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A NOTE ON FOREIGN EXCHANGE INTERVENTIONS AT ZERO INTEREST RATES

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This note uses a nonlinear structural vector autoregression model to empirically investigate the effectiveness of official foreign exchange (FX) interventions in an economy when interest rates are constrained to the zero level, based on Japanese data in the 1990s. The model allows us to estimate the effects of FX interventions operating through different channels. We find that FX interventions are still capable of influencing the foreign exchange rate in a zero-interest-rate environment, even though their effects are greatly reduced by the zero lower bound on interest rates. Our results suggest that although it might be feasible to use the exchange rate as an alternative monetary policy instrument at zero interest rates as proposed by McCallum (Inflation Targeting and the Liquidity Trap, NBER working paper 8225, 2000), the exchange rate–based Taylor rule may not be very effective in achieving the ultimate policy goals.

Keywords: Zero Interest Rates, Sterilized Intervention, Exchange Rates

1. INTRODUCTION

An economic environment where interest rates are close to zero presents a serious challenge to the conduct of monetary policies, because the standard practice of lowering the short-term nominal rate through open market operations is no longer feasible.[1] Some economists think that in this situation monetary policies are completely impotent [e.g., Summers (1991)]. Other economists, however, believe that there are still alternative routes for monetary policy to influence the price level and aggregate demand [e.g., Meltzer (1995)]. One of the potential routes, often discussed in the literature, is through foreign exchange rates. McCallum (2000, 2001) suggests that, instead of relying on the conventional interest-rate policy, which no longer works with the zero bound, a central bank can adopt a Taylor-type policy rule with the exchange rate as the instrument.[2]

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In this note, using Japanese data for the 1990s,[3] we investigate whether or not official foreign exchange (FX) interventions[4] are effective in influencing exchange rates in an economy with zero interest rates. There are two motivations for this exercise. First, examining the effectiveness of FX interventions at zero interest rates helps determine whether it is feasible to use the foreign exchange rate as an alternative monetary policy instrument under the zero–interest rate regime. If the interventions cannot produce any significant change in exchange rates, this puts in doubt the proposal of an exchange rate–based monetary policy rule as a way to combat deflation and stagnation when interest rates are close to zero. Second, the issue of the effectiveness of FX interventions has intrinsic interest in its own right. It has long been one of the most popular topics in academic as well as policy circles, and there is a vast literature on it.[5] Moreover, a zero–interest rate environment offers some advantages for examining FX interventions.

FX interventions influence exchange rates through several potential channels. They can be classified into two distinct groups, which we call the interest-rate channel and the non–interest rate channel. Through the first channel, an FX intervention produces a change in interest rates by altering the money supply, which in turn leads to a change in exchange rates. Through the second channel, an FX intervention affects exchange rates through something other than interest rates (such as the portfolio effect). In other words, this channel works even when interest rates do not change. In the empirical literature, FX interventions are often classified into unsterilized and sterilized intervention. When FX interventions are followed by open market operations offsetting their impacts on the money supply, or sterilized, interest rates are not altered. So if sterilized interventions are to be effective, they must operate through the non–interest rate channel. By now there is some consensus in the empirical literature that unsterilized FX interventions can influence exchange rates [see, e.g., Sarno and Taylor (2001)]. In contrast, the results are mixed for sterilized FX interventions.[6] When interest rates are already at the zero bound or close to it, foreign currency purchases by the government in the FX market will increase the monetary base but will not alter interest rates. So the interest-rate channel is blocked in this situation, and if FX interventions are to be effective, they must operate through the non–interest rate channel. Thus, FX interventions at zero interest rates and sterilized interventions share one important common feature.[7] The zero–interest rate environment provides us with an opportunity to examine the effectiveness of FX intervention through the non–interest rate channel.

To examine the effectiveness of FX intervention when nominal interest rates are close to zero, we adopt an empirical method with the following two new features. First, rather than using a single equation, we develop a dynamic system that treats FX interventions and conventional monetary policy together. Kim (2003) proposed this strategy, noting that there are quite important interactions between the two policies. Second, we explicitly take into account the zero lower bound on nominal interest rates when we estimate the reaction function of monetary policy. The resulting nonlinear structural vector autoregression model allows us to examine

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two separate response curves of the exchange rate to exogenous FX intervention shocks: one corresponds to the positive–interest rate regime and the other to the zero–interest rate regime [Iwata and Wu (2006)].

Applying the model to Japanese data during the 1990s, we find that FX interventions remain capable of influencing the FX rate even when the interest rate is at the zero bound. An outright purchase of the U.S. dollar by the Bank of Japan at zero interest rate still leads to a small but significant depreciation of the yen against the dollar. On the other hand, the zero lower bound has greatly reduced the impact of FX interventions on the exchange rate according to a comparison between the impulse-response functions under the positive– and the zero–interest rate regimes. An exogenous FX intervention shock also has much smaller effects on output and price level when interest rates are at the zero lower bound. This implies that the exchange rate–based monetary policy may not be very effective in achieving the policy's ultimate goals.

The rest of the note is organized as follows. Section 2 describes the data used in this study. Section 3 discusses our econometric strategy. Section 4 presents the main results and section 5 concludes.

2. DATA AND BACKGROUND

2.1. Data

In this note, we use Japanese monthly data from 1991 to 2002.[8] Figure 1 displays (a) the exchange rate, (b) FX interventions, (c) the overnight call rate, and (d) the growth rate of the monetary aggregate in Japan during the 1990s. By choosing this period, we can avoid major structural changes in the Japanese monetary policy within the sample.

