生駒経済論叢　第７巻第１号　2009年７月

Impulse Response of the Exchange Rate Volatility to a Foreign Exchange Intervention Shock[1]

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Abstract This paper uses Lin's technique (1997) to report on the impulse response function analysis that traces the dynamics of exchange rate volatility from innovations in Japanese foreign exchange intervention. Using a multivariate GARCH model, we employed a volatility impulse response function based on Lin (1997) to detect the impulse response of exchange rate volatility on a one-unit foreign exchange intervention shock. The main findings of this paper are as follows: (1) a foreign exchange intervention shock leads to a significant increase in exchange rate volatility, and (2) the central bank takes persistent action against the exchange rate volatility shock.

Key words Foreign exchange intervention, Exchange rate volatility, GARCH, causality-in-variance, impulse response function

May 15, 2009 accepted

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(1) I am grateful for the constructive comments and suggestions of Seiichi Fujita, Ryuzo Miyao, and Shigeyuki Hamori of Kobe University. Any remaining errors are my own. This work was supported by KAKENHI (20730210).

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1. Introduction

We suggest a new application for the empirical analysis of the influence of foreign exchange intervention on exchange rate volatility. This paper empirically characterizes how the Japanese foreign exchange intervention has influenced the exchange rate volatility since 1973. In specific terms, we report the impulse response function for exchange rate volatility. Foreign exchange intervention is a very interesting policy because its purpose "is to stabilize the exchange rate of the national currency."(3) This indicates that the policy target is exchange rate volatility or the second moment of the exchange rate. Under the floating exchange rate system, exchange rate volatility often becomes problematic. Let us discuss the subject from the viewpoint of exchange rate volatility. Since Dominguez (1998), the impact of central bank intervention on exchange rate volatility has been empirically analyzed in the literature by employing generalized autoregressive conditional heteroscedasticity (GARCH) models. Dominguez (1998), Nagayasu (2004), and Beine et al. (2002) reported that foreign exchange intervention increased exchange rate volatility. Chang and Taylor (1998) also reported positive and significant impacts on the yen/dollar exchange rate volatility. Frenkel et al. (2005) reported a positive link between the Japanese intervention and exchange rate volatility. Hoshikawa (2008a) shows that frequent intervention reduces exchange rate volatility. These studies provide empirical evidence on the effectiveness of intervention for exchange rate volatility.

On the other hand, numerous studies have been conducted on foreign exchange intervention and the exchange rate level.(4) Dominguez and Frankel (1993) and Ito (2002) pointed out that foreign exchange intervention affected the exchange rate level. Kim (2003) uses the vector autoregression (VAR) approach to measure the effects of foreign exchange intervention shocks. Kim (2003) uses an impulse response function and concludes that intervention influences the ex-

(3) Article 40, Section 2, The Bank of Japan Law.

(4) Refer to Sarno and Taylor (2001) for a recent survey of the literature.

change rate level. The VAR model is widely used to determine the effect of some innovations on the economy. However, the impulse response function analysis has not yet considered nonlinear systems such as multivariate GARCH models in tracing the dynamics of the exchange rate volatility arising from innovations in foreign exchange intervention. Lin (1997) defines the impulse response function for conditional volatility in GARCH models. We employ the volatility impulse response function based on Lin (1997) to detect the impulse response of exchange rate volatility to a one-unit foreign exchange intervention shock by using a multivariate GARCH model.(5)

Two issues motivate our investigation. First, we attempt to connect the impulse response analysis (such as Kim, 2002) and the GARCH methods in previous studies. Hoshikawa (2008b) applies a univariate autoregressive (AR) GARCH model to international reserves data and exchange rate data. He finds evidence of instantaneous causal relationships in mean and variance and feedback causal relationships in mean.(6) This suggests that exchange rate volatility is influenced by information on foreign exchange intervention. In this paper, we extend the univariate AR-GARCH model to a VAR-GARCH model and add an impulse response analysis for conditional volatility. The second motive is to assess the reaction of the central bank to the shock from the exchange rate volatility. The VAR-GARCH system includes the endogenous reaction of Japanese foreign exchange policy. This paper analyzes the dynamic effects between exchange rate volatility and the foreign exchange intervention shock in Japan. We use monthly observations from 1973:1 to 2005:12. Using the estimated VAR-GARCH model, we adopt a volatility impulse response approach based on Lin (1997) in which shocks to international reserves are regarded as the indicator of foreign exchange intervention. We also report the causality-in-variance tests. The causation implies volatility spillover between both variables. The main findings of the paper can be summarized as follows. The impulse response results suggest that Japa-

(5) Hafner and Herwartz (2006) recently defined another volatility impulse response function.

