Foreign Exchange Interventions at Zero Interest Rates

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Abstract
This paper uses a nonlinear structural vector auto-regression model to empirically investigate the effectiveness of official foreign exchange (FX) interventions in an economy when interest rates are constrained at the zero level, based on the 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 while 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.

JEL Classification: E52 (Monetary Policy), E55 (Central Banks), F31 (Foreign Exchange)
Key Words: zero interest rates, sterilized intervention, exchange rates.

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1. Introduction

Bonds and money become perfect substitutes when nominal interest rates approach zero. As a result, nominal rates cannot go below the floor of zero even though the real interest rate may still be higher than that is needed to ensure stable prices and full employment. The question of how monetary policy should be conducted in a zero-interest-rate environment has been attracting a great deal of attention recently among economists as well as policy makers. The well-known question of Keynes about the liquidity trap now appears to be of the urgent practical importance after having been treated as a mere theoretical curiosity for seventy years. This shift of interest clearly reflects the recent macroeconomic events, namely the Japanese economic stagnation and deflation experience in 1990s and the recent record low level of inflation in the US since the great depression. In particular, Japan’s call rate, which is the monetary policy instrument for the Bank of Japan (BOJ), has been essentially zero for more than a decade since 1995, a phenomenon that has never been experienced before in any modern world (see Figure 1).

Such a zero-interest-rate environment 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. If an adverse shock hits the economy when nominal interest rates are close to zero, what extra ammunition will still be in the hands of central banks? If the economy is already facing deflation and zero interest rates, what can a

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1 The central bank can set the policy interest rate below zero if it prefers, but market rates such as the interbank money market rate would not go below zero.
2 The issue on how the zero lower bound constraints may interfere the conduct of monetary policy is discussed by Fuhrer and Madigan (1997), Orphanides and Wieland (1998), Clouse et al. (2000), Reifschneider and Williams (2000), Wolman (1999), and others. The issue on what monetary policy can do when the economy is in the liquidity trap is discussed by Bernanke and Reinhart (2004), Bernanke, Reinhart and Sack (2004), Buiet and Panigirtoglou (1999), Eggertsson (2003), Eggertsson and Woodford (2003, 2004), Krugman (1998), McCallum (2000, 2001), Svensson (2001) and others.
3 See Alhearme et al. (2002) for Japan’s experience in the 1990s.
central bank do to get out of the liquidity trap? Some economists think that in this situation monetary policies are completely impotent (e.g. Summers 1991). Some 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, as 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. For example, when inflation is too low or output is below its potential level, the home currency will be depreciated. Such a policy rule can be accomplished via central bank’s outright purchases of foreign currency in the foreign exchange (FX) markets. These unsterilized interventions increase domestic money supply and create expected inflation, hence lower the real interest rate. Moreover, a real depreciation of the home currency raises foreign demand for exports and reduces home demands for imports. Such an exchange rate policy therefore acts as an expansionary monetary policy under the zero-interest-rate constraint.

The proposal is not without controversies, however. For example, in McCallum’s model, the uncovered interest parity (UIP) relation is replaced by the exchange-rate-based Taylor rule. Christiano (2000) argues that the UIP is essentially an Euler equation from the inter-temporal optimization that underlies the IS-LM specification of McCallum’s model and cannot be simply dropped out. The UIP relation questions the feasibility of the exchange-rate-based policy rule because a purchase of foreign currency by a central bank may not lead to a depreciation of the

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4 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.
domestic currency if nominal interest rates are constrained by the zero lower bound.\(^5\) This theoretical debate highlights the difficulties of the issue regarding monetary policies under the zero-interest-rate regime.

In this paper, we take on an empirical approach. Using the Japanese data in the 1990s, we investigate whether or not official foreign exchange (FX) interventions\(^6\) 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, it would put in doubt the proposal of an exchange-rate-based monetary policy rule as a way to combat deflation and stagnation when interest rates are constrained at the zero lower bound. In this sense, it is an issue of crucial policy importance, especially when Japan is still struggling in the middle of deflation.