Japan has suffered protracted deflation and economic stagnancy since the collapse of the speculative asset price bubble in early 1990. In response to this economic downturn, the Bank of Japan (BOJ) aggressively lowered nominal interest rates. In the late 1990s, the BOJ adopted what they call a "zero interest rate policy." The goal of this policy is to avoid further intensifying deflationary pressures and stop the economic downturn. The BOJ's firm commitment to the zero–interest rate policy is reflected in the well-cited statement of a BOJ official: "We [the BOJ] will continue the zero interest rate policy until we reach a situation where deflationary concerns are dispelled" (Governor Hayami's statement at a press conference on April 13, 1999). In short, the policy undertaken by the BOJ in the late 1990s was to move nominal interest rates down as low as possible by satiating the money market with an excess supply of funds. One important aspect of the zero–interest rate policy is that exogenous monetary easing will not result in any further movement in the interest rate when the rate is already at the zero lower bound. Therefore, although the stance of monetary policy can be directly measured by the interest rate when it is positive, the interest rate at zero is no longer an adequate indicator of the policy stance.

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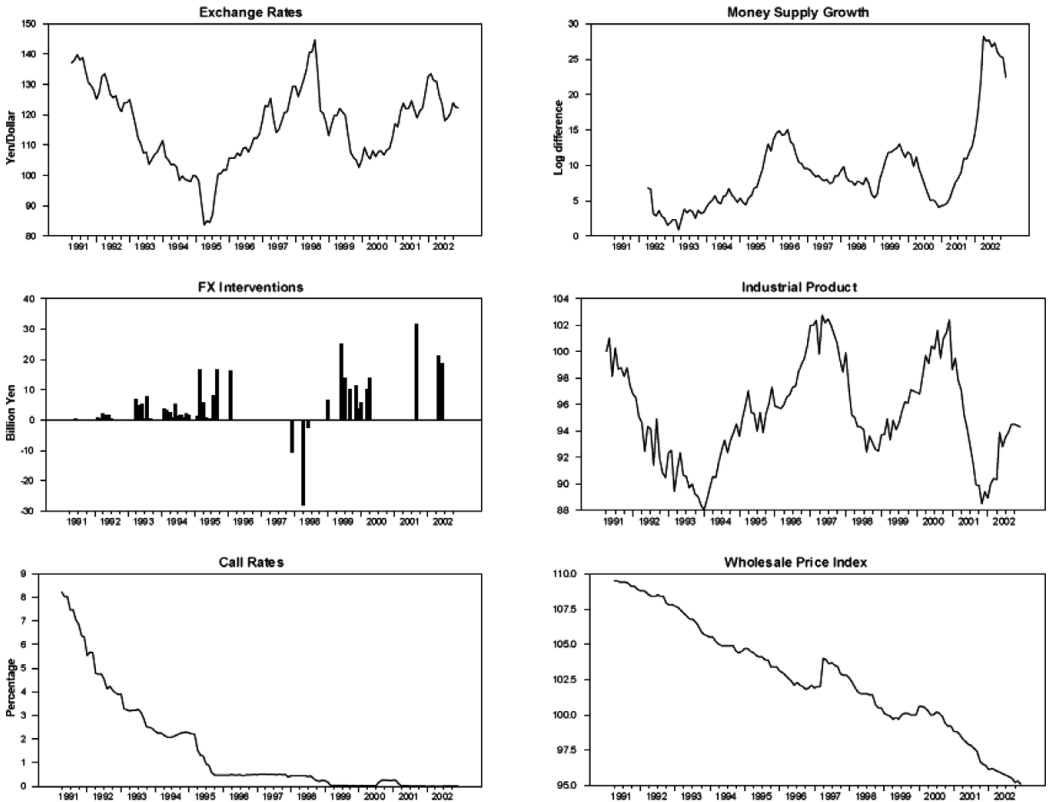


FIGURE 1. Exchange rates, FX Interventions, and monetary policy.

2.2. The Interest Rate as a Censored Variable

To model the described behavior of the monetary authority in Japan, we make the following specification. Let R_t be the short-term nominal interest rate and let R_t^* be a latent variable measuring the true stance of monetary policy. R_t^* is in general not observable by an econometrician but is directly linked to R_t through the relation

$$R_t = \begin{cases} R_t^* & \text{if } R_t^* \geq \text{c} \\ c & \text{otherwise} \end{cases}, \tag{1}$$

where c is a lower bound on the nominal interest rate at which R_t is regarded as essentially zero. We choose the lower bound c to be 0.50%[9] and use the terms *zero interest rate* and *zero lower bound* even when the actual lower bound is not necessarily exactly zero.

2.3. FX Intervention Policy Shock

To examine the effectiveness of FX intervention, many studies regress the exchange rate change on a measure of interventions, usually the net amount of foreign currency purchases, along with other control variables. This standard practice is a sensible way to investigate when high-frequency (e.g., daily) data are used. With lower-frequency data such as monthly or quarterly, however, this type of regression becomes problematic. Because FX interventions are reactions of the government or the central bank to macroeconomic conditions, they are inherently endogenous. An intervention is attempted to affect the exchange rate, whereas whether and when to intervene is affected by the level of the exchange rate. This endogeneity problem is common to any policy function. To cope with this problem, we need to separate the endogenously determined component of the policy variable from exogenous shocks. To evaluate the impact of FX interventions on the exchange rate, we need to estimate the impact of the exogenous policy shock on the exchange rate. To this end we set up the system to include two policy reaction functions: monetary policy and FX intervention along with other key macroeconomic variables and estimate them at the same time. The model is described in the next section.