(6) Hoshikawa (2007b) reports the residual-based causality test proposed by Cheung and Ng (1996).

nese foreign exchange intervention has a positive spillover effect on exchange rate volatility. Furthermore, the shock in exchange rate volatility leads to persistent intervention in the foreign exchange market. Finally, we find evidence of the feedback causal relationships in variance.

This paper is organized as follows. Our aims are presented in Section 2. Section 3 contains the data and methodology. The estimation results are provided in Section 4, and Section 5 shows the impulse response function for conditional volatility. Finally, some conclusions are offered in Section 6.

2. Empirical Background

This section presents the unresolved questions in this field. First, it will be useful to examine the two effects of intervention in the foreign exchange market: the effect of interventions (1) on the exchange rate level (first moment) and (2) on exchange rate volatility (second moment). The GARCH model is widely used in modeling the changes in the exchange rate volatility. In the literature, the impact of central bank intervention on exchange rate volatility has been empirically analyzed using GARCH models. The previous studies typically employ the following GARCH model:

$$\Delta s_t = \beta x_t + \gamma INT_t + u_t, \quad u_t \sim N(0, h_t)$$
$$h_t = \alpha_0 + \alpha_1 u_{t-1}^2 + \alpha_2 h_{t-1} + \phi \mid INT_t \mid .$$

Here, Δs_t is the change in the exchange rate, x_t is a vector of economic factors that may influence the left-hand side variable and INT_t is the amount of foreign exchange intervention. The first equation shows the conditional mean dynamics, and the second equation shows the conditional variance dynamics. If parameter γ is significant, foreign exchange intervention influences the exchange rate level. If parameter ϕ in the variance equation is significant, intervention influences exchange rate volatility. Given the information set at time $t-1$, h_t is predetermined in the basic GARCH models. However, the estimation equation includes an exogenous intervention variable that is not determined at time $t-1$. The problem then arises with respect to exogenous intervention variable INT_t with the information set at time $t-1$. In contrast, the empirical literature on central bank reaction functions uses the typical reaction function that takes following form:

$$INT_t = \rho x_t + \kappa \Delta s_t + v_t .$$

In this equation, intervention is considered as the endogenous variable. The central bank may react to exchange rate volatility; therefore, we need to consider its reaction.(7) Using the VAR model, Kim (2003) considers intervention and exchange rate as endogenous variables. The VAR model takes the following form:

$$\Phi(L) y_t = \varepsilon_t ,$$

where $\Phi(L)$ is a matrix polynomial in the lag operator L, y_t is an $n \times 1$ data vector including the foreign exchange intervention and exchange rate, and ε_t is an $n \times 1$ disturbances vector. The VAR model can be rewritten in the following vector moving average representation:

$$y_t = \Psi(L) \varepsilon_t ,$$

and the impulse response function can be obtained as

$$\frac{\partial y_{t+s}}{\partial \varepsilon_t '} = \Psi_s .$$

Using the impulse response function, Kim (2003) reports that foreign exchange intervention shocks have significant effects on the exchange rate level; however, the effects of intervention on exchange rate volatility cannot be captured. When we analyze foreign exchange intervention, it is important to note that exchange

(7) See Almekinders and Eijffinger (1996).

rate volatility is the same as the exchange rate level.

The following questions now arise. Can we analyze the impulse response function that traces the dynamics of the exchange rate volatility arising from foreign exchange intervention shocks? Does foreign exchange intervention react to exchange rate volatility? Does foreign exchange intervention and exchange rate in the second moment influence each other? This paper addresses the above questions.

3. Data and Methodology

3.1 Data

The exchange rate, $SPOT_t$, is the spot yen/dollar rate (end of the month), and the international reserves data, $RESERVE_t$, is in million dollar units at the end of the month from 1973 : 1 to 2005 : 12.(8) We use the first difference of logarithm of the international reserves data, $R_t = \ln(RESERVE_t) - \ln(RESERVE_{t-1})$, as a proxy variable of Japanese foreign exchange intervention and the yen-dollar exchange rate, $S_t = \ln(SPOT_t) - \ln(SPOT_{t-1})$. In Japan, the actual foreign exchange intervention data has been available only recently. We use the international reserves data instead of the actual intervention data.(9) Justifying the proxy variable, we can show the simplest form of regression using the first difference of international reserves data and monthly foreign exchange intervention data. Here, the sample period spans from 1991:4 to 2005:12 because the disclosed Japanese foreign exchange intervention data is available only for this period.(10) The result of the regression is as follows:

