the Federal Reserve, Bundesbank and Bank of Japan. The results of the existing literature are reappraised and refined. In particular, unilateral CBIs are found to be more successful than coordinated ones. The likely implications of these findings are then discussed.

Introduction

It is now more than two decades since the Plaza Agreement signed on September 22, 1985 and the Louvre Accord on February 22, 1987[1]. These agreements were signed in order to induce a depreciation of the US dollar and promote stability in currency markets, respectively. Economists, policy makers and central bank analysts still lack conclusive evidence on the impact of CBIs on exchange returns and especially on volatility. The majority of the empirical literature suggests that unilateral, and even coordinated intervention of two central banks, does not affect exchange returns and has, in most of the cases, the opposite outcome on volatility from that expected (among others, see Tuna, 2011; Pasquariello, 2010; Fatum, 2009, 2008; Beine et al., 2007; Mark and Moh, 2007; Brandner et al., 2006; Edison et al., 2006; Dominguez, 2006; Frenkel et al., 2005; Beine, 2004; Brissimis and Chionis, 2004; Beine et al., 2003, 2002; Fatum, 2002; Humpage, 1999; Baillie and Osterberg, 1997; Bonser-Neal and Tanner, 1996; Catte et al., 1992)[2]. That is, interventions associated with the Louvre Accord have generally led to an increase in volatility as opposed to the intended decrease.

The purpose of this paper is to shed some light on the impact of official Central Bank Interventions (CBIs) on exchange rate returns, volatility and correlations of the DM (Euro after the 1999) and the JPY against the US dollar. This paper adds to the literature of CBIs in various respects. First, instead of relying only on G3 official CBIs, namely, interventions by the Bank of Japan (BoJ), the Bundesbank (or the ECB, after 1999) and the Federal Reserve, this study also includes interventions by the Bank of England (BoE). Thereby, the impact of the G4 official CBIs is examined. Such investigation will provide additional insights on the argument that coordinated interventions are more powerful than unilateral ones (see, for instance Gnabo and Teiletche, 2009; Reitz and Taylor, 2008; Morel and Teiletche, 2008; Carracedo and Manzano, 2008; Dominguez, 2006; Fatum and Hutchison, 2006; Beine and Szafarz, 2006; Nagayasu, 2004; Beine, 2004; Fatum, 2002; Sarno and Taylor, 2001; Humpage, 1999; Tseng, 1998; Baillie and Osterberg, 1997; Catte et al., 1992; Dominguez, 1990).

Second, the literature has so far not investigated in a comprehensive way the number of central banks engaged in coordinated intervention. One of the main questions this paper tries to answer is whether the impact on exchange rate dynamics is more significant when two central banks intervene in coordination as opposed to three central banks. The approach adopted in this paper explicitly allows the investigation of the impact of officially announced coordinated interventions of two and three central banks, since the Bank of England (BoE) also intervened in coordination with another two central banks, and which was part of the G6 Louvre Accord (1987). Accounting for the BoE's interventions will more accurately assess the impact of officially announced CBIs in the post-Louvre Accord period. Ideally, we would investigate the impact of officially announced CBIs of all the countries that were involved in the Louvre Accord. That is, including the Bank of Canada (BoC) and the Bank of France (BoF), in addition to the Bank of England. However, since this paper examines the impact of officially announced CBIs, and since neither the BoC nor the BoF officially announce their interventions, at least for our sample period, they cannot be taken into account in this research.

This paper focuses on the signalling channel through which CBIs might affect exchange rate dynamics and not the portfolio balance channel, as the empirical literature is not very supportive of the latter.

[1] The Plaza agreement was signed by the G5 countries, specifically France, West Germany, Japan, USA and UK, and the Louvre Accord by the G6 countries (Canada, France, West Germany, Japan, USA and UK). Italy was also an invited member in the Louvre Accord by declined to finalize the agreement.
[2] See Neely (2005) and Sarno and Taylor (2001) for a survey of the studies regarding the effect of foreign exchange interventions in developed countries. For a similar survey in emerging markets see Menkhoff (2012).

The key findings are that unilateral CBIs are found to be more successful in influencing exchange returns than coordinated CBIs, when interventions of the Bank of England are taken into account. Coordinated CBIs increase volatility as the number of central banks involved in the coordination process increases.

The remainder of this paper is organized as follows. Section 1 describes the methodology and data. Section 2 presents the empirical results and the final section concludes.

1. Methodology and data

The exchange rate data used in this study consist of daily observations of spot exchange rates of the Deutsche mark (Euro after 1999) and the Japanese yen, all against the US dollar, for the period of April 2, 1991 to October 19, 2001, obtained from the Bank of England online database[1].

Following previous work on spot exchange rates data, where the spot rates are generally non-stationary, we focus on daily exchange rate returns defined as: $r_t = \ln(y_t) - \ln(y_{t-1})$, where y_t is the spot exchange rate at time t, with $t = 1,2,..., T$, and ln is the natural logarithm. According to the results of the Augmented Dickey-Fuller (ADF) test-statistic (not reported but available upon request) the null hypothesis of a unit root in the first logarithmic differences of each exchange rates series is rejected.

The CBI data consist of official interventions of the Federal Reserve (FED), the Bank of Japan (BoJ), the Bundesbank (BB) (European Central Bank, ECB, after 1999) and the Bank of England (BoE)[2]. Specifically, the series involve central bank purchases/sales of the Japanese yen and the Deutsche mark (Euro after 1999) measured in US dollars.

In order to assess the signalling channel, through which CBIs could influence exchange rates and their volatility, we use dummy variables that take the value of 1 when a central bank intervenes and 0 otherwise. In addition, we examine the impact of both unilateral and coordinated interventions of central banks. In the case of unilateral interventions, we use up to four dummies for CBIs (capturing the impact of the G4 central banks included in our sample) in the JPY/USD and the DM(EUR)/USD markets. In the case of coordinated interventions, since each of the four banks intervened in both the DM(EUR)/USD and the JPY/USD (apart from the Bundesbank (ECB) which intervened only in the DM(EUR)/USD), it seems

appropriate to use only two dummy variables reflecting the coordinated interventions of two central banks and one dummy for coordinated intervention of three central banks. Table 1 provides the definitions of the dummy variables used.

Table 1. Dummy variables definitions

Variable	Definition
Dummy variables in the conditional mean equation	
dFED$_{DM(EUR)}$	Unilateral interventions of the FED in the DM(EUR)/USD market.
dBOJ$_{JPY}$	Unilateral interventions of the BoJ in the JPY/USD market
dBB$_{DM(EUR)}$	Unilateral interventions of the BB(ECB) in the DM(EUR)/USD market
dBoE$_{JPY}$	Unilateral interventions of the BoE in the JPY/USD market
dCoDM(EUR)	Coordinated interventions of 2 central banks in the DM(EUR)/USD market
dCoDM(EUR)3	Coordinated interventions of 3 central banks in the DM(EUR)/USD market
dCoJPY	Coordinated interventions of 2 central banks in the JPY/USD market
Dummy variables in the conditional variance equation	
δFED$_{DM(EUR)}$	Unilateral interventions of the FED in the DM(EUR)/USD market
δBOJ$_{JPY}$	Unilateral interventions of the BoJ in the JPY/USD market
δBB$_{DM(EUR)}$	Unilateral interventions of the BB(ECB) in the DM(EUR)/USD market
δBoE$_{JPY}$	Unilateral interventions of the BoE in the JPY/USD market
δCoDM(EUR)	Coordinated interventions of 2 central banks in the DM(EUR)/USD market
δCoDM(EUR)3	Coordinated interventions of 3 central banks in the DM(EUR)/USD market
δ CoJPY	Coordinated interventions of 2 central banks in the JPY/USD market

As previously discussed the literature typically finds the estimated parameter of coordinated interventions on exchange rate volatility to be significant, however, incorrectly signed (see Gnabo and Teiletche, 2009; Beine et al., 2009b; Beine, 2004; Fatum, 2002; Humpage, 1999; Catte et al., 1992, among others). Nevertheless, the empirical literature has examined so far the impact of coordinated interventions of a maximum of two central banks. In this research, we provide novel results for coordinated interventions conducted by three central banks.