3. VAR MODEL

3.1. Model

The VAR system we estimate consists of three groups of variables. The first group includes standard macroeconomic variables such as output (y) and price (p). Monetary policy is assumed to respond to these variables contemporaneously. The second group is money market variables, including a short-term nominal interest rate (the overnight interbank call rate, R) and the growth rate of aggregate money (Δm). These variables contain information about the stance of monetary policy. The last group includes FX market variables, namely the yen/dollar nominal

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exchange rate (x) and the amount of net dollar purchases by the BOJ (f). Denote these three groups of variables by $\mathbf{Y}_t$, $\mathbf{W}_t^*$, and $\mathbf{X}_t$, respectively, where $\mathbf{Y}_t$, $\mathbf{W}_t^*$, and $\mathbf{X}_t$ are all 2×1 vectors. The VAR system is then given by

$$\begin{bmatrix} \mathbf{Y}_t \\ \mathbf{W}_t^* \\ \mathbf{X}_t \end{bmatrix} = \mathbf{B}(L) \begin{bmatrix} \mathbf{Y}_t \\ \mathbf{W}_t \\ \mathbf{X}_t \end{bmatrix} + \boldsymbol{\mu} + \mathbf{u}_t, \tag{2}$$

where $\mathbf{Y}_t = (y_t, p_t)'$, $\mathbf{W}_t^* = (R_t^*, \Delta m_t)'$, $\mathbf{W}_t = (R_t, \Delta m_t)'$, $\mathbf{X}_t = (x_t, f_t)'$, $\mathbf{B}(L) = \mathbf{B}_1 L - \cdots - \mathbf{B}_p L^p$, with L being the lag operator, and $\boldsymbol{\mu}$ is a vector of constants. $\mathbf{Y}_t$ contains log output and log price level. The term $\mathbf{u}_t$ stands for a vector of one-step-ahead forecast errors and is assumed to be distributed as $N(0, \boldsymbol{\Sigma})$, where $\boldsymbol{\Sigma}$ is a symmetric positive definite matrix. It is important to note that in equation (2), $\mathbf{W}_t^*$ on the left-hand side of the equation includes the latent variable R_t^*, whereas $\mathbf{W}_t$ on the right-hand side of the equation includes the actual interest rate R_t, which is related to R_t^* in a nonlinear way. This specific feature yields a model that exhibits interesting dynamics.

3.2. Identification

The structural form of the system (2) can be written as

$$\mathbf{A}_0 \mathbf{Z}_t^* = \mathbf{A}(L)\mathbf{Z}_t + \mathbf{A}_0 \boldsymbol{\mu} + \boldsymbol{\varepsilon}_t, \tag{3}$$

where $\mathbf{Z}_t^* = [\mathbf{Y}'_t, \mathbf{W}_t^{*'}, \mathbf{X}'_t]'$ and $\mathbf{Z}_t = [\mathbf{Y}'_t, \mathbf{W}'_t, \mathbf{X}'_t]'$. The term $\boldsymbol{\varepsilon}_t = [\boldsymbol{\varepsilon}_t^{Y'}, \boldsymbol{\varepsilon}_t^{M'}, \boldsymbol{\varepsilon}_t^{X'}]'$ stands for the fundamental macroeconomic shocks. Note that $\boldsymbol{\varepsilon}_t^M = (\varepsilon_t^s, \varepsilon_t^d)'$ and $\boldsymbol{\varepsilon}_t^X = (\varepsilon_t^x, \varepsilon_t^f)'$, where ε_t^s is the exogenous monetary policy shock, ε_t^d is the exogenous money demand shock, ε_t^x is the exogenous FX shock, and ε_t^f is the exogenous intervention policy shock. We assume that $\boldsymbol{\varepsilon}_t \sim N(\mathbf{0}, \mathbf{I}_m)$.

We impose the following restrictions to identify the model. First, we assume that the exogenous money market shock ε_t^M and the FX market shock ε_t^X do not affect the output and price level ($\mathbf{Y}_t$) in the same period, which is a quite standard identification restriction in the literature [e.g., Christiano et al. (1999)], especially when monthly data are used. Second, we assume that monetary authorities do not respond contemporaneously to the exchange market variables $\mathbf{X}_t$ when setting the interest rate. This assumption is consistent with the BOJ's statement during this period. Third, we assume that the FX intervention responds only to the exchange rate shock and is not affected contemporaneously by the macroeconomic or money market shocks. This is because there is no evidence that the BOJ used the exchange rate as a monetary policy instrument during this period. Fourth, money growth is assumed to be affected by all shocks contemporaneously, except the exchange rate shock. This appears to be reasonable because money demand might respond to the FX intervention shock through either the signaling channel or the portfolio-balance channel, whereas it does not respond directly to exchange rate shocks.

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Fifth, the exchange rate movements are assumed to reflect exogenous shocks of all variables.

Under these restrictions, we can rewrite (3) as

$$\mathbf{Z}_t^* = \mathbf{B}(L)\mathbf{Z}_t + \boldsymbol{\mu} + \mathbf{C}\boldsymbol{\varepsilon}_t. \tag{4}$$

$\mathbf{C} = \mathbf{A}_0^{-1}$ is the matrix of the impact multipliers, which is expressed as

$$\mathbf{C} = \begin{bmatrix} c_{11} & 0 & 0 & 0 & 0 & 0 \\ c_{21} & c_{22} & 0 & 0 & 0 & 0 \\ c_{31} & c_{32} & c_{33} & 0 & 0 & 0 \\ c_{41} & c_{42} & c_{43} & c_{44} & 0 & c_{46} \\ c_{51} & c_{52} & c_{53} & c_{54} & c_{55} & c_{56} \\ 0 & 0 & 0 & 0 & c_{65} & c_{66} \end{bmatrix}. \tag{5}$$

In the above matrix, "0" indicates zero restriction and "c_{ij}" indicates a free parameter. This form imposes sufficient identifying restrictions to allow investigation of the dynamic response of $\mathbf{Z}_t$ to an intervention shock ε_t^f as well as a monetary policy shock ε_t^s. The system (4), subject to (1) and (5), can be estimated by the maximum likelihood method. The Akaike information criterion (AIC) is used to choose the number of lags in (4).

