ELSEVIER

Journal of International Financial Markets, Institutions and Money 10 (2000) 229–247

Journal of INTERNATIONAL FINANCIAL MARKETS, INSTITUTIONS & MONEY

Foreign reserve and money dynamics with asset portfolio adjustment: international evidence

Reuven Glick [a,*], Michael M. Hutchison [b,1]

[a] *Center for Pacific Basin Monetary and Economic Studies, Federal Reserve Bank of San Francisco, 101 Market Street, San Francisco, CA 94105, USA*

[b] *Department of Economics, Social Sciences 1, University of California, Santa Cruz, CA 95064, USA*

Received 1 November 1998; accepted 5 June 2000

Abstract

In this paper we argue that more complete modeling of foreign exchange intervention and sterilization dynamics is necessary when there are adjustment costs to changing private portfolios and/or the central bank attempts to balance longer-run monetary control against short-term exchange rate objectives. We show that measured correlations between domestic credit and foreign asset changes, often interpreted as 'sterilization coefficients', may be misleading because they vary with the pattern of disturbances as well as private agent and central bank behavior. We assess the empirical significance of this issue by estimating vector error correction models of the domestic and foreign asset components of the monetary base for Japan and Germany. In both countries, we find that that the impact of foreign exchange intervention on domestic credit falls markedly after several months, implying that the degree of sterilization decreases over time. However, the monetary base remained largely insulated as foreign asset positions were subsequently 'unwound.' © 2000 Elsevier Science B.V. All rights reserved.

Keywords: Intervention; Sterilization; Offset coefficients

JEL classification: E51; F33; F41

* Corresponding author. Tel.: + 1-415-9743184; fax: + 1-415-9742168.

E-mail addresses: reuven.glick@sf.frb.org (R. Glick), hutch@cats.ucsc.edu (M.M. Hutchison).

[1] Visiting Scholar, Center for Pacific Basin Monetary and Economic Studies, San Francisco, CA, USA.

PII: S1042-4431(00)00030-5

1. Introduction

The extent to which exchange rate policy may conflict with objectives of domestic output and price stabilization is a central issue facing central banks. Despite the collapse of the Bretton Woods system of fixed exchange rate parities in the early 1970s, central bank intervention in foreign exchange markets continues to be very large in most countries, motivated by explicit rules-based international arrangements to moderate exchange rate variability (e.g. the former European Monetary System) or intermittent discretionary efforts at policy coordination (e.g. Plaza and Louvre Accords). Movements in foreign exchange reserves in Japan and Germany, for example, are large in magnitude and highly correlated with exchange rate swings (see Figs. 1 and 2).

The 'portfolio balance' channel, through which sterilized (non-monetary) intervention changes the currency denomination of relative asset supplies and thereby the risk premium (if assets are imperfect substitutes) and exchange rate, has

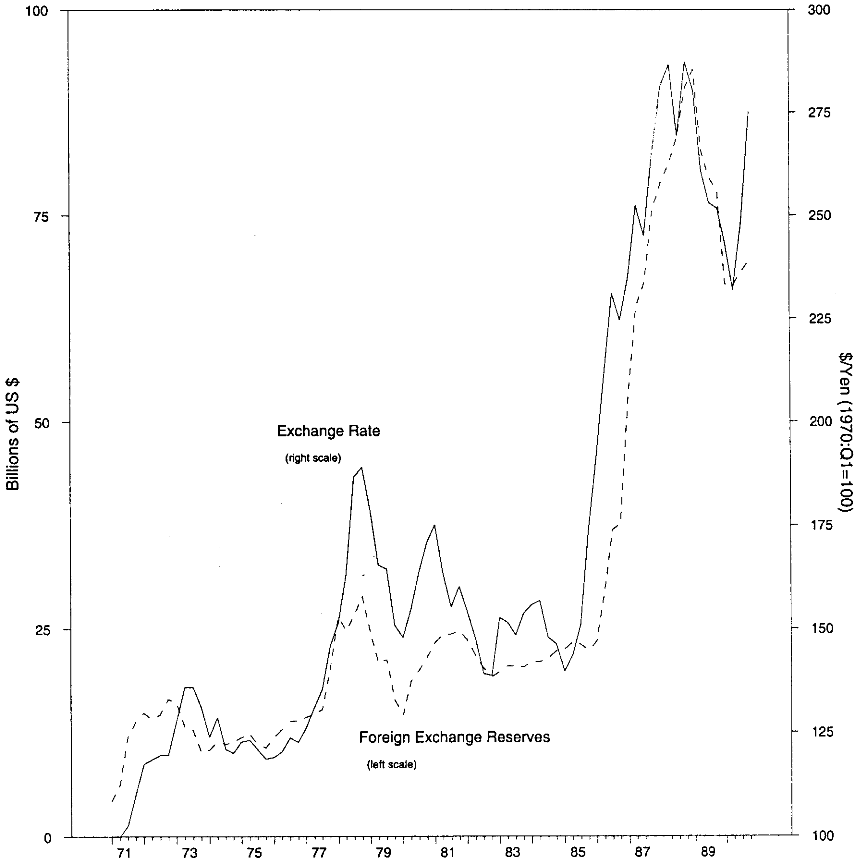

Fig. 1. Japan: exchange rate and foreign exchange reserves.

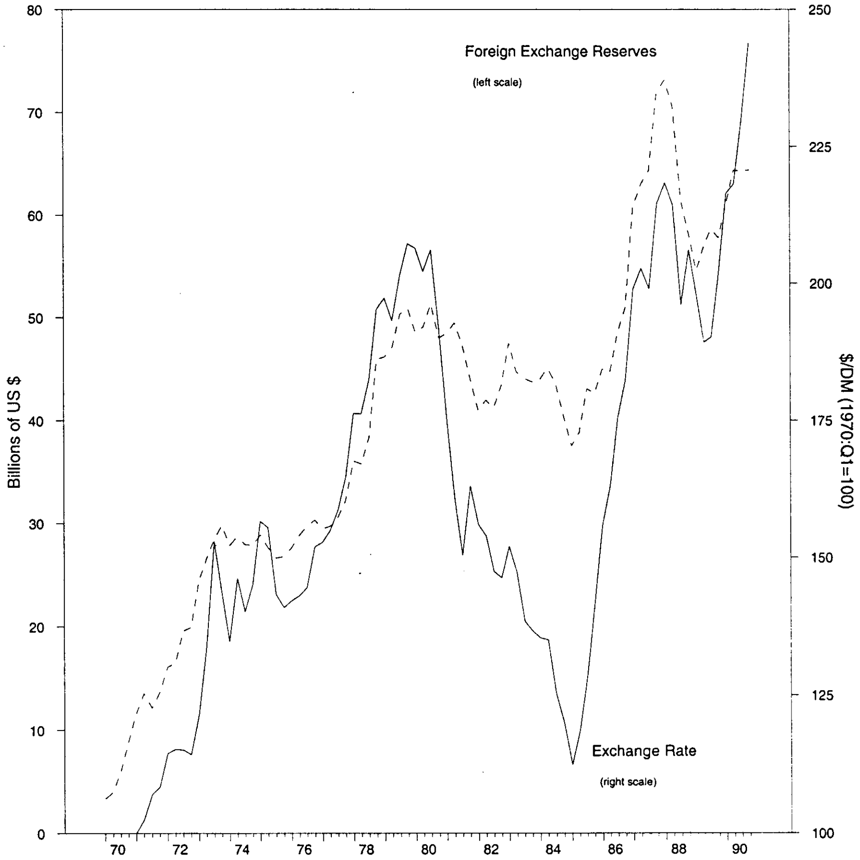

Fig. 2. Germany: exchange rate and foreign exchange reserves.