1.1. The DCC approach. Let $yt = (y_{1t}, y_{2t})'$ be the 2x1 vector of DM(EUR) and JPY exchange returns against the USD. Following Engle (2002), we define the DCC model as

$$y_t = \mu_t(\theta) + \varepsilon_t, \text{ where } \varepsilon_t|\Omega_{t-1} \sim N(0, H_t), \quad (1)$$

$$\varepsilon_t = H_t^{1/2}u_t, \text{ where } u_t \sim N(0, I), \quad (2)$$

$$H_t = D_tR_tD_t, \quad (3)$$

where $\mu_t = E(y_t|Q_{t-1})$ is the conditional mean of yt given the information set Q_{t-1}, available at time $t - 1$, and u_t is the residual. We will model the mean, μ_t,

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either as an autoregressive or a moving average process depending on the serial correlation properties of the series. H_t is the conditional covariance matrix, $D_t = diag(h_{11t}^{1/2}, \ldots, h_{22t}^{1/2})'$ is a diagonal matrix of square root conditional variances, where h_{11t} and h_{22t} can be defined as any univariate GARCH-type model, and R_t is the $tx\left(\frac{2(2-1)}{2}\right)$ matrix containing the time-varying conditional correlations defined

$$R_t = diag(q_{11,t}^{-1/2}, q_{22,t}^{-1/2})Q_t diag(q_{11,t}^{-1/2}, q_{22,t}^{-1/2}), \quad (6)$$

where $Q_t = (q_{ij,t})$ is a 2x2 symmetric positive definite matrix given by:

$$Q_t = (1 - \alpha - \beta)\overline{Q} + \alpha u_{t-1}u_{t-1}' + \beta Q_{t-1}, \quad (7)$$

where $u_t = (u_{1t}, u_{2t})'$ is the 2x1 vector of standardized residuals, $\overline{Q}$ is the 2x2 unconditional variance matrix of u_t, and α and β are nonnegative scalar parameters satisfying $\alpha + \beta < 1$.

The DCC model is estimated using the Quasi-Maximum Likelihood (QML) estimator under a multivariate Student distribution (see Harvey et al., 1992; Fiorentini et al., 2003), as the normality of the residuals is rejected.

1.2. The effect of CBI. In order to assess the impact of CBIs on exchange returns, volatility and correlations the DCC model of Engle (2002) can be easily extended to incorporate exogenous variables as:

$$y_t = \mu_t + d_t X_t + \varepsilon_t, \text{ where } \varepsilon_t | \Omega_{t-1} \sim N(0, H_t), \quad (8)$$

$$\varepsilon_t = H_t^{1/2} u_t, \text{ where } u_t \sim N(0, I), \quad (9)$$

$$H_t = D_t R_t D_t, \quad (10)$$

where d_t is the nx1 vector of parameters entering the mean equation and X_t is a nx1 vector of exogenous variables that denote the set of central bank interventions at time t. The specification for the proposed model has a different evolution for Q_t that enters the R_t matrix containing the time-varying conditional correlations and the later enters the conditional variance/covariance matrix H_t according to:

$$Q_t = (1 - \alpha - \beta)\overline{Q} + \alpha u_{t-1}u_{t-1}' + \beta Q_{t-1} + \delta_t X_t, \quad (11)$$

where δ_t is the nx1 vector of parameters entering the conditional variance equation and X_t is a nx1 vector of exogenous variables that denote the set of central bank interventions at time t[1]. We focus on the impact of both unilateral and coordinated CBIs on exchange returns, variances and correlations.

2. Empirical results

2.1. Descriptive statistics. Table 2 presents descriptive statistics of the mark(euro), and the yen returns series for the period from April 2, 1991 to October 19, 2001. According to Table 2, the daily unconditional standard deviations of the JPY/USD return is greater than that for the DM(EUR) exchange return, indicating that volatility is greater in the JPY as opposed to the DM(EUR) returns. The excess kurtosis parameter estimate is significantly greater than zero for each returns series indicating non-normality of returns. In addition, the excess kurtosis coefficient in JPY returns is more than twofold than that in DM(EUR) returns, indicating that extreme episodes (such as currency crises) are more than twice likely to occur in the JPY than in the DM(EUR) market. In addition, the Jarque-Bera statistic confirms that exchange returns are, as expected, not normally distributed since the null hypothesis of normally distributed returns is persuasively rejected and the data are clearly skewed.

Table 2. Descriptive statistics of returns
(April, 2, 1991-October, 19, 2001)

	DM(EUR)	JPY
Mean	0.0001	-0.0001
Standard deviation	0.0068	0.0073
Skewness	-0.1294 [0.01]**	-0.7031 [0.00]**
Excess kurtosis	2.1193 [0.00]**	5.7496 [0.00]**
Normality test (JB)	507.11 [0.00]**	3897.6 [0.00]**
Q(10)	18.885 [0.04]*	20.746 [0.02]*
Q^2(10)	143.94 [0.00]**	288.63 [0.00]**
ARCH (5)	12.590 [0.00]**	27.489 [0.00]**

Note: [] denote p-values. Q(10) and Q^2(10) is the Ljung-Box statistic for serial correlation in raw series and squared series, respectively. JB refers to the Jarque-Bera test. * 5% significant; ** 1% significant.

The Ljung-Box Q statistic which tests the null hypothesis of no serial correlation in the return and the squared return series rejects the null hypothesis up to 10 lags. The presence of strong nonlinear dependencies in the squared return series is also supported by Engle's ARCH-LM statistic in the last row of Table 2 which reports evidence of ARCH effects in the return series up to 5 lags. The null hypothesis of no ARCH effects is rejected for each series at the 1% level of significance.

Figure 1, plots the exchange rates and returns series for the DM(EUR) and the JPY, all against the USD. One can clearly observe the introduction of the Euro at the beginning of 1999[2]. Focusing on the returns plots on the lower part of Figure 1, one can see the phenomenon of volatility clustering, that is, large (small) changes tend to be followed by large (small) changes of either sign.

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[1] More precisely, the dummy variables for CBIs equal to 1 when central bank(s) intervene in the purchase or sale of US dollars and to 0 when no intervention occurs. See Table 1 for a specific definition of the dummy variables used.