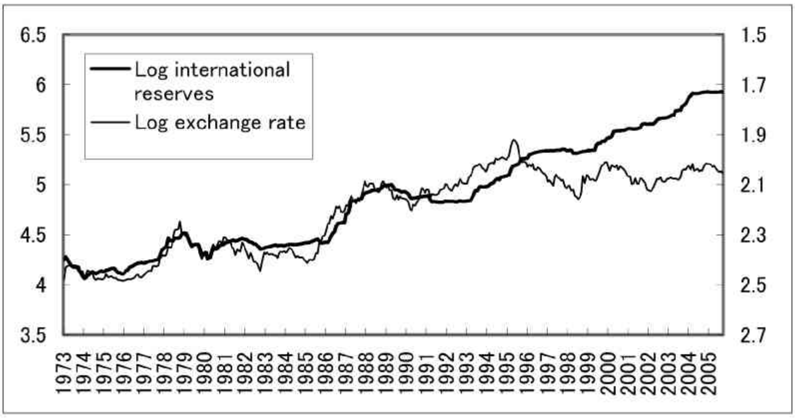
(8) The data sources are the home pages of the Bank of Japan and the Ministry of Finance.

(9) In Kim (2003) and Obstfeld (1983), foreign reserve data is also used instead of actual intervention data.

(10) Since July 2001, the Japanese Ministry of Finance has been conducting the disclosure of daily intervention records from April 1991 to the present (http://www.mof.go.jp/english/e1c021.htm). Intervention reports prior to April 1991 are not disclosed.

$$\Delta RESERVE_t = \underset{(245.85)}{1148.2} + \underset{(0.0347)}{1.09997}\ INT_t, \bar{R}^2 = 0.881 \tag{1}$$

where $\Delta RESERVE_t$ is the first difference of international reserves data and INT_t is the amount of actual foreign exchange intervention data; Newy-West HAC standard errors are reported within parentheses. The adjusted coefficient of determination $\bar{R}^2$ is 0.88 and the coefficient of INT_t is nearly 1. Change in the international reserves is a good proxy variable of foreign exchange intervention. Figure 1 plots the logarithms of the exchange rate and the international reserves, $\ln(SPOT_t)$ and $\ln(RESERVE_t)$, respectively. The international reserves increased when the yen appreciated because international reserves are strongly linked to the foreign exchange intervention. Under the floating exchange rate system, international reserves have small volatility without foreign exchange intervention. When the authority conducts foreign exchange intervention, international reserves volatility increases.



Note: The logarithm of exchange rate is presented on the right axis and that of Japanese international reserves, on left axis.
Source: Hoshikawa (2009).

Figure 1. The logarithm of the exchange rate and international reserves

3.2 VAR-GARCH modeling

We model the dynamics of both international reserves and the exchange rate using the time series models such as the commonly used VAR models and the GARCH process. The use of the VAR structure in the mean equation is justified for a bivariate time series due to its simplicity. We use the VAR model in the mean equation as follows:

$$\mathbf{y}_t = \mathbf{\Phi}_0 + \mathbf{\Phi}_1 \mathbf{y}_{t-1} + \varepsilon_t , \tag{2}$$

where

$$\mathbf{y}_t = \begin{bmatrix} S_t \\ R_t \end{bmatrix}, \mathbf{\Phi}_0 = \begin{bmatrix} \phi_{01} \\ \phi_{02} \end{bmatrix}, \mathbf{\Phi}_1 = \begin{bmatrix} \phi_{11} & \phi_{12} \\ \phi_{21} & \phi_{22} \end{bmatrix}, \varepsilon_t = \begin{bmatrix} \varepsilon_{1,t} \\ \varepsilon_{2,t} \end{bmatrix}, \tag{3}$$

and is normally distributed $\varepsilon_t \mid I_{t-1} \sim N(\mathbf{O}, \mathbf{H}_t)$ with its corresponding conditional variance covariance matrix given by

$$\mathbf{H}_t = \begin{bmatrix} h_{11,t} & h_{12,t} \\ h_{12,t} & h_{22,t} \end{bmatrix}. \tag{4}$$