When the economy is in a liquidity trap with zero interest rates, money demand is likely to behave quite differently than in a normal environment with positive interest rates. We therefore allow for the possibility that when the nominal interest rate is zero, money growth Δm_t responds differently to ε_t^Y and ε_t^M as well as ε_t^x. We also allow a different intercept term for Δm_t in model (4) when the zero bound is approached.[10]

4. EMPIRICAL RESULTS

To investigate the effects of FX intervention, we compute the impulse-response functions (IRFs) of the estimated VAR system specified in (4) and (5). This approach allows us to focus on the effects of exogenous FX intervention shocks. In general, the IRF of a particular variable in the VAR system is obtained by the difference of the h-step-ahead forecast of the variable with a current shock of a unit size from the forecast without the shock, i.e., $E(\mathbf{Z}_{t+h} \mid \Omega_{t-1}, \varepsilon_t) - E(\mathbf{Z}_{t+h} \mid \Omega_{t-1})$, where Ω_{t-1} stands for the information set at $t-1$, and $h = 1, 2, \ldots$ is the time horizon. In a standard linear model, this difference reduces to the hth order parameters in its moving-average (MA) representation. In a VAR with a censored left-hand variable, however, the MA representation is no longer linear in the shocks. As a result, the IRF for the nonlinear model is dependent upon the entire history of the series as well as on the size and direction of the shock.[11] This state-dependent feature of the IRF allows us to analyze the policy effects conditional on the current state of the system. In particular, IRFs under the zero–interest rate and positive–interest rate regimes can be computed separately.

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Iwata and Wu (2006) use this procedure to examine the effect of a monetary policy shock when the interest rate is zero as well as when it is positive. For comparison, Figure 2 displays the results for output, price, and interest rates, reproduced using the current dataset, extended from the original one employed in Iwata and Wu (2006). The qualitative patterns are quite similar to the original results: A monetary policy shock still has a positive impact on output under the zero–interest rate regime, but its magnitude is significantly weakened. In the current exercise, the output response is somewhat weaker than in the previous study.

Figure 3 displays the dynamic responses of (a) output, (b) price, (c) the nominal short-term rate, (d) money growth, (e) the exchange rate, and (f) FX intervention to an exogenous intervention shock when the interest rate is on the zero bound (the left-side panels) and when it is positive (the right-side panels). The shock is standardized to one standard deviation. The 90% error bands are drawn with dotted lines.

As we can see clearly from Figure 3, when the interest rate is positive, a positive FX intervention shock (a purchase of the U.S. dollar against the yen) results in a large depreciation of the yen, i.e., an increase in the yen/dollar exchange rate [see Figure 3(e)]. Because money also increases significantly in response to the FX intervention shock [see Figure 3(d)], it suggests that the FX intervention to a large extent is not sterilized or only partially sterilized. The increased money supply lowers the nominal interest rate [see Figure 3(c)] and raises the price level [see Figure 3(b)]. As a result, the yen depreciates in real terms and the real interest rate falls as well, leading to an increase in output [see Figure 3(a)]. These dynamic responses to an exogenous FX intervention shock when the interest rate is positive are entirely consistent with the predictions of standard economic theory and the results of previous empirical studies on the effects of unsterilized FX interventions.

When the interest rate is zero, however, an exogenous FX intervention shock produces quite different responses from the economic variables. First, from Figure 3(f), we can see that the FX intervention shocks are almost identical under the two interest-rate regimes. Nonetheless, in response to the shock, the short-term interest rate remains at the zero level [see Figure 3(c)], and there is only a marginal increase in money growth [see Figure 3(d)], which is much smaller than that when the interest rate is positive. This is not surprising. At zero interest rates, the interest-rate channel is effectively shut down as domestic bonds and money become perfect substitutes, leaving aggregate money supply and the nominal interest rate unchanged.

More interestingly, from Figure 3(e), we find that the FX intervention shock still has a significant effect on the exchange rate under the zero–interest rate regime. The yen/dollar exchange rate responds positively to a purchase of the U.S. dollar by the Bank of Japan, although the interest rate remains at the zero level.