[2] The DM(EUR)/USD returns series on the bottom left panel in Figure 1 have been adjusted to account for the introduction of the Euro in 1999.
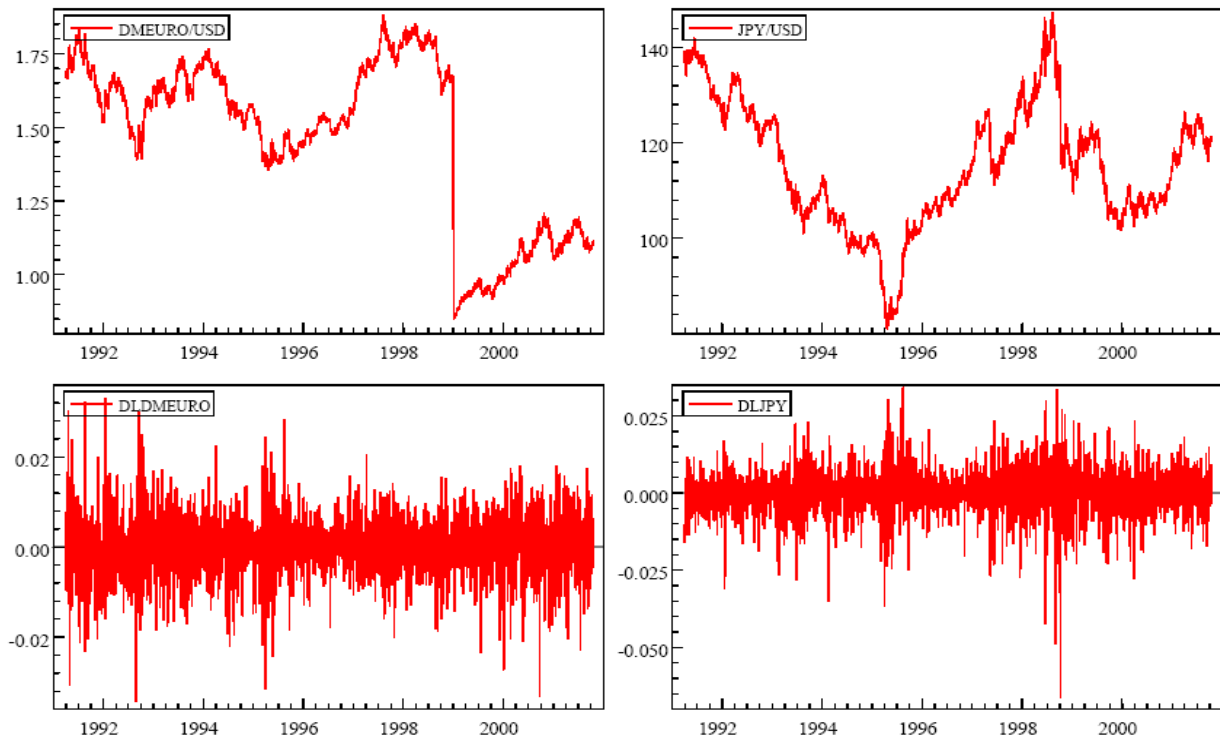
Fig. 1. DM(EUR)/USD and JPY/USD exchange rates and returns series (April, 2, 1991-October, 19, 2001)

The findings of higher order serial correlation, non-normality, non-linear dependency and volatility clustering support the decision to model exchange rate volatility using a GARCH-type process under the Student's *t*-distribution.

Columns 1 and 2 in Table 3 present the number of days that CBIs were carried out under the G4 assessment and under Beine's (2004) G3 assessment (which serve as the base for our comparisons), respectively. As previously indicated, and as can also be observed from Table 3, the number of interventions for the variables in common among this research and Beine's is different due to the intervention definitions in this research[1].

Table 3. Central bank interventions:
(April, 2, 1991-October, 19, 2001)

Beine (2004)		
	G4 assesment	G4 assessment
JPY/USD	Number of interventions	
Unilateral FED	0	1
Unilateral BoJ	176	180
Unilateral BoE	1	-
Coordinated interventions of 2 central banks	22	19
DM(EUR)/USD		
Unilateral FED	7	12
Unilateral BoJ	0	0
Unilateral BB/ECB	5	6
Unilateral BoE	8	-
Coordinated interventions of 2 central banks	10	12
Coordinated interventions of 3 central banks	6	-

Note: The last column is taken from Table 2 of Beine (2004).

Among the G4 central banks, the Bank of Japan (BoJ) was by far the most active, as it intervened 176 times unilaterally in the JPY/USD market. The FED has conducted its interventions unilaterally only in the DM(EUR)/USD market. In addition, the FED relied solely on coordinated interventions with the BoJ in the JPY/USD market, whereas in the DM(EUR)/USD market it intervened with the BoJ, the BB/ECB and/or the BoE since 1995. The Bundesbank (BB) (or the European Central Bank, ECB, since 1999) has deployed its interventions solely in the DM(EUR)/USD market. A very interesting feature of Table 3 is the nature of the Bank of England

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[1] By definition, in this research, the classification of CBIs differs. For instance, when the dummy variable that represents coordinated interventions conducted by 3 central banks in a currency and on a specific date is equal to 1, then instantaneously the dummy for coordinated interventions conducted by 2 central banks is equal to zero for that specific intervention and date. In addition, the dummy variables that represent the unilateral interventions for each of the 3 central banks are equal to zero on that date. For example, consider the sell of the DM/USD on August 19, 1991 by the BoJ, the BB and BoE. Under Beine's (2004) framework and the rest of the papers that examined CBIs under the G3 assessment (that is without the BoE assessment) the construction of the intervention dummy variables for that date implies that these dummies are equal to zero for unilateral interventions by the BoJ and the BB, and equal to 1 for coordinated interventions of 2 central banks. Under our proposed classification, the dummy variables for unilateral intervention by the BoJ, the BB, the BoE and coordinated interventions of 2 central banks are equal to zero. However, the dummy variable for coordinated intervention of 3 central banks equals to 1. That is why in this classification there are fewer interventions regarding unilateral and coordinated interventions by 2 central banks than those in Beine (2004).

(BoE) interventions. The BoE has intervened in coordination with at least one another central bank in both markets. Unilaterally it has intervened one time in the JPY/USD market and eight times in the DM(EUR)/USD market. Moreover, it has intervened six times in coordination with another two central banks in the DM(EUR)/USD as shown in the last row of column 1 in Table 3. The availability of official intervention data for the BoE motivates the examination of how the impact of CBIs on exchange returns, volatility and correlation changes when the BoE is also taken into account.

2.2. The DCC model performance. Table 4 presents the results of the DCC model performance described in equation (1)-(3).

Table 4. DCC model of DM (EUR) and JPY returns (April, 2, 1991-October, 19, 2001)

Dependent variables		Explanatory variables	
Conditional mean	DM(UER)	Constant	0.0002 (1.99)*
	JPY	Constant	0.0243 (2.41)*
Conditional variance	DM(EUR)	Constant	1.2e-07 (2.10)*
		αDM(EUR)	0.0351 (5.74)**
		βDM(EUR)	0.9596 (131.4)**
	JPY	Constant	0.0035 (2.70)**
		αJPY	0.0416 (6.73)**
		βJPY	0.9517 (135.5)**
		DCCα	0.0132 (261.1)**
		DCCβ	0.9847 (967.3)**
		υ	5.7691 (13.19)**
		Log. lik.	7454.59
Standardized residuals based tests			
		Q(20)	79.964 [0.45]
		Q²(20)	87.440 [0.20]

Note: t-statistics are in parenthesis. * and ** denote 5% and 1% significance, respectively.

The DCC model seems to perform very well in terms of capturing the DM(EUR)/USD and the JPY/USD exchange rate dynamics: (1) both exchange returns exhibit heteroskedasticity, based on the significant estimated coefficients of the individual GARCH models; (2) the conditional correlations of the DM(EUR)/USD and the JPY/USD returns are highly persistent as shown by the significant parameter estimates (α and β) of the DCC GARCH model; (3) Li and McLeod (1981) test (which is a multivariate version of the Box-Pierce/Ljung-Box portmanteau test statistic for serial correlation) cannot reject the null hypothesis of no serial correlation on both standardized and squared standardized residuals, up to 20 lags; (4) the DCC model indicates that the correlations between these two returns are indeed time-varying. This can also be clearly seen in Figure 2, which plots the dynamic conditional correlation of the estimated DCC model in Table 4. The correlations during April 2, 1991 to October 19, 2001 vary between -0.05 to 0.8. Beginning from 1991, correlations between those two markets gradually declined till 1994, then there was an increasing trend till the mid-1995 followed by a declining trend till the end of 2000 when they became negative. Since the beginning of 2001, correlations varied around -0.05 to 0.2.