received little empirical support (Rogoff, 1984; Edison, 1993)[2]. This implies a potential conflict between intervention (responding to exchange rate objectives) and monetary control. There is a large literature devoted to assessing the extent to which central banks choose to sterilize or insulate the domestic monetary base from international reserve inflows and outflows due to foreign exchange market intervention operations. The empirical work in this area typically focuses on estimating domestic credit 'reaction functions,' where the ability to achieve internal objectives (e.g. monetary targets) despite exchange market intervention depends on the degree of international capital mobility and other factors. Studies along this line for Germany include Herring and Marston (1977), Obstfeld (1983), von Hagen (1989), Neuman and von Hagen (1992); Takagi (1991), Glick and Hutchison (1994), Cargill et al. (1997) have undertaken similar studies in the case of Japan.

[2] There is somewhat more support for the 'signaling' channel. See Fatum and Hutchison (1999).

The objective of this article is to re-examine, in both theoretical and empirical terms, the external/internal policy tradeoff problem. Our contribution focuses on two aspects of the way central banks manage long-run monetary stability with short-term exchange rate stability objectives: (i) the dynamic effects of intervention operations, and (ii) instability in intervention and sterilization relationships. Consider the effects of a sterilized intervention operation (e.g. a central bank purchase of foreign exchange and sale of domestic bonds) when short-term private portfolio adjustment is costly. In this case, intervention has an immediate effect on exchange rates and interest rates, but also sets in motion (because private portfolio holders adjust only gradually) further portfolio adjustments and effects which in turn may elicit additional intervention and sterilization operations by the central bank. Even if private market adjustment is instantaneous, the central bank may consciously follow a dynamic intervention and sterilization strategy in conjunction with its desire to maintain monetary control. For example, bouts of large foreign exchange sales (purchases) in turbulent periods may be followed by a sequence of smaller purchases (sales) in more tranquil periods as the central bank attempts to replenish (draw down) international reserves and limit the ultimate effects on the monetary base.

Instability in observed relationships between intervention and sterilization may arise from a variety of sources. We focus on the variation over time of the underlying disturbances moving exchange rates and other macroeconomic variables. Because foreign asset and domestic credit holdings of the central bank are both endogenous variables, responding differently over time to different types of disturbances, it may be difficult to identify simple 'sterilization' coefficients. Identifying these fundamental disturbances is an important first step in determining the influence of intervention operations on domestic credit and hence its monetary effects.

We illustrate these points analytically in the context of a simple stylized portfolio balance model where the effects of an intervention operation or other disturbance are distributed over time because of portfolio adjustment costs. We calculate impact and longer-term effects arising from these disturbances and draw out the implications for various measures of sterilization. To investigate whether these issues have empirical significance, we consider the dynamics of intervention and sterilization operations in Japan and Germany during the post-Bretton Woods period. Using a vector error correction model (VECM), we are able to separate the short- from the long-term effects of foreign exchange market operations on domestic credit and the monetary base.

The results illustrate the importance of looking beyond the simple impact effects of intervention operations on domestic credit. For both Japan and Germany we find very similar dynamic patterns whereby foreign exchange purchases (sales) are partially offset by counteracting sales (purchases) over a period of ~ 6 months. We find that in both Japan and Germany monetary control has been largely insulated from foreign exchange market interventions through a combination of sterilization operations and the 'unwinding' of foreign exchange positions.

The next section develops the analytical model. Section 3 describes the methodology of the Johansen vector error correction time-series model that we employ in our empirical analysis, discusses the data, and presents the empirical results. Section 4 concludes the paper.

2. Dynamic effects of intervention and sterilization operations

In this section we construct a financial model of a small open economy with monetary authorities that conduct intervention and sterilization operations in asset markets. The specification of the model is intended to illustrate the dynamic adjustment properties of the central bank's foreign reserve and domestic asset holdings in a simple framework[3]. The dynamics in this model come from partial adjustment of private portfolios to current disturbances.

Domestic residents hold domestic money, domestic bonds, and foreign bonds. Domestic private demands for money and bonds are specified as follows:

$$M_t^d = \alpha[p_t + y_t - \beta i_t + \varepsilon_{Mt}] + (1-\alpha)M_{t-1}^d \tag{1}$$

$$B_t^d = \alpha[-(p_t + y_t) + \delta s_t + \delta_1 i_t - \delta_2 i_t^* + \varepsilon_{Bt}] + (1-\alpha)B_{t-1}^{\mathrm{d}} \tag{2}$$

Domestic money demand depends positively on domestic prices p_t and domestic income y_t because of transaction effects, and negatively on the domestic interest rate i_t because of asset substitution. Domestic bond demand depends inversely on the same variables, negatively on the foreign interest rate i_t^* because of substitution effects, and positively on the domestic currency price of foreign exchange s_t because of wealth or expectations effects of the exchange rate on bond demand[4]. The assumption that assets are gross substitutes implies $\beta < \delta_1$. Asset demands also depend on other exogenous variables, ε_M and ε_B, and are characterized by a partial adjustment mechanism whereby short-run demands approach their long-run levels with the speed of adjustment α[5].

On the supply side, the central bank's balance sheet implies

$$M_t^s = \mathrm{FA}_t + \mathrm{DC}_t \tag{3}$$

$$B_t^s = \bar{B}_t - \mathrm{DC}_t \tag{4}$$

[3] See Cuddington (1991, 1993) who utilizes a similar specification to construct measures of exchange rate flexibility.

[4] A domestic currency depreciation positively affects domestic bond demand by raising the domestic currency value of foreign assets (the wealth effect) or, if expectations are regressive, by creating an expected appreciation that lowers the return to holding foreign assets (the expectations effect). The exchange rate can also affect asset market equilibrium via a transaction demand channel through its effect on the domestic-currency price of foreign goods. This channel is easily incorporated into the analysis without affecting results.

[5] We also abstract from more complicated lagged adjustment mechanisms to simplify the exposition.