Economists have long debated the effect of official FX interventions. Three main channels through which the interventions can affect exchange rates are discussed in the literature: (a) the interest-rate channel, (b) the portfolio-balance

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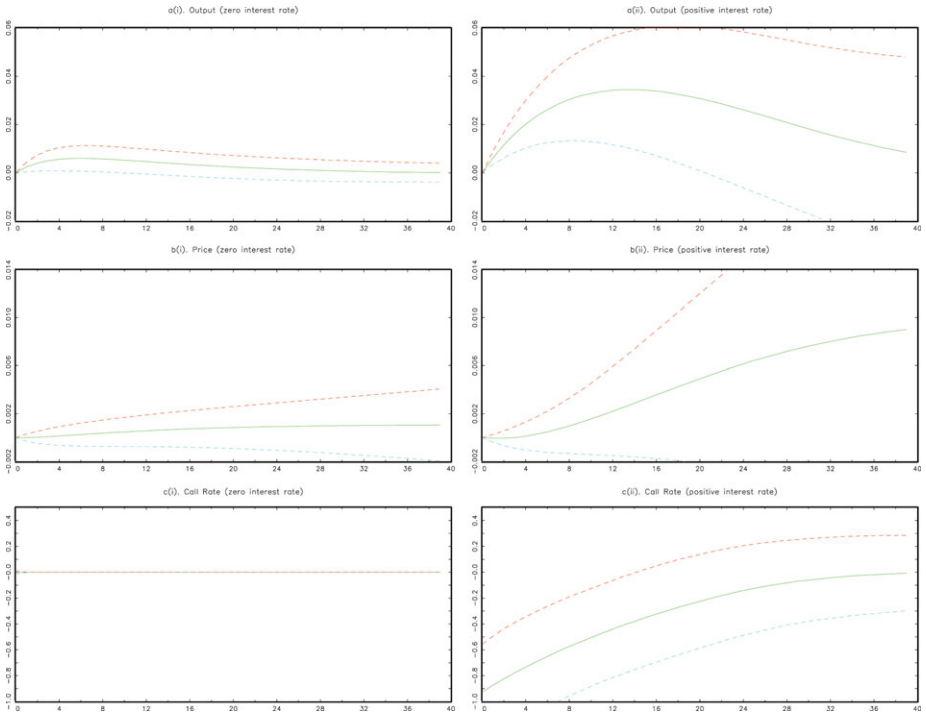


FIGURE 2. Dynamic responses of a monetary policy shock. *Note*: This figure displays the dynamic responses of (a) output, (b) price, and (c) the nominal short-term interest rate to an exogenous monetary policy shock. Diagrams on the left hand show the responses when the interest rate is positive, whereas those on the right hand show the responses when the interest rate is at the zero bound. The shock is standardized to one standard deviation. The 90% error bands are drawn with the dotted lines.

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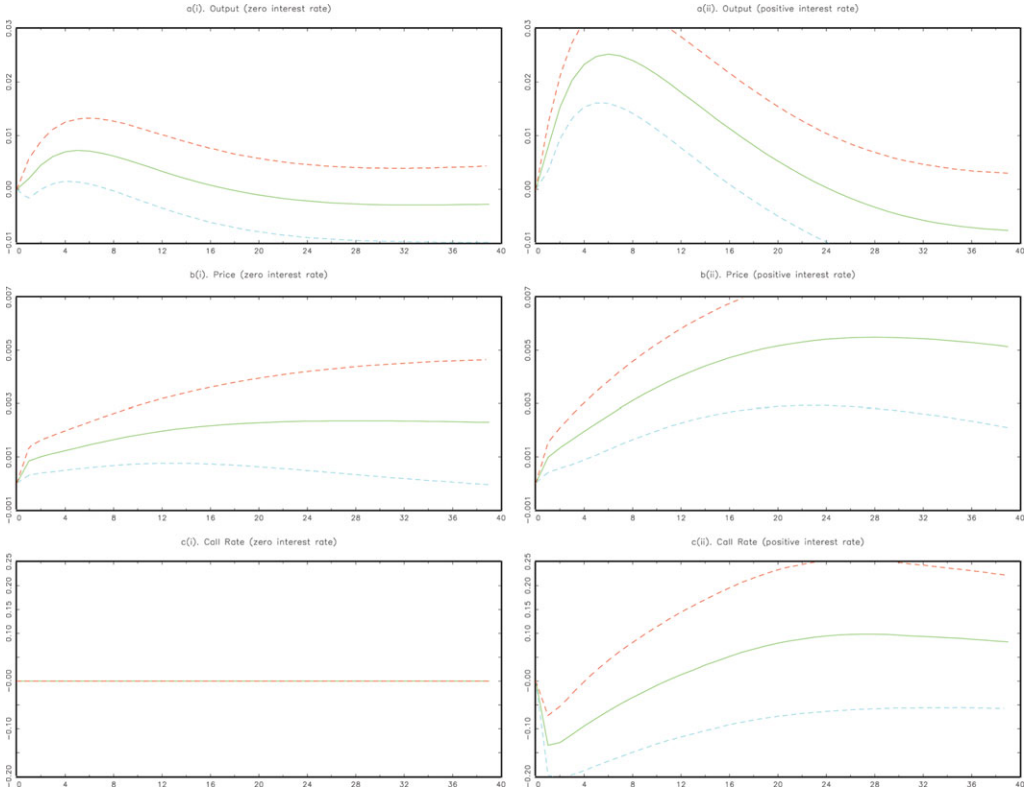


FIGURE 3. Dynamic responses of an FX intervention shock. *Note*: This figure displays the dynamic responses of (a) output, (b) price, (c) the nominal shortterm rate, (d) money growth, (e) the exchange rate, and (f) FX intervention to an exogenous intervention shock. Diagrams on the left show the responses when the interest rate is positive, whereas those on the right show the responses when the interest rate is on the zero bound. The shock is standardized to one standard deviation. The 90% error bands are drawn with the dotted lines.