As in Engle and Kroner (1995), let us consider the bivariate GARCH (1, 1) model. We use a popular BEKK (1, 1, 1) representation given by

$$\mathbf{H}_t = \mathbf{CC}' + \mathbf{A}\varepsilon_{t-1}\varepsilon'_{t-1}\mathbf{A}' + \mathbf{GH}_{t-1}\mathbf{G}' \tag{5}$$

$$= \begin{bmatrix} c_{11} & 0 \\ c_{21} & c_{22} \end{bmatrix} \begin{bmatrix} c_{11} & c_{21} \\ 0 & c_{22} \end{bmatrix} + \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix} \begin{bmatrix} \varepsilon_{1,t-1}^2 & \varepsilon_{1,t-1}\varepsilon_{2,t-1} \\ \varepsilon_{1,t-1}\varepsilon_{2,t-1} & \varepsilon_{2,t-1}^2 \end{bmatrix} \begin{bmatrix} a_{11} & a_{21} \\ a_{12} & a_{22} \end{bmatrix}$$

$$+ \begin{bmatrix} g_{11} & g_{12} \\ g_{21} & g_{22} \end{bmatrix} \begin{bmatrix} h_{11,t-1} & h_{12,t-1} \\ h_{12,t-1} & h_{22,t-1} \end{bmatrix} \begin{bmatrix} g_{11} & g_{21} \\ g_{12} & g_{22} \end{bmatrix}, \tag{6}$$

or

$$h_{11,t} = c_{11}^2 + a_{11}^2 \varepsilon_{1,t-1}^2 + 2a_{11}a_{12}\varepsilon_{1,t-1}\varepsilon_{2,t-1} + a_{12}^2 \varepsilon_{2,t-1}^2$$

$$+ g_{11}^2 h_{11,t-1} + 2g_{11}g_{12}h_{12,t-1} + g_{12}^2 h_{22,t-1} \tag{7}$$

$$h_{12,t} = c_{11}c_{21} + a_{11}a_{21}\varepsilon_{1,t-1}^2 + (a_{11}a_{22} + a_{12}a_{21})\varepsilon_{1,t-1}\varepsilon_{2,t-1} + a_{12}a_{22}\varepsilon_{2,t-1}^2$$

$$+g_{11}g_{21}h_{11,t-1} + (g_{11}g_{22} + g_{12}g_{21})h_{12,t-1} + g_{12}g_{22}h_{22,t-1}, \tag{8}$$

$$h_{22,t} = c_{21}^2 + c_{22}^2 + a_{21}^2\varepsilon_{1,t-1}^2 + 2a_{21}a_{22}\varepsilon_{1,t-1}\varepsilon_{2,t-1} + a_{22}^2\varepsilon_{2,t-1}^2$$

$$+g_{21}^2 h_{11,t-1} + 2g_{21}g_{22}h_{12,t-1} + g_{22}^2 h_{22,t-1}. \tag{9}$$

Here, h_{11} is exchange rate volatility and h_{22} is the volatility of international reserves. One of the key advantages of the BEKK representation is that the positivity of $\mathbf{H}_t$ is automatically guaranteed.

The concept of causality-in-variance has recently been introduced by Cheung and Ng (1996) . Hoshikawa (2008b) reports the residual based causality-in-variance tests for the exchange rate data and international reserves data in Japan. Caporale et al. (2002) adopt a multivariate GARCH framework and test for the relevant zero restrictions on the conditional variance parameter. In this paper, we parameterize the conditional volatility relation and test the zero restrictions.

The volatility spillover from R_t to S_t is represented in the coefficients of a_{12} and g_{12}; the coefficients a_{21} and g_{21} indicate that S_t spills over to R_t. We test the null hypothesis—given by $H_0 : a_{12} = g_{12} = 0$—that h_{22} does not have a causal effect on h_{11}. There is a volatility spillover between both the variables if the null hypothesis is rejected. This suggests that nonlinear causality exists. In this paper, we test if the international reserves volatility does not cause exchange rate volatility. If there exists a causal relationship in variance, then foreign exchange intervention can influence exchange rate volatility. The null hypothesis $H_0 : a_{21} = g_{21} = 0$ indicates that exchange rate volatility does not cause international reserves volatility.

3.3 Impulse response function for conditional volatility

The impulse response function for conditional volatility is suggested by Lin (1997). A brief description of the methodology is given below. The impulse response of conditional volatility is defined as

$$V_{s,n} = \partial \mathbf{vech}(\mathbf{H}_{t+s|t}) / \partial \mathbf{dg}(\varepsilon_t \varepsilon'_t), \tag{10}$$

where $V_{s,n}$ is an $n \times N$ matrix, $n = (N+1)N/2$, and $\mathbf{dg}(\varepsilon_t \varepsilon'_t) = (\varepsilon_{1,t}^2, \varepsilon_{2,t}^2, \ldots, \varepsilon_{N,t}^2)'$. In this paper, N equals 2 and $n = 3$. Using the **vech** operator, equation (5) can be written in the following form:

$$h_t = c + au_{t-1} + bh_{t-1} \tag{11}$$

In the above equation, $h_t = \mathbf{vech}(\mathbf{H}_t)$, $c = \mathbf{vech}(\mathbf{CC}')$, $a = \mathbf{D}^+(\mathbf{A} \otimes \mathbf{A})\mathbf{D}$, $b = \mathbf{D}^+(\mathbf{G} \otimes \mathbf{G})\mathbf{D}$, and $u_t = \mathbf{vech}(\varepsilon_t \varepsilon'_t)$. Further, the duplication matrices D^+, D are given by

$$D^+ = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & \frac{1}{2} & \frac{1}{2} & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}, D = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \tag{12}$$