The money supply equals the sum of the central bank's holdings of foreign asset reserves FA_t plus its supply of bond-backed domestic credit DC_t. The total supply of domestic bonds available to the private sector equals the total supply of bonds issued by the government $\bar{B}$ net of the central bank's holdings of bonds DC_t.

The following semi-reduced form expression involving FA_t and DC_t may be obtained by (i) assuming money market equilibrium, i.e. $M_t^s = M_t^d$, and equating Eqs. (1) and (3), (ii) assuming bond market equilibrium holds, i.e. $B_t^s = B_t^d$ equating Eqs. (2) and (4) and solving for i_t, and (iii) substituting for i_t in the first expression:

$$\mathrm{FA}_t = -\left(1 - \frac{\beta}{\delta_1}\right)\mathrm{DC}_t + (1-\alpha)\left(1 - \frac{\beta}{\delta_1}\right)\mathrm{DC}_{t-1} + \alpha\beta\left(\frac{\delta}{\delta_1}\right)s_t + \alpha z_t + (1-\alpha)\mathrm{FA}_{t-1} \tag{5}$$

where $z_t \equiv z_{Mt} + (\beta/\delta_1)z_{Bt}$ is a composite asset excess demand disturbance term, $z_{Bt} \equiv -p_t - \delta_2 i_t^* - y_t + \varepsilon_{Bt}$, is a composite bond market excess demand disturbance term, and $z_{Mt} \equiv p_t + y_t + \varepsilon_{Mt}$ is a composite money market excess demand disturbance term.

Eq. (5) is similar to the semi-reduced form capital flow equations estimated in studies of the offset coefficient. It implies that, all other things constant, the offset of a current or lagged domestic credit expansion in foreign reserves is negative but less than unity (because $\beta < \delta_1$). In the special case of perfect asset substitutability $\delta_1 = \delta_2 \to \infty$, domestic and foreign interest rates are always equal and the offset coefficient is equal to minus one.

Solving Eq. (5) for s_t gives

$$s_t = \frac{\mathrm{FA}_t + (1-\beta/\delta_1)\mathrm{DC}_t - (1-\alpha)(1-\beta/\delta_1)\mathrm{DC}_{t-1} - \alpha z_t - (1-\alpha)\mathrm{FA}_{t-1}}{\alpha\delta(\beta/\delta_1)} \tag{6}$$

Eq. (6) represents a reduced-form expression for the equilibrium exchange rate that equates private money and bond demands with supply. The domestic currency depreciates (s rises) in response to an increase in current levels of foreian reserves FA_t or domestic credit DC_t or to a decrease in excess asset demand z_t. The exchange rate depends negatively on lagged money aggregate components as long as the speed of asset market adjustment is less than infinite ($\alpha < 1$).

The central bank is assumed to adjust its holdings of foreign reserves and bonds in response to movements in the exchange rate and other exogenous factors z_D, respectively, according to the following intervention and sterilization equations:

$$\mathrm{FA}_t = -(\rho_M + \rho_B)s_t \tag{7}$$

$$\mathrm{DC}_t = \rho_B s_t + \gamma_D z_{Dt} \tag{8}$$

The parameter $\rho_M + \rho_B$ measures the intensity of the central bank's intervention actions against changes in the exchange rate. It is assumed $\rho_M + \rho_B > 0$ indicating that such actions involve 'leaning against the wind.' The parameter ρ_B measures the desire of the central bank to sterilize unwanted current changes in the monetary base resulting from its intervention in the foreign exchange market. z_D may be interpreted as representing exogenous factors influencing the target level of the domestic credit component of the money supply, aside from the exchange rate.

While z_D may depend on some of the same factors as z, such as y and p for example, for simplicity, we assume z_D and z are uncorrelated. $\gamma_D > 0$ indicates a desire by authorities to accumulate domestic bonds. Note Eqs. (3), (7) and (8) imply $M_t^s = -\rho_M s_t + \gamma_d z_{Dt}$. Unsterilized intervention is represented by $\rho_M > 0$ and $\rho_B = 0$. Sterilized intervention is represented by $\rho_M = 0$ and $\rho_B > 0$.

Substituting Eq. (6) for s_t in Eqs. (7) and (8) gives two equations in FA_t and DC_t (and their lags) as well as the two disturbance terms z_t and z_{Dt}. Expressing the system in matrix form, dropping the terms involving $\bar{B}$ for convenience, and solving gives

$$\begin{bmatrix} \mathrm{FA}_t \\ \mathrm{DC}_t \end{bmatrix} = \frac{(1-\alpha)}{\Omega} \begin{bmatrix} (\rho_M + \rho_B) & (\rho_M + \rho_B)(1 - \beta/\delta_1) \\ -\rho_B & -\rho_B(1 - \beta/\delta_1) \end{bmatrix} \begin{bmatrix} \mathrm{FA}_{t-1} \\ \mathrm{DC}_{t-1} \end{bmatrix} + \frac{1}{\Omega} \begin{bmatrix} \alpha(\rho_M + \rho_B) & -(\rho_M + \rho_B)(1 - \beta/\delta_1)\gamma_D \\ -\alpha\rho_B & [\Omega + \rho_B(1 - \beta/\delta_1)]\gamma_D \end{bmatrix} \begin{bmatrix} z_t \\ z_{Dt} \end{bmatrix} \tag{9}$$

where $\Omega = \rho_M + \rho_B(\beta/\delta_1) + \alpha\delta(\beta/\delta_1) > 0$. The system is in the form of a vector autoregression because FA_t and DC_t each depend on lags of each other (if $\alpha < 1$) as well as on the contemporaneous disturbances to the system (if $\rho_M, \rho_B \neq 0$) — z_t and z_{Dt}[6].

Inspection of Eq. (9) yields the following impact multipliers for the effects of private asset demand shocks and domestic credit shocks:

$$\frac{\Delta \mathrm{FA}_t}{\Delta z_t} = \frac{\alpha(\rho_M + \rho_B)}{\Omega} > 0 \tag{10}$$

$$\frac{\Delta \mathrm{DC}_t}{\Delta z_t} = -\frac{\alpha\rho_B}{\Omega} < 0 \tag{11}$$

$$\frac{\Delta \mathrm{FA}_t}{\Delta z_{Dt}} = -\left[\frac{\rho_M + \rho_B}{\Omega}\right]\left[1 - \frac{\beta}{\delta_1}\right]\gamma_D < 0 \tag{12}$$

$$\frac{\Delta \mathrm{DC}_t}{\Delta z_{Dt}} = \left[1 + \frac{p_B}{\Omega}\left[1 - \frac{\beta}{\delta_1}\right]\right]\gamma_D > 0 \tag{13}$$

It is apparent that the adjustment responses of foreign assets and domestic credit depend on private sector asset demand parameters (β, δ, δ_1), the asset speed of adjustment (α), and central bank intervention parameters (ρ_M, ρ_B), as well as on the nature of the underlying disturbance.