Fig. 2. Conditional correlations of the DM(EUR)/USD and the JPY/USD returns

Having evaluated the performance of the basic DCC model for the DM(EUR)/USD and JPY/USD exchange returns dynamics, we now extend the DCC with exogenous variables to incorporate the impact of both unilateral and coordinated officially announced interventions.

2.3. The impact of coordinated interventions. The analysis begins with the impact of coordinated interventions on exchange returns, variances and correlations under the G4 assessment. These results are presented in Table 5. Columns (a) and (b), (c) and (d), and (e) present the results for coordinated interventions of 2 central banks in the DM(EUR)/USD and the JPY/USD markets, of 3 central banks in the DM(EUR)/USD market, and of 3 central banks in the DM(EUR)/USD market together with the coordinated interventions of 2 central banks in the JPY/USD market, respectively.

Table 5. Coordinated CBIs: signalling channel analysis of DM(EUR) & JPY (1991-2001)

Dependent var.		Explanatory var.	(a)	(b)	(c)	(d)	(e)
Condit. mean	DM(USD)	Constant	0.0002 (2.30)*	0.0002 (2.30)*	0.0002 (2.12)*	0.0002 (2.13)*	0.0002 (2.07)*
		dCoDM(EUR)	0.0015 (0.49)				
		dCoDM(EUR) 3			0.0059 (1.62)		
		dCoJPY	3E-05 (0.02)				
	JPY	Constant	0.0229 (2.33)*	0.0231 (2.24)*	0.0248 (2.51)*	0.0247 (2.36)*	0.0240
		dCoDM(EUR)	0.1858 (0.77)				
		dCoDM(EUR) 3			0.1194 (0.64)		
		dCoJPY	-0.0019 (-0.01)				
Condit. var.	DM(EUR)	Constant	3.4e-07 (2.26)*	3.4 e -07 (2.09)*	3.2e-07 (2.29)*	3.3e-07 (2.48)*	3.3e-07 (2.23)*
		δCoDM(EUR)	7.2e-06 (0.90)	7.4e-06 (0.88)			
		δCoDM(EUR) 3			2.1e-05 (1.57)	2e-05 (2.14)*	2.4e-05 (1.76)
		δCoJPY	-3.3e-07 (-0.09)	-2.1e-07 (-0.06)			2.3e-06 (0.63)
		αDM(EUR)	0.0352 (5.78)**	0.0348 (5.72)**	0.0326 (5.78)**	0.0330 (5.17)**	0.0332 (5.19)**
		βDM(EUR)	0.9589 (135)**	0.9592 (130)**	0.9612 (140)**	0.9605 (133)**	0.9600 (126)**
	JPY	Constant	0.0036 (2.34)*	0.0037 (2.49)*	0.0037 (2.34)*	0.0037 (2.49)*	0.0039 (2.25)*
		δCoDM(EUR)	-0.0690 (-3.05)**	-0.0736 (-1.73)			
		δCoDM(EUR) 3			0.0123 (0.28)	0.0181 (0.51)	0.0231 (0.58)
		δCoJPY	0.1082 (2.31)*	0.1123 (2.37)*			0.0950 (1.98)*
		αJPY	0.0394 (5.66)**	0.0396 (6.30)**	0.0420 (6.30)**	0.0420 (6.08)**	0.0407 (6.19)**
		βJPY	0.9522 (122)**	0.9519 (126)**	0.9506 (121)**	0.9506 (123)**	0.9497 (115)**
		DCCα	0.0190 (4.99)**	0.0192 (4.93)**	0.0182 (4.91)**	0.0183 (4.91)**	0.0192 (5.01)**
		DCCβ	0.9789 (229)**	0.9787 (227)**	0.9798 (233)**	0.9796 (232)**	0.9789 (225)**
		υ	5.8473 (14.06)**	5.8471 (13.29)**	5.8535 (12.85)**	5.8766 (13.29)**	5.9604 (13.36)**
		Log. lik.	7461.2	7460.6	7460.1	7458.9	7461.6
Standardized residuals based tests							
		Q(20)	78.62 [0.49]	78.73 [0.49]	77.76 [0.52]	76.26 [0.57]	75.75 [0.58]
		Q^2(20)	87.28 [0.20]	86.35 [0.22]	93.55 [0.10]	97.12 [0.06]	92.56 [0.11]

Note: Parentheses and brackets are the t-statistics and p-values, respectively. * and ** denote 5% and 1% significance, respectively.

When coordinated interventions are conducted by only 2 central banks in the DM(EUR)/USD and the JPY/USD markets, they have a significant impact only on the JPY volatility. However, no significant impact on exchange returns is evident. That is, coordinated interventions do not affect exchange returns, which in line with the empirical literature. These results are presented in columns (a) and (b) of Table 5. Under specification (a), the dummy variables for coordinated CBIs that enter in both the mean and variance equations, attract significant coefficients only in the latter equation. Specifically, coordinated interventions in the DM(EUR)/USD market significantly decrease the JPY volatility whereas, coordinated interventions in the JPY/USD market significantly increase the JPY volatility. In addition, coordinated CBIs in the DM(EUR)/USD and the JPY/USD markets do not have a significant impact on the DM(EUR) volatility. After dropping the dummy variables for the coordinated CBIs on returns, as they were found insignificant, the new specification under column (b) reports reduced impact of coordinated interventions on volatility. Now, coordinated CBIs in the DM(EUR)/USD markets do not significantly decrease the JPY volatility (the estimated parameter δCoDM is significantly negative only at the 10% level). The signs and significance of the rest of the parameter estimates remain similar to those under specification (a). That is, when exactly two central banks intervene in coordination can significantly affect the volatility of returns, and in some cases in the correct direction. Under (a) and (b) specifications, the Li and McLeod (1981) test reports no evidence of serial correlation on both standardized and squared standardized residuals, up to 20 lags. Thus, we find instances that coordinated interventions of two central banks under the G4 assessment in the DM(EUR)/USD market to significantly decrease JPY volatility.

In addition, the existing literature suggests that coordinated interventions have a more significant impact on volatility as opposed to unilateral ones (see, for instance Reitz and Taylor, 2008; Morel and Tei'letche, 2008; Carracedo and Manzano, 2008; Dominguez, 2006; Fatum and Hutchison, 2006; Beine and Szafarz, 2006; Nagayasu, 2004; Beine, 2004, 2003; Fatum, 2002; Humpage, 1999; Tseng, 1998; Baillie and Osterberg, 1997; Catte et al., 1992; Dominguez, 1990). The results reported in the next section, regarding the impact of unilateral interventions under the DCC model, are in line with this finding. However, there is no paper, to our knowledge, that examines the impact of a greater number of two central banks intervening in coordination. If the previous argument is correct, then coordinated interventions of three central banks should increase even more the impact on exchange rate volatility compared to interventions of one or two central banks.

According to Table 3, the Bank of England (BoE) intervened six times in our investigation sample in coordination with another two central banks in the DM(EUR)/USD market. Thus, it would be of interest to see how our results change when three central banks coordinate their interventions. Besides, apart from the FED, the BoJ and the BB/ECB, the BoE was among the G6 that signed the Louvre Accord in 1987 (and which officially announces its interventions). As previously mentioned, the aim of the Louvre Accord was to stabilize the turbulent international currency markets. Hence, the post-Louvre period performance of the impact of a greater number of central banks intervening in coordination on exchange rate dynamics is of great importance.