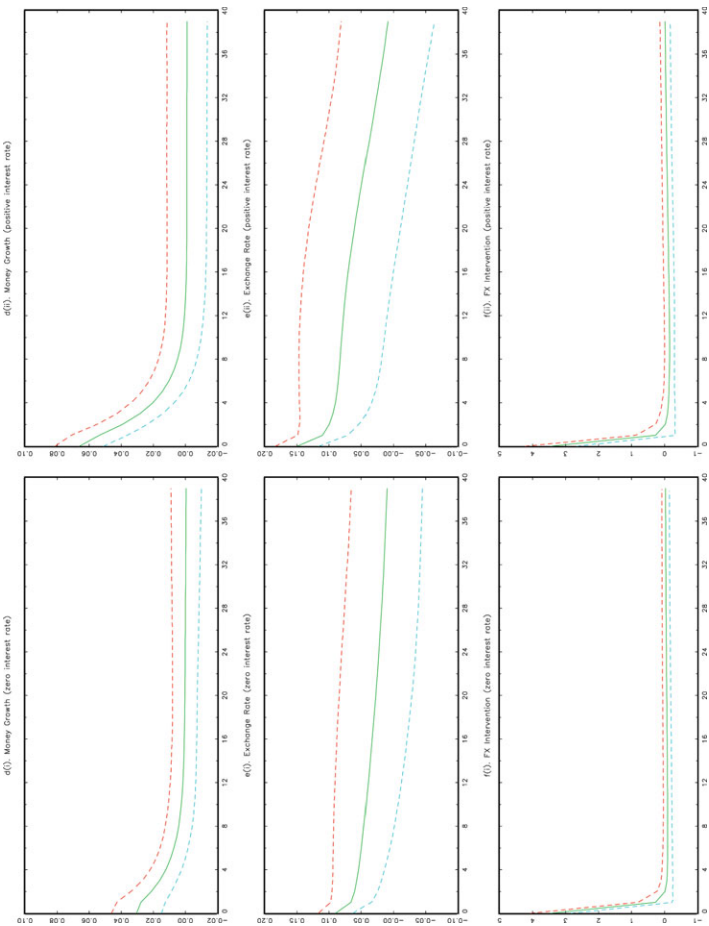


FIGURE 3. Continued.

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channel, and (c) the signaling channel. These three channels are not necessarily mutually exclusive but are assumed to work together in normal circumstances. When purchases of a foreign currency are not followed by subsequent open-market sales of government bonds—in other words, the interventions are not sterilized—they necessarily increase money supply and hence lower interest rates. The UIP relation then implies that the lower domestic interest rates should be associated with the expected future appreciation of the currency, which, in turn, leads to its immediate depreciation because the expected future exchange rate does not change instantly. Most economists appear to agree that this interest-rate channel does work and that unsterilized interventions can influence exchange rates [see, e.g. Sarno and Taylor (2001)], as is being confirmed by the IRFs under the positive–interest rate regime.

On the other hand, when the effect of FX interventions on the domestic money supply is neutralized by subsequent open market sales, or the interventions are sterilized, neither money supply nor the interest rate will be changed, and hence, the interest-rate channel will no longer be effective. The interventions, if they are to continue to affect the exchange rate, have to operate through other channels.

In particular, some economists have argued that because sterilized interventions effectively replace foreign bonds with domestic bonds (with the domestic money supply left unchanged), the increase in the supply of domestic bonds in the market relative to the supply of foreign bonds necessitates a fall in the relative price of domestic bonds (after adjustment for the exchange rate). This is how the interventions affect the exchange rate through the portfolio-balance channel. A necessary condition for this channel to work is that the foreign and domestic bonds are perceived by investors as imperfect substitutes. However, even if the foreign and domestic bonds are perfect substitutes, FX interventions can still be effective through the signaling or expectations channel [Mussa (1981)]. Investors may view interventions as a signal about the future stance of monetary policy. A shift in the expectations concerning future movements of the money supply will affect the exchange rate now.

Empirical results in the existing literature about the effectiveness of the above two channels are not conclusive. Early studies on the effectiveness of sterilized intervention are mostly negative [Edison (1993)]. The quality of the data used in those studies is, however, somewhat questionable. Because direct data on interventions were not available, early studies infer intervention activities from movements in international reserves. However, the latter represent a very inaccurate proxy for intervention activities, because reserves may change for a variety of other reasons. Recent studies using the new direct data released by the governments of the United States and Japan tend to find more positive evidence for the effectiveness of sterilized interventions [see Dominguez (1990), Dominguez and Frankel (1993a, 1993b), Fatum and Hutchison (1996), Ito (2002), Kim (2003), and Chaboud and Humpage (2005), among others].

The findings in this note not only confirm the results from these recent studies of unsterilized interventions, but also offer a direct measure of the importance

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of the non–interest rate channel (the portfolio-balance and signaling channels) of FX interventions in comparison to the interest-rate channel. As we can see from Figure 3(e), in response to almost identical FX intervention shocks, the depreciation of the yen is much smaller (about half the size) under the zero–interest rate regime than when the interest rate is positive. The difference in the IRFs therefore gives us a measure of the effect of FX interventions operating through the interest-rate channel. The result suggests that the interest-rate channel is the single most important mechanism by which FX interventions affect the exchange rate. The zero lower bound on interest rates eliminates almost half of the impact of FX interventions on the exchange rate by rendering all interventions practically sterilized.

Empirical studies based on high-frequency data have often found that sterilized FX interventions have little significant effect on the exchange rate. They often report a small and short impact, even if the interventions have some effect. The results in this note suggest that those studies may have missed the portfolio-balance or signaling effects of FX interventions. On one hand, our results clearly indicate that, even at zero interest rates, FX interventions can still produce significant effects on the exchange rate. On the other hand, it is unlikely that changes in expectation or portfolio balance can take place at, say, daily frequency.