$v_t = u_t - h_t$ is a martingale difference sequence, and equation (11) is expressed by

$$h_t = c + (a+b)h_{t-1} + av_{t-1}. \tag{13}$$

Let $h_{t+s|t}$ be the prediction of h_{t+s} conditional on the information set at time t. With respect to $h_{t+s|t}$, it can be shown that

$$\begin{aligned} h_{t+1|t} &= c + (a+b)h_t + av_t \\ h_{t+2|t} &= c + (a+b)h_{t+1|t} \\ &\cdots \\ h_{t+s|t} &= c + (a+b)h_{t+s-1|t}. \end{aligned} \tag{14}$$

The volatility impulse response function $V_{s,n}$ is obtained by taking matrix derivatives with respect to $\mathbf{dg}(\varepsilon_t \varepsilon'_t)$,

$$V_{1,n} = aL_{n,N}$$

$$V_{2,n} = (a+b)V_{1,n},$$
$$\cdots$$
$$V_{s,n} = (a+b)V_{s-1,n}. \qquad (15)$$

Here, $L_{n,N}$ is an $n \times N$ matrix of $\partial v_t / \partial \mathbf{dg}(\varepsilon_t \varepsilon'_t)$ with zero and one element.

The purpose of this paper is to show how foreign exchange intervention shock spills over to exchange rate volatility using the volatility impulse response function. It indicates the nonlinear effects of foreign exchange intervention shock.

4. Empirical results

4.1 Estimation results of the bivariate VAR-GARCH model

In this section, we report the empirical results. The estimated results of the bivariate VAR-GARCH model are reported in Table 1. Several regression diagnostics are reported at bottom of the table. Log L denotes the value of the log likelihood. $Q(6)$ and $Q^2(6)$ are the Ljung-Box statistics, which are calculated from the first 6 autocorrelation coefficients of the standardized residuals and their squares. The standardized residuals $\xi_t = (\xi_{1,t}, \xi_{2,t})'$ are calculated by $\xi_t = \mathbf{H}_t^{-\frac{1}{2}} \varepsilon_t$.(11) The first column shows the type of coefficients. The remaining columns from left to right show the results under the headings Result 1 (full sample period), Result 2 (subsample), and Result 3 (dummy variable is included). Result 1 in Table 1 reports the estimated VAR-GARCH parameters for the full sample period from January 1973 to December 2005.(12) Using the full sample period, the estimate of a_{12} is statistically significant at the 1% level with a negative value of -0.252, and the estimate of g_{12} is statistically significant at the 5% level.

The Ljung-Box statistics indicate that the null hypothesis of no autocorrelation

(11) Cholesky factorization is used to obtain $\mathbf{H}_t^{\frac{1}{2}}$.

(12) In this paper, the Schwarz-Bayesian information criteria (SBIC) are used to choose the final models from various possible VAR-GARCH specifications. The lag order of the VAR process in the mean equation (2) is chosen as 1 and the GARCH (1, 1) model is chosen in equation (5).

is accepted for the standardized residuals and their squares in both specifications of the foreign reserves the exchange rate. This suggests that the selected specifications explain the data well. Next, we must consider the subsample period. In Figure 1, the movements of the exchange rate and international reserves were closely interrelated from 1973 to the mid-1990s, although this relationship clearly changed after the latter half of the 1990s. Ito (2003) stated this to be the outcome of the revision in the Japanese foreign exchange policy in the late 1990s. The yen appreciated from near 300 yen/dollar in 1973 to 80 yen/dollar in 1995, and then reversed and depreciates to 120 in 2005. There is a possibility that intervention is an asymmetry in the appreciation and depreciation of the yen. Another reason for this is the East Asian currency crisis of July 1997, which increased the yen/dollar rate volatility. This suggests the possibility of a structural break in the variance equation. For this reason, we use only the pre-crisis data. Result 2 again reports our estimation of the parameters using the subsample period from 1973:1 to 1997:6. Furthermore, Result 3 reports the following estimation result when we add the East Asian currency crisis dummy variable in variance equation (7):

$$h_{11,t} = c_{11}^2 + a_{11}^2\varepsilon_{1,t-1}^2 + 2a_{11}a_{12}\varepsilon_{1,t-1}\varepsilon_{2,t-1} + a_{12}^2\varepsilon_{2,t-1}^2$$
$$+g_{11}^2 h_{11,t-1} + 2g_{11}g_{12}h_{12,t-1} + g_{12}^2 h_{22,t-1} + \gamma dummy_t. \tag{16}$$