---

[6] This system has the single root $\Omega/[(1-\alpha)(\rho_M + \rho_B\beta/\delta_1)] > 1$, implying that it is stable.

If the underlying disturbance arises from a private sector shock z_t in the form of, say, an exogenous purchase of domestic bonds by foreigners (ε_{Bt}), Eqs. (10) and (11) imply that the initial impact is for the central bank's holdings of foreign asset to rise and domestic credit to fall. Intuitively, FA_t depends positively on current excess private asset demand z_t because the resulting pressure for domestic currency appreciation induces the accumulation of foreign assets through 'leaning-against-the-wind' intervention actions. To the extent the central bank seeks to sterilize the effects of the rise in foreign assets in response to the currency appreciation ($\rho_B > 0$), the foreign asset demand shock induces an offsetting decline in domestic credit. The magnitude of the asset changes depends on the intensity of intervention and the speed of asset adjustment. For example, as ρ_M declines and intervention lessens, the exchange rate is allowed to adjust more and the direct impact on foreign assets declines. As α falls and asset markets adjust less quickly, the less the change of the current exchange rate in response to the asset demand shock and the less the need for immediate intervention.

Eqs. (12) and (13) give the impact multipliers for an exogenous increase in domestic credit in the form of an exogenous open market purchase by the central bank. From Eq. (12), a domestic credit shock z_{Dt} leads to a decline in foreign assets as the government intervenes against the depreciation of the domestic currency induced by the corresponding increase in the money supply[7]. As ρ_M declines (intervention is less), the exchange rate is allowed to adjust more and the direct impact on foreign assets declines. In the absence of any intervention, sterilized or unsterilized, ρ_M and ρ_B equal zero, the exchange rate floats freely, and there is no direct impact on foreign assets[8]. From Eq. (13), the impact effect on domestic credit of a z_{Dt} shock is positive. Intuitively, an increase in z_{Dt} increases the targeted level of domestic credit directly. In addition, the corresponding increase in the money supply depreciates the currency, inducing intervention by the sale of foreign assets. Sterilizing the effects of this intervention leads to a further increase in DC_t.

Eqs. (10)–(13) together imply that the apparent degree of sterilization as measured by the contemporaneous movement in domestic credit and foreign exchange reserves depends on the type of disturbance. Specifically, in the case of a domestic credit shock z_{Dt} the contemporaneous correlation is given by

$$\frac{\Delta \mathrm{DC}_t/\Delta z_{Dt}}{\Delta \mathrm{FA}_t/\Delta z_{Dt}} = -\frac{\Omega + \rho_B(1-\beta/\delta_1)}{(\rho_M+\rho_B)(1-\beta/\delta_1)} < 0$$

[7] It should be noted that the second bracketed term in Eq. (12) is the traditional offset coefficient. The term in the first set of brackets reflects the extent to which the exchange rate is managed. For ρ_M equal to infinity, resulting in a fixed exchange rate, this term equals unity and foreign assets fall by $1-(\beta/\delta_1)$. This can be seen more clearly by using the definition of Ω to rewrite the first term as $(1+\rho_B/\rho_M)/(1+\Omega'/\rho_M)$ where $\Omega' \equiv (\beta/\delta_1)\rho_B + (\alpha\delta\beta/\delta_1)$.

[8] Observe also that the impact offset coefficient depends not just on the central bank's intervention and sterilization intensity but also on the speed of asset adjustment α (through Ω). As α rises and asset markets adjust more quickly, the less the change of the exchange rate in response to the domestic credit shock and the less the change in foreign assets.

while, if the underlying shock arises from a private sector shock z_t, it can be shown that the contemporaneous correlation is

$$\frac{\Delta \mathrm{DC}_t/\Delta z_t}{\Delta \mathrm{FA}_t/\Delta z_t} = -\frac{\rho_B}{(\rho_M + \rho_B)} < 0$$

A comparison of these two expressions indicates that a given increase in foreign assets is associated with a smaller decline in domestic credit in the case of a z shock than a z_D shock, implying a lesser degree of sterilization. This points to the difficulty in interpreting simple correlations between DC_t and FA_t. Because both are endogenous variables, the contemporaneous correlation between them depends on structural parameters and underlying fundamental disturbances.

Eq. (9) yields long-term dynamic implications for the adjustment responses of FA_t and DC_t as well. We address here the response to a private sector shock z_t in the form of, say, an exogenous purchase of domestic bonds by foreigners (ε_{Bt}), the focus of our empirical analysis in Section 3. It can be shown that[9]

$$\frac{\Delta \mathrm{FA}_{t+n}}{\Delta z_t} = \left[\frac{(1-\alpha)(\rho_M + \rho_B\beta/\delta_1)}{\Omega}\right]^n \left[\frac{\alpha(\rho_M + \rho_B)}{\Omega}\right] > 0 \tag{14}$$

$$\frac{\Delta \mathrm{DC}_{t+n}}{\Delta z_t} = -\left[\frac{(1-\alpha)(\rho_M + \rho_B\beta/\delta_1)}{\Omega}\right]^n \left[\frac{\alpha\rho_B}{\Omega}\right] < 0 \tag{15}$$

Observe that a temporary shock has long-term effects on the adjustment of the central bank's foreign assets and domestic credit, when there are portfolio adjustment costs ($\alpha < 1$). When private portfolio adjustment takes time, the central bank will have to sterilize a continuing inflow (outflow) of foreign exchange over time following an initial foreign (domestic) currency-support intervention operation. Observe also that, since the term in the first set of square brackets is less than one, the response of FA_t and DC_t declines over time.

In practice, of course, the dynamics will be more complicated than this stylized model suggests. For example, this specification assumes the 'intensity' of central bank intervention and sterilization is constant over time and, therefore, does not capture features of a dynamic strategy implicit when a central bank states that it is concerned with medium-term control of the money supply. Nonetheless, the model serves to illustrate the importance of identifying fundamental disturbances, and how the complete path of intervention and sterilization operations over time needs to be investigated in order to capture the ultimate net effect of particular shocks on the monetary base. We allow for a much richer dynamic structure in the empirical model below.

[9] The system in Eq. (9) can be expressed more compactly as $Y_t = ABY_{t-1} + CZ_t$, where $Y_t \equiv [\mathrm{FA}_t, \mathrm{DC}_t]'$, $Z_t = [z_t, z_{Dt}]'$, $A \equiv (1-\alpha)/\Omega$, and B and C denote the first and second matrices of coefficients in Eq. (9), respectively. It is straightforward to show that the nth period multiplier for the response to shocks at time t is given by $\Delta Y_{t+n}/\Delta Z_t = C(AB)^n = CA^nB(\rho_M + \rho_B\beta/\delta_1)^{n-1}$.