Figures 3(a) and 3(b) also report the dynamic responses of output and price to an exogenous FX intervention shock at zero interest rate. Notice that the price level increases in response to an FX intervention shock. Even if the nominal interest rate is constrained at the zero level, the real interest rate falls with a higher rate of inflation. Moreover, such an increase in the price level plus an increase in the yen/dollar exchange rate lead to a real depreciation of the yen. These two effects combine to create an increase in output, as predicted by the standard economic theory. In comparison to the IRFs under the positive–interest rate regime, however, the increases in output and price level are much smaller when the interest rate is at the zero level.

McCallum (2000) has proposed the use of the exchange rate as an alternative monetary policy instrument when the nominal short-term interest rate is constrained by the zero lower bound. Our results in Figure 3 suggest that although an exchange rate–based monetary policy rule might be a feasible alternative, its effectiveness in reaching the ultimate policy goal is still unclear, given the small impact of FX intervention shocks on output and the price level. Nonetheless, it is interesting to notice that there is a striking qualitative resemblance between IRFs from our empirical model in Figure 3 and McCallum's (2000) IRFs based on the simulations of his theoretical model [see Figures 4 and 5 of McCallum (2000)].

5. CONCLUSION

This note uses a nonlinear structural VAR model to investigate empirically the effectiveness of official FX interventions in an economy when interest rates are constrained at the zero level, based on Japanese data in the 1990s. The model

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allows us to estimate the effects of FX interventions operating through different channels. We find that FX interventions are still capable of influencing the FX rate in a zero–interest rate environment, even though their effects are greatly reduced by the zero lower bound on interest rates. Our results suggest that although it might be feasible to use the exchange rate as an alternative monetary policy instrument at zero interest rates, as proposed by McCallum (2000), the exchange rate–based Taylor rule may not be very effective in achieving the ultimate policy goals.

NOTES

1. The issue of how the zero lower bound constraints may interfere with the conduct of monetary policy is discussed by Fuhrer and Madigan (1997), Orphanides and Wieland (1998), Wolman (1998), Clouse et al. (2000), Reifschneider and Williams (2000), and others. The issue on what monetary policy can do when the economy is in a liquidity trap is discussed by Krugman (1998), Buiter and Panigirtzoglou (1999), McCallum (2000, 2001), Svensson (2001), Eggertsson (2003), Eggertsson and Woodford (2004), Bernanke and Reinhart (2004), Bernanke et al. (2004), and others.

2. An alternative strategy was proposed by Svensson (2001), who suggests that the currency be pegged at a substantially devalued exchange rate, along with announcing a price-level target path in order to raise inflationary expectations.

3. See Alhearne et al. (2002) for Japan's experience in the 1990s.

4. We use the term "FX intervention," whenever the government authorities intervene in the FX market by buying or selling foreign exchange normally against their own currency in order to affect the exchange rate.

5. See Sarno and Taylor (2001) for a recent survey of the literature.

6. Difficulty in investigating the effectiveness of sterilized FX interventions comes partly from the government authority's secretive attitude, not revealing their conduct of sterilization. Even when official data on intervention are available, those on sterilization are not.

7. Christiano (2000) also pointed out this similarity. However, there are important differences between an intervention at zero interest rate and a sterilized intervention. The monetary base will increase with interventions at zero rates, but will not with sterilized interventions.

8. The variables include (a) the Japanese wholesale price index, (b) index of industrial production, (c) the interbank overnight call rate, (d) the aggregate money supply (M1), (e) the yen/dollar exchange rate, and (f) the official foreign exchange intervention (net purchase of dollars in terms of yen). Data on the price level and the interest rate are obtained from the BOJ website. Data on industrial production, M1, and the exchange rate are obtained from the International Financial Statistics of the IMF. The official intervention data are from the Japanese Ministry of Finance's Web site.

9. A visual examination of the plot of the call rate in Figure 1 gives support for such a specification. Moreover, it is also supported by Krugman (1997), which argues that at a nominal rate of 0.43% "the economy is clearly in a very good approximation to liquidity trap conditions."

10. Because ML estimation of our model with nonlinearity and many parameters is already quite complicated, we tried only a limited number of different specifications. First, there is a concern that the BOJ might have switched its policy instrument to a monetary base around 2001. To take into account this possibility, we relaxed the restriction $c_{34} = 0$ but imposed $c_{43} = 0$. The result turned out to be quite similar to the case of the original specification, but with slightly wider error bands. Second, we tried a few models with more relaxed restrictions on the intervention reaction function. In particular, we relaxed the restrictions $c_{61} = c_{62} = 0$ and found that the IRFs behave in an unnatural way with excessive jags.

11. Following the literature on nonlinear impulse response [Koop et al. (1996); Potter (2000)], we treat a nonlinear IRF as the difference between a pair of conditional expectations $E(\mathbf{Z}_{t+h} \mid \Omega_{t-1}, \varepsilon_t) - E(\mathbf{Z}_{t+h} \mid \Omega_{t-1})$, where Ω_{t-1} stands for the information set at $t-1$, and $h = 1, 2, \ldots$ is the time horizon. To calculate the conditional expectations, we simulate the model in the following manner.

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First, we draw the model parameters from the sampling distribution of the ML estimates. Second, we draw ε_{t+j} from $N(0, I_m)$ for $j = 1, 2, \ldots, h$. Third, we simulate the model conditional on a given parameter value, each historical point in our sample as the initial value, and a particular shock ε_t. This process is repeated 200 times to generate parameters, and 500 times to generate shocks. The estimated conditional expectation is obtained as the average of the outcomes.