The results for coordinated interventions of three central banks in the DM/USD market are presented under columns (c) and (d) in Table 5. Since there were not any coordinated interventions conducted by three central banks in the JPY/USD market, we can only examine the impact of coordinated interventions of three central banks in the DM(EUR)/USD market.

Under column (c) the dummies representing coordinated interventions of three central banks in the DM(EUR)/USD market enter both in the conditional mean and variance equations, whereas under column (d) enter only in the conditional variance equation.

Table 5 shows that, under column (c), the impact of coordinated CBIs of three central banks is dramatically different to the impact of coordinated interventions of two central banks. Specifically, coordinated interventions of three central banks in the DM/USD market do not have a significant impact on exchange returns and volatilities. However, when the insignificant impact of three central banks in the DM/USD in the conditional mean equation is removed, the results under column (d) show that coordinated interventions of three central banks significantly increase the DM(EURO) volatility. The robustness of these results is strengthened even when coordination of three central banks in the DM(EUR)/USD market are modeled together with the coordination of two central banks in the JPY/USD market. These results are presented under column (e) in Table 5. That is, the greater number of central banks engaging in coordinated interventions does not necessarily increase the effectiveness on volatility. On the contrary, when more than two central banks intervene in coordination the outcome is rise in exchange rate volatility. The DCC model under the various specifications in Table 5 do not suffer from serial correlation as the Li and McLeod (1981) test reports no evidence of serial correlation on both standardized and squared standardized residuals up to 20 lags. Figure 3, which plots the dynamic conditional correlations of the DCC model without exogenous variables (specification in Table 4), together with the ones from the DCC with exogenous variables in the estimations under columns (b) and (d) of Table 5, shows that the magnitude of correlations is slightly intensified due to coordinated interventions and which is in line with Nikkinen and Vähämaa (2009).

Fig. 3. Dynamic conditional correlations of the DM(EUR)/USD and the JPY/USD returns, including those from columns (b) and (d) of Table 5

These results could be of great importance for central banks' decisions on conducting coordinated interventions in a currency. According to these results if central banks wish to reduce exchange rate volatility, then it is preferable to intervene in coordination with only one another central bank and not in coordination with another two central banks; if intervention occurs in coordination with more than one another central bank it will not have the anticipated outcome. If a central bank wishes to affect its exchange returns it should not intervene in coordination. Intervening in coordination with at least another central bank will have no effect on exchange returns, as the vast majority of the literature suggests.

2.4. The impact of unilateral interventions. The empirical results of the impact of unilateral CBIs on exchange rate returns, variances and correlations are presented in Table 6. Columns (a) and (b) present the results for the G3 and G4 unilateral CBIs, respectively[1].

Table 6. Unilateral CBIs: signalling channel analysis of DM(EUR) & JPY (1991-2000)

Dependent variables		Explanatory variables	(a)	(b)
Conditional mean	DM(EUR)	Constant	0.0003 (2.96)**	0.0003 (2.70)**
		$dFED_{DM(EUR)}$	-0.0013 (-0.56)	-0.0013 (-0.59)
		$dBOJ_{JPY}$	-0.0011 (-2.88)**	-0.0011 (-2.48)*
		$dBB_{DM(EUR)}$	0.0051 (1.79)	0.0051 (1.54)
		$dBoE_{JPY}$		0.0319 (6.29)**
	JPY	Constant	0.0310 (3.39)**	0.0310 (3.27)**
		$dFED_{DM(EUR)}$	-0.2029 (-1.01)	-0.2081 (-1.28)
		$dBOJ_{JPY}$	-0.1394 (-3.91)**	-0.1392 (-3.23)**
		$dBB_{DM(EUR)}$	0.0064 (0.05)	0.0074 (0.05)
		$dBoE_{JPY}$		0.7673 (3.11)**
Conditional variables	DM(EUR)	Constant	1e-05 (40.6)**	3e-07 (2.15)*
		$\delta FED_{DM(EUR)}$	-4e-06 (-0.77)	-4e-06 (-0.67)
		δBOJ_{JPY}	1e-06 (2.15)*	1e-06 (1.60)
		$\delta BB_{DM(EUR)}$	1e-06 (0.14)	-1e-06 (-0.11)
		δBoE_{JPY}		-2.2e-06 (-0.08)

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[1] The dummy variables used in the evaluation of the impact of the G3 and G4 CBIs are based on those in column 1 of Table 3. That is, these dummies are based on the definition of CBIs under the G4 assessment. In the following section which involves robustness analysis we present the results of the impact of unilateral interventions according to the dummies used in Beine's (2004) paper under the G3 assessment.

Table 6 (cont.). Unilateral CBIs: signalling channel analysis of DM(EUR) & JPY (1991-2000)

Dependent variables		Explanatory variables	(a)	(b)
		αDM(EUR)	0.0344 (8.16)**	0.0344 (5.70)**
		βDM(EUR)	0.9583 (252)**	0.9589 (129)**
	JPY	Constant	0.0036 (2.69)**	0.0037 (2.24)*
		δFED$_{DM(EUR)}$	-0.0020 (-0.04)	-0.0033 (-0.05)
		δBOJ$_{JPY}$	0.0020 (0.37)	0.0020 (0.28)
		δBB$_{DM(EUR)}$	-0.0850 (-4.76)**	-0.0854 (-3.58)**
		δBoE$_{JPY}$		-0.0281 (-0.34)
		αJPY	0.0393(6.71)**	0.0394 (5.93)**
		βJPY	0.9537 (136)**	0.9534 (117)**
		DCCα	0.0187 (7.21)**	0.0184 (4.58)**
		DCCβ	0.9790 (327)**	0.9793 (213)**
		υ	5.7413 (14.11)**	5.7555 (22.87)**
		Log. lik.	7467.5	7474.8
Standardized residuals based tests				
		$Q(20)$	78.4882 [0.50]	78.2778 [0.50]
		$Q^2(20)$	84.8886 [0.25]	86.3596 [0.22]

Note: Parentheses and brackets are the t-statistics and p-values, respectively. * and ** denote 5% and 1% significance, respectively.

The results of the DCC model extended with exogenous variables under column (a) in Table 6 provide evidence that unilateral G3 interventions have little impact on both mean returns and variances. Only CBIs conducted by the BoJ in the JPY/USD market significantly affect both the JPY and DM(EUR) returns. Specifically, unilateral interventions of the BoJ cause an appreciation of the US dollar. Unilateral interventions of the FED and the BB do not have a significant impact on the two returns.

Another interesting feature of column (a) in Table 6 is that unilateral interventions of the BoJ and the BB(ECB), have a significantly negative and positive externality effect in the JPY/USD and the DM(EUR)/USD markets, respectively. That is, unilateral interventions of the BoJ in the JPY/USD market significantly increase the DM(EUR) volatility and unilateral interventions of the BB(ECB) in the DM(EUR)/USD market significantly reduce the JPY volatility. The unilateral intervention impact of the FED on volatility of both returns is correctly negatively signed but insignificant.

Including the BoE's unilateral interventions under our G4 assessment, the results seem to be more straightforward. Column (b) in Table 6, which presents these results, shows no evidence of significant increase in volatility due to unilateral official CBIs, which is in line with central banks' intentions. That is, the impact of the BoJ intervention in the JPY/USD market on the DM(EURO) volatility now becomes insignificantly positive and the BB(ECB) intervention in the DM(EUR)/USD market on the DM(EURO) volatility is now correctly negatively signed, although insignificant. The impact of interventions of the BoE in the JPY/USD market on both returns' volatility is also correctly signed, although insignificant.