We define the dummy variable that assumes the value 1 from July 1997 to October 1998, and 0 otherwise. After the Asian currency crisis that occurred in July 1997, Japan announced the "New Miyazawa Initiative" in October 1998. This initiative included a package of support measures totaling $30 billion.

The coefficients of GARCH term, $a_{11}, a_{22}, g_{11}, g_{22}$, are generally highly significant for Results 1 to 3, and these results are similar to Hoshikawa (2008b). This suggests that the international reserves data and exchange rate data follow the

(13) The ARCH Lagrange multiplier (LM) test statistics in the OLS residuals for the VAR model are 5.16 for exchange rate data and 20.98 for international reserves data. The ARCH-LM statistics for both the residuals indicate that the null hypothesis of no ARCH effect is rejected at the 5% significance level.

Table 1. Estimation results of the VAR-GARCH model

	Result 1		Result 2		Result 3	
	Coefficient	S. E	Coefficient	S. E	Coefficient	S. E
ϕ_{01}	−0.0015	0.0016	−0.0023	0.0019	−0.0014	0.0016
ϕ_{02}	0.006**	0.002	0.0036	0.0023	0.0049**	0.0018
ϕ_{11}	0.0635	0.0554	0.1064	0.08	0.0696	0.0642
ϕ_{12}	−0.0381	0.051	−0.03	0.0553	−0.0436	0.0533
ϕ_{21}	−0.1381**	0.0492	−0.0631	0.0725	−0.0863	0.0524
ϕ_{22}	0.3857**	0.0648	0.4311**	0.0717	0.3757**	0.0551
c_{11}	0.0206**	0.0028	0.0094**	0.0032	0.0158**	0.0035
c_{21}	−0.0258**	0.0015	−0.0087**	0.002	−0.0048	0.0039
c_{22}	−0.0112**	0.0038	−0.0006	0.004	−0.0005	0.0022
a_{11}	−0.3026**	0.0734	−0.3482**	0.0898	−0.3234**	0.0795
a_{12}	−0.252**	0.0822	−0.2459**	0.0588	−0.0206	0.0575
a_{21}	−0.1167	0.072	0.0411	0.0861	−0.2719**	0.0532
a_{22}	0.4563**	0.0898	0.403**	0.059	0.3379**	0.0458
g_{11}	0.7384**	0.1116	0.9335**	0.0542	0.8273**	0.0868
g_{12}	0.4289*	0.1978	0.0795*	0.0398	−0.1713**	0.0427
g_{21}	0.2347	0.1783	−0.1253*	0.0581	0.0807*	0.0374
g_{22}	0.1943	0.3156	0.8416**	0.0295	0.8520**	0.0263
dummy	—		—		0.0006**	0.0002
ξ_1						
$Q(6)$	7.400	[0.285]	5.538	[0.477]	8.0976	[0.231]
$Q^2(6)$	5.058	[0.536]	10.55	[0.103]	10.387	[0.109]
ξ_2						
$Q(6)$	10.486	[0.106]	7.427	[0.283]	7.193	[0.303]
$Q^2(6)$	3.696	[0.718]	4.208	[0.649]	3.8427	[0.698]
Log L	1619.09		1197.13		1637.54	

Note: Maximum likelihood standard errors (S. E) are reported above. ** denotes significance at the 1% level and *, at the 5% level. Log L denotes log likelihood. $Q(6)$ and $Q^2(6)$ are the Ljung-Box statistics with 6 lags for the standardized residuals ($\xi_i, i=1,2$) and their squares.

GARCH process.[13] The dummy variable in Result 3 is positive and significant at the 1% level. This result demonstrates that the currency crisis increased the exchange rate volatility.