3. Empirical analysis

3.1. Methodology

The discussion in Section 2 emphasizes the need to investigate the complete dynamic path of private market as well as of central bank portfolio adjustment behavior. To do so we employ a time-series methodology. Specifically, we examine a data system (X_t) consisting of the logarithm of real output as measured by industrial production (IP), the logarithm of the consumer price level (CPI), central bank foreign assets (FA), and central bank domestic assets (DC). Because the time series elements of X_t are likely nonstationary processes, the model is expressed in first differences in vector error-correction model (VECM) form:

$$\Delta X_t = \Gamma_1 \Delta X_{t-1} + \ldots + \Gamma_{k-1} \Delta X_{t-k+1} + \pi X_{t-k} + \varphi D + \mu + v_t \tag{16}$$

where Γ, π, and φ are matrices of coefficients, $\Delta = 1 - L$ (L is the lag operator), k denotes the lag length, D is a vector of seasonal dummy variables, and μ is a constant. This is related closely to the system in Eq. (9), but with y and p, proxied by IP and the CPI, now treated as endogenous variables, and allowance for a more complex dynamic structure and interactions among the variables.

We denote the composite errors to the four equations of the model as v_y, v_p, v_{FA}, v_{DC}, using this ordering in a recursive Choleski decomposition to identify the contemporaneous disturbances, so that shocks to domestic credit and foreign assets do not influence either output or prices within the current month. The foreign asset shock v_{FA}, the focus of our interest, is identified as having an immediate effect on domestic credit, but influences output and prices with a one-month lag. We may think of v_{FA} as analogous to a shock to domestic bond demand (ε_B), perhaps due to an exogenous foreign capital inflow, which simultaneously influences foreign assets and domestic credit.

3.2. Data and unit root tests

The variables of interest in the empirical analysis are the domestic assets of the central bank (DC), foreign assets of the central bank (FA), the logarithm of the consumer price level (CPI), and the logarithm of industrial production (IP) for Japan and Germany. The data consist of monthly observations over the sample period of 1978–1990 for Japan and 1974–1990 for Germany. The Japanese sample period begins with the start of public announcements of central bank money growth projections, which were part of the 'money-focused' monetary policy introduced in the late 1970s (Suzuki, 1985; Fukui, 1986). The German sample period begins with the collapse of the Bretton Woods system of fixed exchange rates, allowing for several observations at the beginning of the new regime to incorporate lagged values. Both samples end in 1990 due to evidence of structural changes occurring in the 1990s. The source and construction of data are presented in the Appendix A.

Both univariate and multivariate unit root test are conducted to determine whether or not the variables are non-stationary. Dickey–Fuller, augmented Dickey–Fuller, and Phillips–Perron univariate test statistics (unreported) generally indicate that the unit root null hypothesis cannot be rejected for the FA and DC variables in (log) level form for both Japan and Germany and for Japanese CPI and IP. However, German CPI and IP appear to be stationary according to these tests. All of the univariate tests overwhelmingly reject the unit root null hypothesis for the variables in first difference form[10]. Table 1 presents stationarity tests (with a null hypothesis of stationarity) using the Johansen multivariate procedure[11] (Johansen, 1991). These tests indicate that all of the variables, including German CPI and IP, are non-stationary in levels (i.e. the null hypothesis is rejected) when one cointegrating vector is assumed (as is suggested in the next section). Because the bulk of the evidence indicates the variables are non-stationary in levels, but stationary in differences, we proceed on this assumption and test for cointegration[12].

Table 1
Multivariate stationarity tests log likelihood ratio test[a]

p–r	*R*	DC	FA	CPI	IP	USIR	95% Critical value
Japan							
4	1	23.18	19.41	17.89	21.03	13.04	9.49
3	2	13.10	8.90	9.46	10.52	2.89	7.81
2	3	11.87	6.63	6.74	8.70	2.72	5.99
1	4	6.73	2.22	5.45	6.68	0.12	3.84
Germany							
4	1	29.70	36.31	37.22	34.69	35.01	9.49
3	2	9.72	16.86	16.40	16.08	16.89	7.81
2	3	1.05	3.30	2.87	2.43	3.17	5.99
1	4	1.05	0.94	0.85	0.01	0.68	3.84

[a] Note: the model is estimated with 11 seasonal dummies and unconstrained constant term. Test statistic is χ^2 distributed with p–r degrees of freedom, where p is the number of endogenous variables and r is number of cointegrating vectors postulated. Null hypothesis is that the focus variable is stationary.

[10] These results are available upon request. A unit root is rejected with the Dickey–Fuller test for Japanese FA and with the Phillips–Perron test for Japanese CPI at 5%, though not at 10%, significance levels.

[11] The multivariate tests also include the 3-month US Treasury bill rate (USIR), included in increased variants of the time series models estimated in the following section. See footnote 13.

[12] A number of studies of the inflation process in industrial countries in the post-war period have found evidence that the inflation rate is not stationary (Culver and Papell, 1997), or that it has a long memory, even if mean reverting (Baillie et al., 1996). However, Japan is generally an exception in these studies, where the hypothesis of a stationary inflation rate cannot be rejected. Moreover, our finding of a stationary inflation rate for Germany may be attributable to the shorter time series that we use.

Table 2
Johansen maximum likelihood cointegration tests[a]

	Japan				Germany		
Null	Alternative	Statistic	Critical value		Statistic	Critical value	
			95%	90%		95%	90%
Maximum eigenvalue							
$r=0$	$r\geq 1$	22.75	27.14	24.78	27.87**	27.14	24.78
$r\geq 1$	$r\geq 2$	14.65	21.07	18.90	9.47	21.07	18.90
$r\geq 2$	$r\geq 3$	6.07	14.90	12.91	4.50	14.90	12.91
$r\geq 3$	$r\geq 4$	0.55	8.18	6.50	0.21	8.18	6.50
Trace							
$r=0$	$r\geq 1$	44.02	48.28	45.23	42.05	48.28	45.23
$r\geq 1$	$r\geq 2$	21.28	31.53	28.71	14.18	31.53	28.71
$r\geq 2$	$r\geq 3$	6.63	17.95	15.66	4.71	17.95	15.66
$r\geq 3$	$r\geq 4$	0.55	8.18	6.50	0.21	8.18	6.50

[a] Note: a constant and 11 seasonal dummy variables are included in all estimations.
** (*) denotes a 5% (10%) significance.

3.3. Cointegration test results and formulation of the VECM model

Table 2 presents Johansen maximum likelihood cointegration tests, based on both maximum eigenvalue and trace statistics, using four-variable systems (DC, FA, CPI, and IP) for Japan and Germany (Johansen and Juselius, 1990). Seasonally unadjusted data are used in the tests, which include constant terms and eleven seasonal dummy variables. The lag length of the VECM model in which the cointegrating tests are imbedded is 6 months.