In addition to the previous results, under column (a) in Table 6, of the impact of the G3 CBIs on exchange returns (with the use of dummies under the G4 assessment), unilateral interventions of the BoE significantly affect both DM(EUR) and JPY returns, under column (b) in Table 6. That is, taking into account the BoE, unilateral interventions seem to have a significant effect on returns and volatility. One major point of central banks' decisions to intervene is to decrease rather than increase exchange rate volatility. In this research we provide evidence that unilateral interventions are somewhat more productive, as their impact on returns is significant, and on volatility is correctly negatively signed and significant in the case of the BB(ECB) interventions in the DM(EUR)/USD market on the JPY volatility. No evidence that any of the unilateral interventions significantly increases volatility is reported, which is in line with central banks' intentions.

The conditional correlations of the DM(EUR) and JPY returns are highly persistent as shown by the significant estimated α and β parameters of these two DCC models in Table 6. Figure 4, which plots the dynamic conditional correlations of the DCC without exogenous variables (specification shown in Table 4), together with the ones from the DCC with exogenous variables from (a) and (b) in Table 6 shows that unilateral interventions slightly increase the magnitude of correlations.

Fig. 4. Dynamic conditional correlations of the DM(EUR)/USD and the JPY/USD returns, including those from columns (a) and (b) of Table 6

2.5. Robustness analysis. Having found evidence that unilateral interventions are more productive as opposed to coordinated interventions of 2 or 3 central banks under the G4 assessment, as the former affect returns and in minor cases reduce volatility, in this section several robustness checks are being performed. In order to check the robustness of the results regarding the impact of the officially announced G4 unilateral and coordinated CBIs, dummy variables representing the impact of officially announced G3 CBIs were constructed. That is, we omitted the BoE interventions, and replicated Beine's (2004) analysis by using the same dates and variables but under the DCC framework[1]. These results are presented in columns (a) and (b) on Table 7.

Table 7. Replication of Beine (2004) estimations under the G3 impact through the DCC model

Dependent variables		Explanatory variables	Coordinated interventions		Unilateral interventions	
			(a)	(b)	(c)	(d)
Conditional mean	DM(EUR)	Constant		0.0002 (2.21)*		0.0002 (2.35)*
		dCoDM(EUR)	0.0035 (1.44)			
		dCOJPY	-0.0001 (-0.07)			
		dFED$_{DM(EUR)}$			0.0003 (0.17)	
		dBB$_{DM(EUR)}$			0.0050 (1.76)	
	JPY	Constant		0.0236 (2.48)*		0.0239 (2.49)*
		dCoDM(EUR)	0.1451 (0.90)			
		dCOJPY	0.0333 (0.17)			
		dBOJ$_{JPY}$			-0.0655 (-1.73)	
		dBOJ$_{DM(EUR)}$			0.0280 (0.00)	
Conditional variables	DM(EUR)	Constant	4e-07 (2.01)*	4e-07 (2.39)*	4e-07 (2.48)*	4e-07 (41.84)**
		δCoDM(EUR)	1e-05 (1.82)	2e-05 (2.06)*		
		δCOJPY	-1e-06 (-0.18)	-1e-06 (-0.15)		
		δFED$_{DM(EUR)}$			-4e-06 (-0.83)	-4e-06 (-0.82)
		δBoJ$_{JPY}$			1e-06 (1.69)	1e-06 (2.14)*
		δBB$_{DM(EUR)}$			1e-06 (0.15)	3e-06 (0.27)
		αDM(EUR)	0.0334 (5.37)**	0.0330 (5.29)**	0.0344 (6.10)**	0.0341 (26.79)**
		βDM(EUR)	0.9588 (116)**	0.9592 (127)**	0.9579 (137)**	0.9585 (866)**
	JPY	Constant	0.0042 (2.35)*	0.0042 (2.51)*	0.0036 (2.91)**	0.0037 (8.28)**

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[1] The dummy variables used for the G3 assessment were constructed based on the number of CBIs shown in the last column of Table 3.

Table 7 (cont.). Replication of Beine (2004) estimations under the G3 impact through the DCC model

Dependent variables		Explanatory variables	Coordinated interventions		Unilateral interventions	
			(a)	(b)	(c)	(d)
		δCoDM(EUR)	-0.0123 (-0.50)	-0.0090 (-0.32)		
		δCOJPY	0.1009 (1.98)*	0.1021 (1.99)*		
		δFED$_{DM(EUR)}$			-0.0019 (-0.0357)	-0.0032 (-0.0651)
		δBOJ$_{JPY}$			0.0022 (0.3555)	0.0022 (0.4500)
		δBB$_{DM(EUR)}$			-0.0825 (-3.8711)**	-0.0842 (-3.8631)**
		αJPY	0.0404 (5.9160)**	0.0406 (5.7592)**	0.0392 (7.1439)**	0.0400 (30.6338)**
		βJPY	0.9496 (112.1868)**	0.9495 (107.9598)**	0.9539 (148.3135)**	0.9528 (831.0234)**
		DCCα	0.0190 (4.4552)**	0.0196 (4.8976)**	0.0183 (4.8422)**	0.0184 (19.1672)**
		DCCβ	0.9791 (209.2930)**	0.9784 (215.6425)**	0.9795 (227.6701)**	0.9793 (873.6994)**
		υ	6.0272 (12.8189)**	5.9500 (13.0542)**	5.8488 (14.5558)**	5.7838 (17.7490)**
		Log. lik.	7460.2167	7462.4958	7460.6221	7461.1064
Standardized residuals based tests						
		Q(20)	77.8420 [0.5157]	76.0561 [0.5730]	78.6535 [0.4898]	79.4615 [0.4643]
		Q²(20)	88.8644 [0.1675]	92.9871 [0.1036]	83.1936 [0.29470]	86.4296 [0.2165]

Note: Parentheses and brackets are the t-statistics and p-values, respectively. * and ** denote 5% and 1% significance, respectively.

The results are qualitatively identical to those of Beine (2004) obtained from the estimation of the VECH model for the equivalent parameters. That is, officially announced G3 unilateral and coordinated interventions affect exchange rate volatility and have no impact on returns. These results justify the robustness of the results obtained in the previous under the G4 assessment through the DCC framework.

Another point of interest is to examine whether specific central banks whose unilateral interventions were found to be effective, could still be effective when conducted in coordination with another specific central bank. As evidence indicated above that

the Bundesbank (or ECB after 1999) interventions in the DM(EUR)/USD market reduce volatility, it is of interest to check whether the Bundesbank (ECB) intervening together with at least another central bank could decrease exchange rate volatility. The Bundesbank (ECB) intervened in coordination with at least another central bank in the DM(EUR)/USD market fifteen times. The choice of specific central banks intervening in coordination might shed more light on the positive effect of coordinated interventions on volatility found in the literature. Table 8 presents the empirical results for coordinated CBIs wherein the BB(ECB) is one among the banks involved.

Table 8. Coordinated CBIs of Bundesbank (ECB) plus at least another central bank

Dependent variables		Explanatory variables	Coordinated interventions
Conditional mean	DM(UER)	Constant	0.0002 (2.247)*
		dCoDM(EUR)	0.0034 (1.525)
	JPY	Constant	0.0241 (2.545)*
		dCoDM(EUR)	0.1340 (1.077)
Conditional variance	DM(EUR)	Constant	3.62e-07 (2.637)*
		δCoDM(EUR)	1e-05 (1.801)
		αDM(EUR)	0.0330 (5.566)**
		βDM(EUR)	0.9593 (139.1)**
	JPY	Constant	0.0038 (2.530)*
		δCoDM(EUR)	-0.0052 (-0.189)
		αJPY	0.0427 (6.566)**
		βJPY	0.9501 (119.6)**
		DCCα	0.0185 (5.221)**
		DCCβ	0.9794 (241.96)**
		υ	5.8490 (13.90)**
		Log. lik.	7459.8
Standardized Residuals Based Tests			
		Q(20)	78.32 [0.500]
		Q²(20)	93.82 [0.093]

Note: Parentheses and brackets are the t-statistics and p-values, respectively. * and ** denote 5% and 1% significance, respectively.