Table 2 presents the results of the causality-in-variance test. Using the Wald test, hypothesis testing $H_0 : a_{12} = g_{12} = 0$ is performed on the models. We reported the Wald test statistics and the associated p-values for Results 1 to 3. The null hypothesis that international reserves do not cause exchange rate volatility is rejected at the 1% significance level for Results 1 to 3. This suggests that the volatility of foreign reserves leads to exchange rate volatility. Volatility spillover from international reserves to the exchange rate indicates that foreign exchange intervention has a nonlinear effect on exchange rate volatility. The definition of causality is closely related to forecasting error. If there is no causal relationship in variance between foreign exchange intervention and the exchange rate, then information on foreign exchange intervention does not affect the forecast of exchange rate volatility. This suggests that the expectations of exchange rate volatility are influenced by information about intervention. Next, the null hypothesis—expressed as $H_0 : a_{21} = g_{21} = 0$—that exchange rate volatility does not lead to international reserves volatility is generally rejected. This indicates that the Japanese authority reacts to the exchange rate volatility. Table 2 implies the feedback causal relation in volatility.

Table 2. Causality-in-variance test

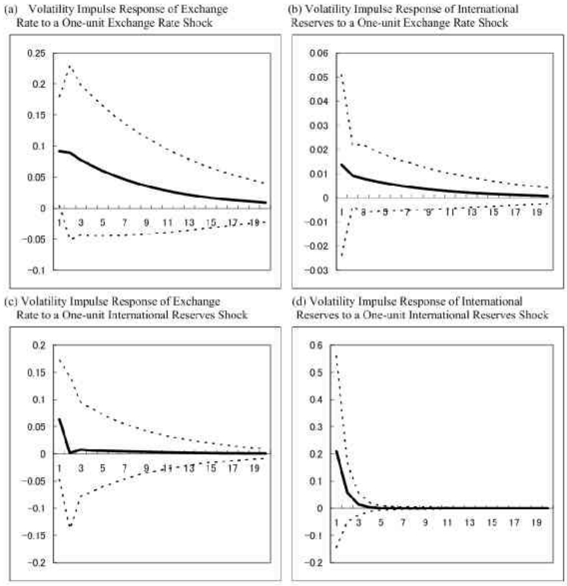
		Wald test statistics	p-value
Full sample (Result 1)			
R does not cause S	$H_0 : a_{12}=g_{12}=0$	10.730	[0.005]
S does not cause R	$H_0 : a_{21}=g_{21}=0$	4.965	[0.084]
Subsample (Result 2)			
R does not cause S	$H_0 : a_{12}=g_{12}=0$	17.511	[0.0002]
S does not cause R	$H_0 : a_{21}=g_{21}=0$	13.541	[0.0011]
With dummy (Result 3)			
R does not cause S	$H_0 : a_{12}=g_{12}=0$	27.956	[0.00]
S does not cause R	$H_0 : a_{21}=g_{21}=0$	23.683	[0.00]

Note: Wald test statistics for the null hypothesis are reported and are distributed as a χ^2 distribution. P-values are reported within parentheses.

4.2 Impulse response of conditional volatility

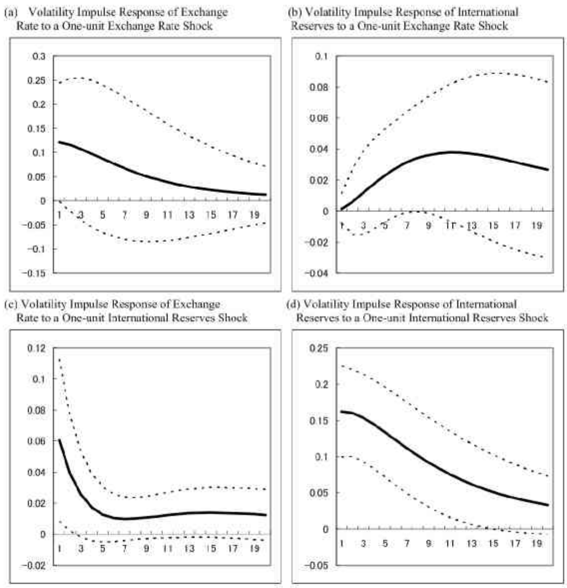
We now report the volatility impulse response function based on Lin (1997). The impulse response functions for the volatility of the yen/dollar exchange rate to a one-unit international reserves shock(shown by solid lines)are plotted in Figure 2(c). The dashed lines illustrate 95% confidence intervals. Figures 2 to 4 report the value of impulse response functions for conditional volatility and their standard errors for Results 1 to 3.