The Japanese cointegration results are consistent across both the maximum likelihood and trace tests. They indicate that no cointegrating vectors exist, and the Japanese system is modeled as a VAR in first-differences with no error correction mechanism.

The maximum eigenvalue test on the German system indicates the presence of one cointegrating vector, but no cointegrating vectors are suggested by the trace test. We model the German system as a VECM with a single error correction term, i.e. a VAR system in first-differences with a single cointegrating vector imposed to capture the equilibrium relationship in the levels data[13].

[13] We also consider an expanded five-variable model that includes the US 3-month Treasury bill interest rate, ordered before the foreign asset variable. In the five-variable Japanese system, the maximum eigenvalue test suggests the presence of at most one cointegrating vector, while the trace test indicates that no cointegrating vectors exist. Both cointegration tests indicate the presence of a single cointegrating vector in the five-variable German system. Modeling the five-variable Japanese and German systems as VECMs with a single error correction term gives virtually identical results as those with their respective four-variable systems, and are not presented for brevity.

3.4. Variance decompositions

Table 3 presents the forecast error variance decompositions of domestic credit using the VECM model estimates and identifying restrictions described in Section 3.3. In every case, foreign asset shocks dominate other disturbances in explaining unexpected movements in domestic credit. These range from 40% of the explained variance (Japan, 30 months ahead) to 92% (German, 5 months ahead). Regardless of the forecast horizon, it appears that a substantial part of domestic credit movements represents a response to fluctuations in foreign asset holdings of the central bank.

3.5. Impulse response functions

Figs. 3 and 4 present the response of domestic credit (upper panel), foreign assets (middle panel) and the monetary base (MBS, lower panel) to a one unit rise in foreign assets held by the Bank of Japan and Bundesbank, respectively. Ninety-five percent confidence boundaries are shown[14]. The impulse responses from the four-variable, six-lag VAR model (for Japan) and VECM model (for Germany) are shown. The cumulative monetary base response to the foreign asset shock need not be estimated separately as it is simply the sum of the domestic credit and foreign asset responses.

Turning to the upper panel in Fig. 3, the model estimates indicate that a foreign asset purchase by the Bank of Japan is followed by an initial sterilization of $\sim 80\%$,

Table 3
Domestic credit variance decompositions

Step	IP	CPI	FA	DC
Japan				
1	2	0	54	44
5	3	3	56	38
10	2	5	49	44
20	2	6	42	50
30	2	6	40	52
Germany				
1	3	2	84	11
5	1	5	92	2
10	3	10	86	1
20	16	13	68	3
30	28	11	56	5

[14] Standard error bands for the impulse response functions are found by taking 1000 draws from a Normal-inverse Wishart distribution, shocking the variance-covariance matrix of the VAR residuals (the posterior distribution of the VAR coefficients) and calculating impulse responses for each draw. We compute the confidence band by calculating boundaries such that 5% (50 draws) of the simulated values lie above the upper boundary value and 5% lie below the lower boundary value.

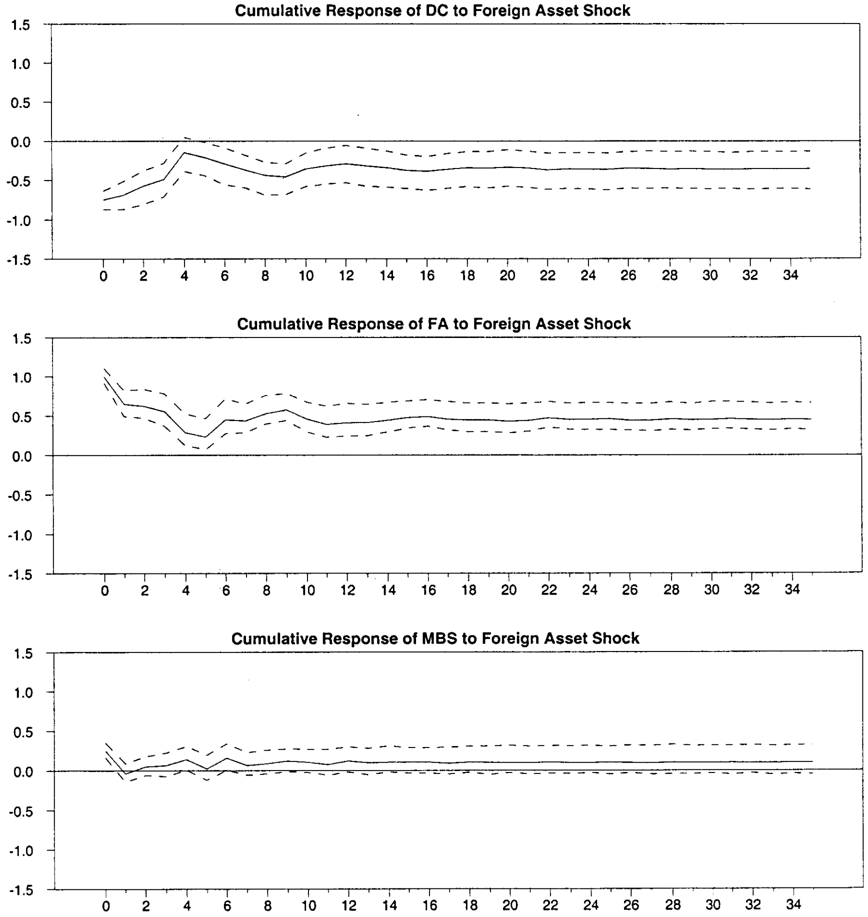

Fig. 3. Japan: impulse responses.

but that this weakens over time to a value of $\sim 40\%$ after 4–6 months. In Fig. 4, initial Bundesbank sterilization appears to be 100%, but also declines over time to a value of $\sim 50\%$ after 2 years. In both cases, very high sterilization coefficients, presumably indicating an initially high degree of insulation from exchange rate policy actions, decline markedly over time.

Interestingly, however, in both Japan and Germany lower sterilization coefficients over time do not seem to indicate any lack of monetary control. The monetary base in both cases (lower panel in Figs. 3 and 4) does not seemingly respond to foreign exchange market intervention at either the short horizon, when offsetting sterilization operations in domestic credit appears high, or longer (two year) horizons, when offsetting sterilization operations in domestic credit appears low.

The reason for this seeming anomaly, shown in the middle panel of Figs. 3 and 4, is that both the Bank of Japan and Bundesbank seem to partly 'unwind' their initial intervention operations (purchases of foreign assets) within about four to six months through offsetting interventions (sales of foreign assets). The combination of the two offsetting operations — partly on domestic credit and partly on foreign assets — largely insulates the monetary base, and presumably the broader monetary aggregates, from exchange rate policy in Japan and Germany over the sample periods investigated.