According to these results, coordinated interventions involving the BB(ECB) neither significantly affect exchange returns nor volatility. Hence, even when a central bank, whose unilateral interventions are found to be effective, intervenes in coordination with another central bank, its impact on exchange returns and volatility diminishes[1]. This is in line with the empirical literature and which strengthens our previous results that coordinated CBIs do not have the anticipated effect on volatility.

Another interesting feature is to assess whether there exist any asymmetries that is to investigate whether the purchase of US dollars has a different impact than the sale of US dollars in the foreign exchange markets. One would expect that the purchase (sale) of US dollars to be associated with a US

dollar appreciation (depreciation). If instead a purchase (sale) of US dollars is followed by a US dollar depreciation (appreciation), then this may be due to a market inefficiency[2]. In addition, if successful, CBIs should significantly decrease volatility.

In order to assess whether any asymmetries exist whenever CBIs take place, two sets of dummy variables were constructed. The one set of dummies involves dummies that are equal to one when a central bank purchases US dollars and zero otherwise, and the other set involves dummies that are equal to one when a central bank sells US dollars and zero otherwise. The number of purchases and sales of US dollars by each central bank are presented in Table 9. The BoJ again is the most active central bank with 149 purchases and 27 sales of US dollars during our sample period.

Table 9. Purchase and sale of USD (1991-2001)

	Purchase of USD	Sale of USD
JPY/USD	Number of interventions	
Unilateral FED	0	0
Unilateral BoJ	149	27
Unilateral BoE	0	1
Coordinated interventions of 2 central banks	18	4
DM(EUR)/USD		
Unilateral FED	6	2
Unilateral BoJ	0	0
Unilateral BB/ECB	0	0
Unilateral BoE	0	0
Coordinated interventions of 2 central banks	6	4
Coordinated interventions of 3 central banks	5	2

The estimation results for the purchase and sale of USD are presented in Tables 10 and 11, respectively. According to Table 10, coordinated purchases of US dollars do not significantly affect returns. In addition, coordinated purchases of USD in general increase volatility, the greater the number of central banks involved. Under column (b) we see that coordinated purchases of USD significantly increase JPY volatility.

In the case of unilateral CBIs, only purchases of USD by the BoJ lead to a significant appreciation of the US dollar [3,4]. That is, unilateral purchases of US dollars are found to be more productive than coordinated ones in terms of their effect on returns, as they are associated with the intended appreciation of the US dollar. No significant effects of unilateral CB purchases of USD on volatility is reported.

Table 10. The impact of purchase of USD (1991-2001)

Dependent variables		Explanatory variables	Coordinated interventions		Unilateral interventions
			(a)	(b)	(c)
Conditional mean	DM(EUR)	Constant	0.0002 (2.329)*	0.0002 (2.164)*	0.0003 (2.783)**
		dCoDM(EUR)	0.010 (1.412)		
		dCoDM(EUR) 3		0.0020 (0.500)	
		dCOJPY	-0.0014 (-0.642)		
		dFED$_{DM(EUR)}$			-0.0028 (-1.535)
		dBOJ$_{JPY}$			-0.0012 (-2.765)**

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[1] Other combinations of coordinated CBIs were investigated and the results were of the same qualitative nature. These results can be obtained from the author upon request.

[2] It can be explained by the leaning-against-the-wind effect, which means that the central bank attempts to reverse the direction of the exchange rates and to influence the trend movement of its currency.

[3] Unilateral FED interventions are also found to lead to an appreciation of the US dollar however, the estimated parameters are insignificant.

[4] A decline in the exchange return denotes an appreciation of the US dollar.

Table 10 (cont.). The impact of purchase of USD (1991-2001)

Dependent variables		Explanatory variables	Coordinated interventions		Unilateral interventions
			(a)	(b)	(c)
	JPY	Constant	0.0235 (2.514)*	0.0249 (2.471)*	0.0307 (3.188)**
		dCoDM(EUR)	1.0028 (1.236)		
		dCoDM(EUR) 3		0.0242 (0.115)	
		dCOJPY	-0.0915 (-0.364)		
		dFED$_{DM(EUR)}$			-0.2953 (-1.909)
		dBOJ$_{JPY}$			-0.1740 (-3.923)**
Conditional variables	DM(EUR)	Constant	3e-07 (2.156)*	3e-07 (2.328)*	3e-07 (40.11)**
		δCoDM(EUR)	5e-06 (0.402)		
		δCoDM(EUR) 3		2e-05 (1.818)	
		δCOJPY	1e-06 (0.195)		
		δFED$_{DM(EUR)}$			-4e-06 (-0.653)
		δBoJ$_{JPY}$			1e-06 (1.895)
		αDM(EUR)	0.0374 (5.755)**	0.0322 (5.731)**	0.0362 (25.95)**
		βDM(EUR)	0.95.72 (123.9)**	0.9620 (143.6)**	0.9573 (792.2)**
	JPY	Constant	0.0035 (2.369)*	0.0036 (2.427)*	0.0034 (7.056)**
		δCoDM(EUR)	0.0259 (0.159)		
		δCoDM(EUR) 3		0.0261 (0.653)**	
		δCOJPY	0.0913 (1.221)		
		δFED$_{DM(EUR)}$			-0.0163 (-0.336)
		δBOJ$_{JPY}$			0.0101 (1.711)
		αJPY	0.0406 (5.656)**	0.0420 (6.597)**	0.0404 (27.77)**
		βJPY	0.9511 (114.9)**	0.9508 (127.1)**	0.9519 (741.6)**
		DCCα	0.0185 (5.125)**	0.0182 (4.552)**	0.0194 (16.99)**
		DCCβ	0.9794 (242.7)**	0.9797 (221.9)**	0.9782 (729.3)**
		υ	5.8222 (13.79)**	5.8404 (14.36)**	5.7099 (17.51)**
		Log. lik.	7462.1	7458.9	7463.5
Standardized residuals based tests					
		Q(20)	77.48 [0.527]	76.99 [0.543]	79.97 [0.448]
		Q²(20)	86.48 [0.215]	93.95 [0.092]	83.05 [0.299]

Note: Parentheses and brackets are the t-statistics and p-values, respectively, significance, respectively.

In the case of sales of US dollars the results are as follows. According to Table 11, coordinated sales of USD conducted by two central banks do not significantly affect returns and significantly reduce volatility of the JPY/USD (when conducted in the DM(EUR)/ USD market). However, when coordinated sales of USD are conducted by three central banks, no significant effect on returns nor volatility is present. In the case of unilateral interventions, sales of USD significantly lead to a depreciation of the USD (as expected) when conducted by the Bank of England. In the other cases they are insignificant. More importantly, unilateral sales of USD by the Bank of Japan significantly reduce the JPY volatility.