In Figure 2(c), the magnitude of exchange rate volatility caused by a one-unit foreign exchange intervention shock is 0.0635 at the $t+1$ period. At $t+2$, there is



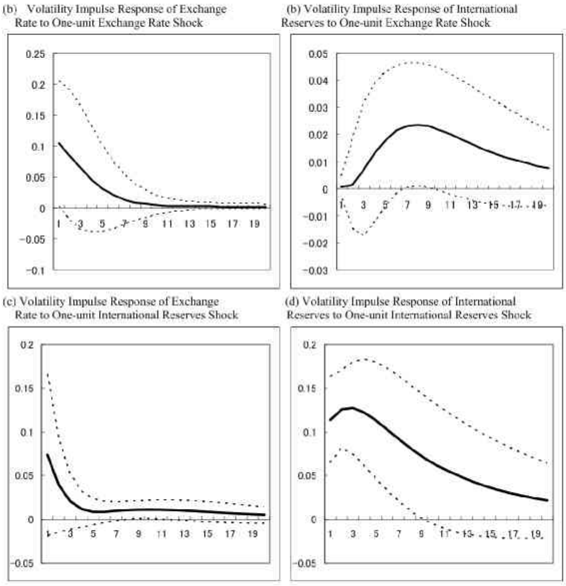
Note: The dashed lines are the 95% confidence intervals, and the solid line is the impulse response.

Figure 2. Volatility Impulse Response Function: Full sample (1973 : 1–2005 : 12)



Note: The dashed lines are the 95% confidence intervals, and the solid line is the impulse response.

Figure 3. Volatility Impulse Response Function: Subsample (1973 : 1–1997 : 6)



Note: The dashed lines are the 95% confidence intervals, and the solid line is the impulse response.

Figure 4. Volatility Impulse Response Function: full sample with dummy

a sudden dip to 0.0016. The impulse response function returns to the 0.0082 level at $t+3$. Further, the shock slowly disappears after $t+3$. The impulse response function captures a dynamic effect of foreign exchange intervention on the expected future exchange rate volatility. However, this is not a significant effect. The volatility impulse response of international reserves to a one-unit exchange rate shock is reported in Figure 2(b). Figures 2(a) and (d) indicate the volatility impulse response to its own shock. Exchange rate volatility gradually declines.

The estimated impulse responses are illustrated in Figures 3 and 4 that use a subsample from 1973:1 to 1997:6 and a full sample with a currency crisis dummy variable, respectively. The subsample period excludes the post-East Asian currency crisis data. Excluding the currency crisis period or including crisis dummy changes the shapes of the impulse response drastically. Figure 3(c) shows that intervention in the foreign exchange market significantly increases the exchange rate volatility in the short run. In Figure 4(c), the impulse response is similar in shape to that in Figure 3(c). These results provide empirical evidence to show that foreign exchange intervention can influence the exchange rate volatility. The reason why interventions increase exchange rate volatility may be the central bank's attempt to correct the exchange rate level. A few years after the Plaza Agreement that occurred in this sample period, the dollar fell by over 50% against the yen. This result indicates that the policy purpose of the authority is the first moment of the exchange rate, and not the second moment. Accordingly, foreign exchange intervention increases exchange rate volatility or uncertainty, as shown in previous studies. In Figures 3(b) and 4(b), the volatility of international reserves increases to some extent following the exchange rate volatility shock. After approximately 10 months, the international reserves volatility begins to fall persistently. This remarkable result shows the nonlinear reaction of the central bank against the exchange rate volatility shock. A comparison of Figures 3 and 4 reveals that the corresponding responses appear similar. In my view, the impulse responses of Figures 3 and 4 are reliable.

Let me summarize the main points that have been made in this section. The results of the causality-in-variance test suggest that there are feedback causal relationships between the exchange rate volatility and international reserves volatility. Furthermore, the impulse response results for conditional volatility suggest that foreign exchange intervention influences exchange rate volatility and that the central bank takes persistent action against the exchange rate volatility shock.

5. Conclusion

This paper investigates whether Japanese foreign exchange intervention influences the exchange rate volatility. To address this question, we adopt the VAR-GARCH model and conduct a volatility impulse response analysis based on Lin (1997) on exchange rate volatility and intervention. The main findings of this paper are as follows: (i) a foreign exchange intervention shock leads to a significant increase in exchange rate volatility; (ii) an exchange rate volatility shock leads to a significant and persistent increase in international reserves volatility; (iii) there are feedback causal relationships between the exchange rate volatility and international reserves volatility. Based on the volatility impulse response analysis, we conclude that foreign exchange intervention increases the exchange rate volatility in the future. Thus, we arrive at the same conclusion as that in Dominguez (1998) and others. However, much remains to be done in this literature. In particular, the identification of a policy shock remains unresolved. However, the volatility impulse response analysis based on Lin (1997) has potential for expansion. For example, it can capture the dynamics of the output volatility arising from monetary policy shocks or foreign exchange intervention shocks.[14] Therefore, there is room for further investigation.

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