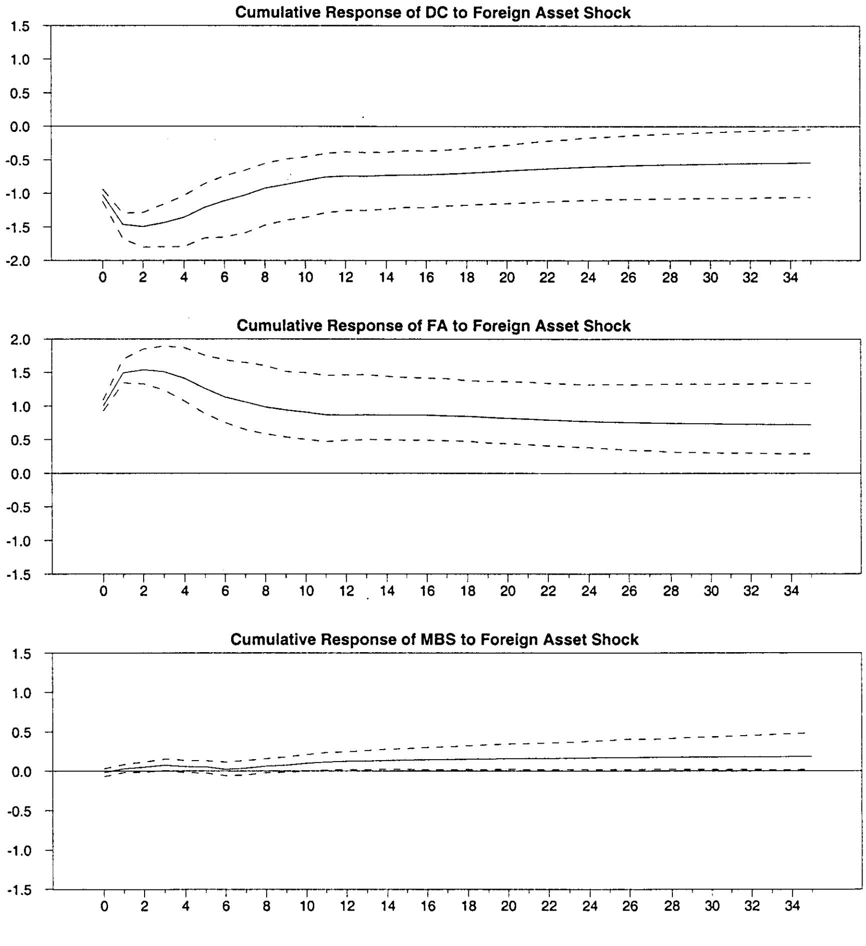

Fig. 4. Germany: impulse responses.

3.6. Comparison with other empirical studies

It is useful to compare our results with other studies for Germany and Japan[15]. Obstfeld (1983) estimates a domestic credit equation for Germany over the 1975–81 period and finds that, once the output gap and inflation are taken into account, the Bundesbank completely sterilizes intervention. We also find a complete offset in the very short run, but sterilization falls gradually as the initial intervention operation is unwound. We reach a similar conclusion as Obstfeld — little monetary effect of intervention policy — but for a different reason.

von Hagen (1989) considers the dynamic effects of intervention operations and finds that the Bundesbank completely sterilizes in the short run, but not in the long run. Neuman and von Hagen (1992) similarly argue that intervention effects on the monetary base are not sterilized permanently, especially when the deutsche mark is strong against both the dollar and EMS currencies. Looking at the relationship of foreign assets on the monetary base alone, we obtain quite similar results to von Hagen (1989) and Neuman and von Hagen (1992). However, because we find that a substantial part of the initial foreign exchange intervention is eventually reversed, the net effect on the monetary base appears to be quite small.

Takagi (1991) directly estimates a single equation for the monetary base in Japan over the 1973–89 period. His explanatory variables are contemporaneous foreign asset changes, the call money rate, inflation and, introducing some dynamics, a lagged value of the monetary base. He finds that the Bank of Japan completely sterilized its reserve movements over the entire sample period, i.e. foreign reserve changes did not influence the monetary base. However, he presents some evidence that the Bank of Japan became more accommodative in the late 1980s, perhaps in response to an upward shift in money demand. Our results, by contrast, indicate that the Bank of Japan was able to insulate base money growth from intervention operations partly by sterilization operations (with less than full sterilization in the medium term) and partly by unwinding its foreign asset position.

Also for Japan, Watanabe (1994) tests the signalling hypothesis of the effectiveness of central bank intervention. Watanabe presents empirical evidence that the Bank of Japan foreign exchange operations consistently preceded changes in the stance of monetary policy. Specifically, he finds that foreign exchange purchases (sales) are generally followed by declines (increases) in the discount rate within 1–3 months and by increases (decreases) in the broad money supply in real terms over a period of more than 2 years. Our results, by contrast, do not suggest that intervention operations lead to significant changes in the money supply over the medium-term horizon.

It is also noteworthy that Ito (1987) emphasizes the Bank of Japan's 'reserve intervention' policy following the G5 Plaza agreement. After heavy sales of dollars in a coordinated move with other central banks immediately following the September 22, 1985 agreement, the Bank of Japan eventually became concerned about the

[15] See Edison (1993) for a of the literature on intervention and monetary control.

rapid appreciation of the yen. The Bank started reverse intervention (dollar purchases) operations in March 1986 when the yen hit the 175 yen/$ level. Our results are consistent with Ito (1987) in the emphasis on reverse intervention. Our results, however, also indicate that it may constitute an important part of a dynamic intervention strategy.

4. Conclusion

In this paper we argue that more complete modeling of intervention and sterilization dynamics needs to be considered when (i) there are adjustment costs to re-balancing private portfolios or (ii) central banks' short- and longer-term behavior and objectives differ. We demonstrate these points in the context of a simple portfolio balance model. Observed correlations between domestic credit and foreign asset changes, often interpreted as 'sterilization coefficients,' may also be misleading since they will vary with the particular pattern of fundamental disturbances as well as over time with private agent and central bank behavior.

We consider simple VECM models for Japan and Germany to investigate the practical import of our argument. We find that the direct impact of a given foreign exchange market intervention on domestic credit varies falls markedly after a few months, implying the degree of sterilization lessens.

Nonetheless, we conclude that the monetary base has been in large part insulated from exchange rate policies in Japan and Germany over most of the post-Bretton Woods period. This is because both central banks apparently make systematic efforts to 'unwind' their foreign asset positions after initial intervention actions. The experiences from these central banks in successfully balancing longer-run monetary control against short-term exchange rate objectives in the 1970s and 1980s may provide lessons for other central banks, particularly the new European System of Central Banks.