Table 11. The impact of USD sale (1991-2001)

Dependent variables		Explanatory variables	Coordinated interventions		Unilateral interventions	
			(a)	(b)	(c)	(d)
Conditional mean	DM(EUR)	Constant	0.0002 (2.398)*	0.0002 (2.206)*	0.0002 (2.456)*	0.0002 (2.390)*
		dCoDM(EUR)	-0.0110 (-1.469)			
		dCoDM(EUR) 3		0.0184 (1.509)		
		dCOJPY	-0.0015 (-0.394)			
		dFED$_{DM(EUR)}$			0.0012 (0.135)	0.0022 (0.161)
		dBOJ$_{JPY}$			-0.0010 (-0.813)	-0.0010 (-1.068)
		dBoE$_{JPY}$				0.0319 (6.268)**
	JPY	Constant	0.0240 (2.641)**	0.0238 (2.288)*	0.0241 (2.564)*	0.0238 (2.440)*
		dCoDM(EUR)	-0.5942 (-1.534)			

Table 11 (cont.). The impact of USD sale (1991-2001)

Dependent variables		Explanatory variables	Coordinated interventions		Unilateral interventions	
			(a)	(b)	(c)	(d)
Conditional variables		dCoDM(EUR) 3		0.4858 (1.267)		
		dCOJPY	-0.3346 (-1.173)			
		dFED$_{DM(EUR)}$			0.4054 (0.907)	0.4122 (0.960)
		dBOJ$_{JPY}$			-0.0296 (-0.343)	-0.0300 (-0.394)
		dBoE$_{JPY}$			0.7744 (3.434)	
	DM(EUR)	Constant	4e-07 (2.489)*	3e-07 (2.171)*	3e-07 (2.354)*	3e-07 (2.229)*
		δCoDM(EUR)	8e-05 (0.581)			
		δCoDM(EUR) 3		1e-05 (0.563)		
		δCOJPY	-1e-05 (-1.60)			
		δFED$_{DM(EUR)}$			1e-05 (0.533)	1e-05 (0.454)
		δBoJ$_{JPY}$			-1e-07 (-0.083)	-1e-07 (-0.096)
		δBoE$_{JPY}$				-1e-05 (-0.338)
		αDM(EUR)	0.0352 (5.863)**	0.0336 (5.495)**	0.0353 (6.143)**	0.0349 (5.822)**
		βDM(EUR)	0.9588 (132.1)**	0.9600 (121.8)**	0.9590 (140.2)**	0.9597 (132.7)**
	JPY	Constant	0.0033 (3.229)**	0.0040 (2.436)*	0.0039 (2.971)**	0.0042 (2.830)**
		δCoDM(EUR)	-0.1096 (-3.1131)**			
		δCoDM(EUR) 3		-0.0645 (-0.879)		
		δCOJPY	-0.0355 (-0.550)			
		δFED$_{DM(EUR)}$			-0.1011 (-1.197)	-0.1054 (-1.261)
		δBOJ$_{JPY}$			-0.0205 (-2.564)*	-0.0212 (-2.404)*
		δBoE$_{JPY}$			-0.0991 (-1.393)	
		αJPY	0.0391 (7.566)**	0.0412 (5.998)**	0.0395 (6.781)**	0.0392 (6.079)**
		βJPY	0.9549 (181.9)**	0.9509 (116.0)**	0.9536 (141.0)**	0.9533 (128.1)**
		DCCα	0.0177 (4.710)**	0.0110 (29615)**	0.0181 (5.540)**	0.0178 (4.452)**
		DCCβ	0.9801 (231.7)**	0.9873 (1173)**	0.9797 (263.8)**	0.9801 (212.5)**
		υ	5.7890 (14.11)**	5.8096 (13.75)**	5.7727 (14.72)**	5.7865 (13.80)**
		Log. lik.	7461.7	7454.1	7459.4	7467.1
Standardized residuals based tests						
		Q(20)	77.57 [0.524]	80.26 [0.438]	80.63 [0.428]	80.62 [0.428]
		Q²(20)	89.10 [0.163]	78.76 [0.1036]	89.04 [0.164]	88.94 [0.166]

Note: Parentheses and brackets are the t-statistics and p-values, respectively. * and ** denote 5% and 1% significance, respectively.

Summing up, even when asymmetries are taken into account, the results are qualitatively similar to those obtained from our main analysis, and thereby strengthening our findings. That is, the more coordination of central banks in the foreign exchange markets, the more detrimental their effect on returns and volatility. Specifically, unilateral purchases and sales of US dollars affect returns in the intended direction and can significantly reduce exchange rate volatility only when conducted by the Bank of Japan. On the contrary, coordinated interventions conducted by two central banks and, especially by three central banks, do not have the intended outcome on both returns and volatility.

Conclusion

In order to shed some light on the effectiveness of official CBIs, this paper examined the signalling channel through which official CBIs, conducted unilaterally or in coordination with two and three central banks, could affect exchange returns, their volatility and dynamic conditional correlations. A novel contribution of this study is the assessment of the impact of the G4 CBIs on exchange returns, volatility and correlations. Specifically, in addition to the impact of G3 CBIs of FED, BoJ and the BB (ECB) in the DM(EUR)/USD and the JPY/USD markets, that has been systematically examined in the literature, this paper provided results on the G4 interventions by adding the BoE. The investigation was extended with the application of the DCC model of Engle (2002) due to its flexible structure and the specification of time-varying conditional correlations. This is another contribution of this paper. The DCC model performed very well under the various specifications and showed that CBIs slightly intensify the DM(EUR) and the JPY dynamic conditional correlations.

Under the G4 assessment, results indicated that official CBIs significantly affect exchange returns only in the case of unilateral interventions. Regarding the impact of CBIs on volatility, it was found that unilateral interventions, in some cases, reduce volatility. Coordinated interventions were found to be more counterproductive the greater the number of central banks intervenes in coordination.

The results of the impact of the G4 CBIs under the DCC assessment are strengthened by various robustness checks, such as re-examining the established G3 assessment, accounting for coordinated interventions by specific central banks that were found to be successful unilaterally, and accounting for asymmetries.

Based on our results, unilateral CBIs can influence returns in the intended direction, whereas coordinated CBIs do not have a significant impact on returns. In terms of the impact of CBIs on exchange rate volatility the results are as follows. Unilateral or even coordinated interventions of 2 central banks, in minor cases, significantly decrease volatility. However, coordinated interventions of 3 central banks in the same currency increase volatility, which is the exact opposite of the central banks' intentions. These results have important implications for the effectiveness of central banks' intervention policy decisions. That is, if central banks wish to influence exchange rates and/or volatility, they should intervene unilaterally. The more central banks intervene in coordination the less, or the opposite from the anticipated, would be the generated outcome.

Moreover, CBIs in one market are found to positively, albeit marginally, affect correlations between foreign exchange markets. That is, CBIs conducted either unilaterally or in coordination intensify co-movements in foreign exchange markets. This is true in a world of highly integrated financial markets and might be the reason why such CBIs, and especially coordinated ones, increase volatility in these markets in most of the cases.

A limitation of the results obtained in this paper is captured by the following counterfactual question: if had not central banks intervened, would the impact on returns and volatility have been different? This is a rather difficult question to address (see, for instance Fatum and Hutchison, 2010, for an initial attempt to address this question). Nonetheless, a recent growing literature has focused on the impact of official statements and speeches of central banks on foreign exchange markets prior to intervention (see, for instance Gnabo and Teiletche, 2009; Beine et al., 2009a, and references therein). Using such an approach, our analysis could be extended to answer the above question and which we leave for future research.

In addition, the analysis in this paper was solely based on the investigation of the signalling channel through which CBIs could affect exchange returns, volatility and correlations using daily data under the DCC model. That is, the portfolio-balance channel was not examined. Hence, an interesting avenue for further research is to investigate the impact of the G4 CBIs in the context of the portfolio-balance channel.

Acknowledgment

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