REFERENCES

Alhearne, A., J. Gagnon, J. Haltimaier, and S. Kamin (2002) Preventing Deflation: Lessons from Japan's Experiences in the 1990s. International finance discussion paper 729, Board of Governors of the Federal Reserve System.

Bernanke, B.S. and V.R. Reinhart (2004) Conducting monetary policy at very low short-term interest rates. *American Economic Review* 94, 85–90.

Bernanke, B.S., V.R. Reinhart, and B.P. Sack (2004) Monetary policy alternatives at the zero bound: An empirical assessment (with discussion). *Brookings Papers on Economic Activity* 2, 1–100.

Buiter, W.H. and N. Panigirtzoglou (1999) Liquidity Traps: How to Avoid Them and How to Escape Them. Working paper 7245, National Bureau of Economic Research.

Chaboud, A.P. and O.F. Humpage (2005) An Assessment of the Impact of Japanese Foreign Exchange Intervention: 1991–2004. International finance discussion paper 824, Board of Governors of the Federal Reserve System.

Christiano, L.J. (2000) Comments on Ben McCallum, "Theoretical analysis regarding a zero lower bound on nominal interest rates." *Journal of Money, Credit and Banking* 32, 905–930.

Christiano, L.J., M. Eichenbaum, and C.L. Evans (1999) Monetary policy shocks: What have we learned and to what end? *Handbook of Macroeconomics*, vol. 1A, pp. 65–148. Amsterdam: North-Holland.

Clouse, J., D. Henderson, A. Orphanides, D. Small, and P. Tinsley (2000) Monetary Policy When the Nominal Short-Term Interest Rate Is Zero. Finance and economics discussion paper, Federal Reserve Board.

Dominguez, Kathryn M. (1990) Market responses to coordinated central bank intervention. *Carnegie–Rochester Conference Series on Public Policy* 32(0), 121–163.

Dominguez, K.M. and J.A. Frankel (1993a) Does foreign-exchange intervention matter? The portfolio effect. *American Economic Review* 83, 1356–1369.

Dominguez, K.M. and Frankel, J.A. (1993b) *Does Foreign Exchange Intervention Work?* Washington, DC: Institute for International Economics.

Edison, Hali J. (1993) The Effectiveness of Central-Bank Intervention: A Survey of the Literature after 1982. Special Papers in International Economics 18, Princeton University.

Eggertsson, B.G. (2003) How to Fight Deflation in a Liquidity Trap: Committing to Being Irresponsible, Working paper WP/03/64, International Monetary Fund.

Eggertsson, B.G. and M. Woodford (2004) Policy options in a liquidity trap. *American Economic Review* 94, 76–79.

Fatum, R. and M. Hutchison (2006) Effectiveness of official daily foreign exchange market intervention operations in Japan. *Journal of International Money and Finance* 25, 199–219.

Fuhrer, J.C. and B.F. Madigan (1997) Monetary policy when interest rates are bounded at zero. *Review of Economics and Statistics* 79, 573–585.

Ito, T. (2002) Is Foreign Exchange Intervention Effective? The Japanese Experiences in the 1990s. Working paper 8914, National Bureau of Economic Research.

Iwata, S. and S. Wu (2006) Estimating monetary policy effects when interest rates are close to zero. *Journal of Monetary Economics* 53, 1395–1408.

Kim, S. (2003) Monetary policy, foreign exchange intervention, and the exchange rate in a unifying framework. *Journal of International Economics* 60, 355–386.

Koop, G., M.H. Pesaran, and S.M. Potter (1996) Impulse response analysis in nonlinear multivariate models. *Journal of Econometrics* 74, 119–147.

https://doi.org/10.1017/S1365100512000120 Published online by Cambridge University Press

Krugman, P. (1998) It's baaack: Japan's slump and the return of the liquidity trap. *Brookings Papers on Economic Activity* 2, 137–187.
McCallum, B.T. (2000) Theoretical analysis regarding a zero lower bound on nominal interest rates. *Journal of Money, Credit and Banking* 32, 870–904.
McCallum, B.T. (2001) Inflation Targeting and the Liquidity Trap. Working paper 8225, National Bureau of Economic Research.
Meltzer, A.H. (1995) Monetary, credit and (other) transmission processes: A monetarist perspective. *Journal of Economic Perspectives* 9, 49–72.
Mussa, M.L. (1981) The Role of Official Intervention. Occasional paper 6, Group of Thirty.
Orphanides, A. and V. Wieland (1998) Price Stability and Monetary Effectiveness When Nominal Interest Rates Are Bounded at Zero. Finance and economics discussion paper 1998-35, Federal Reserve Board.
Potter, S.M. (2000) Nonlinear impulse response functions. *Journal of Economic Dynamics and Control* 24, 1425–1446.
Reifschneider, D. and J.C. Williams (2000) Three lessons for monetary policy in a low inflation era. *Journal of Money, Credit and Banking* 32, 936–966.
Sarno, L. and M.P. Taylor (2001) Official intervention in the foreign exchange market: Is it effective and, if so, how does it work? *Journal of Economic Literature* 39, 839–868.
Summers, L.H. (1991) How should long-term monetary policy be determined? *Journal of Money, Credit and Banking* 31, 277–295.
Svensson, L.E.O. (2001) The zero bound in an open economy: A foolproof way of escaping from a liquidity trap. *Bank of Japan Monetary and Economic Studies* 19(S-1), 277–312.
Wolman, A.L. (1998) Staggered price setting and the zero bound on nominal interest rates. *Federal Reserve Bank of Richmond Economic Quarterly* 84, 1–24.

https://doi.org/10.1017/S1365100512000120 Published online by Cambridge University Press