Acknowledgements

We thank Robert Marquez for valuable research assistance and Charles Pigott for providing data. We have received helpful comments from Michael Bergman, Shinji Takagi, Boo Sjöö, and other seminar participants at the University of Gothenburg, Lund University, Copenhagen Business School, Osaka University, and the Institute for Monetary and Economic Studies at the Bank of Japan. Hutchison's work was supported by grants from the Japan Foundation, the University of California, Pacific Rim Program, and the Japan–US Friendship Commission. The views presented in this paper are those of the authors alone and do not necessarily reflect those of the Federal Reserve Bank of San Francisco or the Board of Governors of the Federal Reserve System.

Appendix A

The exchange rate and dollar-denominated foreign exchange reserves data plotted in Figs. 1 and 2 are from the International Monetary Fund *International Financial Statistics*. The exchange rate series are averages of monthly period average figures from line rf. Foreign exchange reserve stocks each quarter are constructed as the average of end-of-month stock figures. Figures in dollars were obtained from line 1d.d ('Foreign Exchange'). The monthly series were seasonally adjusted using the X-11 procedure for presentation purposes.

In the VECM analysis, the Japanese foreign exchange reserve data most useful for analyzing the linkage between intervention and the monetary base are the yen value of official foreign asset acquisitions by the Bank of Japan. Following the approach of Takagi (1991), we construct an estimate (FA) of the yen value of the BOJ's official foreign assets that is independent of the effects of exchange-rate induced fluctuations in the yen value of existing foreign reserves as well as reinvested interest earnings on foreign assets. This measure, obtained by subtracting available information on the consolidated credit balance of the Bank of Japan and the Foreign Exchange Fund Special Account (FEFSA) to the central government from the BOJ's outstanding credit to the central government, represents an estimate of the outstanding value of the Bank of Japan's credit to the FEFSA. It may be interpreted as the cumulative sum of all purchases (and sales) of foreign exchange bills by the BOJ from the FEFSA, valued at historical exchange-rates. Changes in this sum measure the effect of intervention on the monetary base at the exchange rate prevailing at the time foreign exchange transactions were made.

DC is measured by the difference between a liability sources-side measure of the monetary base, MBS, and our measure of FA. The liability sources-side measure of the BOJ's monetary base, MBS, is defined as the sum of bills discounted, loans, bills purchases, and government bonds held by the BOJ. Other components are excluded because they are relatively minor and/or stable. The end-of-month stock figures obtained from the BOJ *Economics Statistics Monthly*.

Data on the CPI index for Japan is obtained from IFS, line 64; the industrial production (IP) index is from the IFS, line 66.c.

For Germany, all data were obtained from the BIS database. CPI for Germany is the cost of living index (1985 = 100), on all items, non-seasonally adjusted. IP for Germany is 'Total Industrial Production, excluding construction', index (1985 = 100), non-seasonally adjusted. Data on the total monetary base (MB) is 'central bank money' (adjusted for reserve ratio changes). Intervention (AFA) is Bundesbank's purchases/sales of foreign exchange (excluding swaps), non-seasonally adjusted, effective transactions value. The level of Bundesbank foreign asset holdings (FA) is calculated by cumulating AFA to the 'total foreign assets of the monetary authorities' base' for end-of-year 1973 given in *International Financial Statistics*. DC was defined as the difference between the total monetary base and foreign assets.

References

Baillie, R., Chung, C., Tieslau, M., 1996. Analyzing inflation by the fractionally integrated ARFIMA-GARCH model. J. Appl. Econometrics 11, 23–40.

Cargill, T., Hutchison, M., Ito, T., 1997. The Political Economy of Japanese Monetary Policy. MIT Press, Cambridge, MA.

Cuddington, J., 1991. Comparing the intensity of exchange market intervention with Frankel and Aizenman's index of managed float. J. Int. Econ. 31, 383–386.

Cuddington, J., 1993. A generalization and assessment of the index of managed float. Can. J. Econ. 26, 235–240.

Culver, S., Papell, D., 1997. Is there a unit root in the inflation rate? Evidence from sequential break and panel data models. J. Appl. Econometrics 12, 435–444.

Edison, H.J., 1993. The effectiveness of central-bank intervention: a survey of the literature after 1982, Special papers in international finance, no. 18, July, Princeton University.

Fatum, R., M. Hutchison, 1999. Is intervention a signal of future monetary policy? Evidence from the federal funds market. J. Money, Credit Banking 31(1), 54–69.

Fukui, T., 1986. The recent development of the short-term money markets in Japan and changes in the techniques and procedures of monetary control used by the bank of Japan. In: Changes in Money Market Instruments and Procedures: Objectives and Implications. Bank for International Settlements, Basel, pp. 94–126.

Glick, R., Hutchison, M., 1994. Monetary Policy, Intervention, and Exchange Rates in Japan. In: Glick, R., Hutchison, M. (Eds.), Exchange Rate Policy and Interdependence: Perspectives from the Pacific Basin, Ch. 10. Cambridge University Press, New York.

Herring, R., Marston, R., 1977. Sterilization policy: the trade-off between monetary autonomy and control over foreign exchange reserves. Eur. Econ. Rev. 10, 225–343.

Ito, T., 1987. The intraday exchange rate dynamics and monetary policies after the Group of Five agreement. Journal of the Japanese and International Economics 1, 275–298.

Johansen, S., 1991. Estimation and hypothesis testing of cointegrating vectors in Gaussian autoregression models. Econometrica 59, 1551–1580.

Johansen, S., Juselius, K., 1990. Maximum likelihood estimation and inference on cointegration with applications for the demand for money. Oxf. Bull. Econ. Stat. 52, 169–210.

Neuman, M., von Hagen, J., 1992. Germany. In: Fratianni, M., Salvatore, D. (Eds.), Monetary Policy in Developed Economies, Ch. 9. Greenwood, Westport, CT.

Obstfeld, M., 1983. Exchange rates, inflation, and the sterilization problem: Germany 1975–81. Eur. Econ. Rev. 21, 161–189.

Rogoff, K., 1984. On the effects of sterilized intervention: an analysis of weekly data. J. Monetary Econ. 14, 133–150.

Suzuki, Y., 1985. Japan's monetary policy over the past 10 years (Bank of Japan). Monetary Econ. Stud. 3, 1–18.

Takagi, S., 1991. Foreign exchange market intervention and domestic monetary control in Japan, 1973–89. Japan World Econ. 3, 147–180.

von Hagen, J., 1989. Money targeting with exchange rate constraints: the Bundesbank in the 1980s, (Federal Reserve Bank of St. Louis). Econ. Rev. 9-10, 53–69.

Watanabe, T., 1994. The signaling effect of foreign exchange intervention: the case of Japan. In: Glick, R., Hutchison, M. (Eds.), Exchange Rate Policy and Interdependence: Perspectives from the Pacific Basin, Ch. 11. Cambridge University Press, Cambridge, UK.