Second, the issue on the effectiveness of FX interventions has an intrinsic interest itself. 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.\(^7\) Moreover, a zero interest-rate environment gives some advantage for examining FX interventions. The reason is the following. There are several potential channels through which FX interventions would influence exchange rates. They are classified into two distinct groups, which we call the interest rate channel and the non interest rate channel. In the first case, an FX intervention produces a change in interest rates by altering money supply, which in turn leads to a change in exchange rates. In the second case, an FX intervention affects

\(^5\) Although the UIP is a fundamental building block in many theoretical models as Christiano (2000) argues, it is one of the least successful empirical relations in economics.

\(^6\) We use the term “FX intervention,” whenever the government authorities intervene the FX market by buying or selling foreign exchange normally against their own currency in order to affect the exchange rate.

\(^7\) See Sarno and Taylor (2001) for the recent survey of the literature.
exchange rates through something other than interest rates. 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 money supply or FX interventions are 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 (Sarno and Taylor 2005). In contrast the results are mixed for the effectiveness of sterilized FX intervention. When interest rates are already on the zero bound or close to the bound, foreign currency purchases by the government in the FX market would increase monetary base but would not alter interest rates. So, the interest rate channel is precluded in this situation, and if FX interventions are to be effective, they must operate through the non interest rate channel. In this sense, FX interventions at zero interest rates and sterilized interventions share one important common feature. 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 the 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 the conventional monetary policy together. Kim (2002) 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 estimating the reaction function of

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8 Difficulty in investigating the effectiveness of sterilized FX interventions come partly from the government authority’s secretive attitude not to reveal their conduct of sterilization. Even when official data on intervention are available, those on sterilization are not.

9 There are important differences between an intervention at zero interest rates and a sterilized intervention. The monetary base will increase with interventions at zero rates, but will not with sterilized interventions.
monetary policy. The resulting nonlinear structural vector auto-regression (NLSVAR) model allows us to examine two separate response curves of the exchange rate to exogenous FX intervention shocks: one corresponds to the positive-interest-rate regime and the other corresponds 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 foreign exchange rate even when the interest rate is on the zero bound. An outright purchase of the U.S. dollar by the Bank of Japan at zero interest rates still leads to a significant depreciation of the yen against the dollar. This suggests that McCallum’s proposal of an exchange-rate-based policy rule is a feasible alternative to the conventional monetary policy when nominal interest rates are on the zero lower bound. 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 on 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 paper is organized as follows. Section II describes the data used in this study. Section III discusses our econometric strategy. Section IV presents the main results and section V concludes.

2. Data and Background

2.1. Data
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. The overnight call rate, which has been the policy instrument for the BOJ, declined from a peak of 8.2 percent in March 1991 to 2 percent in March 1995. By September 1995, it was lowered below 50 basis points and has remained at that low level since. The yen-dollar exchange rate, on the other hand, exhibited long swings between appreciation and depreciation, while the government aggressively intervened in the foreign exchange market by buying and selling dollars frequently during this period. 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 1990s.

As can be seen in Figure 1 (a), from 1991 the yen started to appreciate and especially sharply in 1994-95. It reached a record high of ¥80/$1 in May 1995. Then it swung all the way back to the level ¥145/$1 in July 1998. Then it turned around and stayed in the range of ¥105 – ¥120 between October 1998 and November 2001. After this period, the yen began swinging again but with smaller fluctuation than in the early 1990s. Between April 1991 and December 2000, the Bank of Japan, acting as the agent of the Ministry of Finance, bought US dollars on 168 occasions for a cumulative amount of $304 billion and sold US dollars on 33 occasions for a cumulative amount of $38 billion.

In this paper, we use monthly data from 1991 to 2002. The variables include (a) the Japanese wholesale price index, (b) index of industrial production, (c) the inter-bank 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 International Financial Statistics of the IMF. The official intervention data are from the Japanese ministry of finance’s website. The choice of the time period between 1991 and 2002 is largely due to (i) the availability of intervention data and (ii) a structural change in the intervention policy after 2003 (Ito 2005). By choosing this period, we can also avoid major structural changes in the Japanese monetary policy within the sample. The dramatic rise in asset prices starting in late 1980s had caused the BOJ to focus its policy activities on asset prices. See Hertzel (1999) for a discussion of Japanese monetary policy since 1970s. After the burst of the asset price bubble in 1990, however, the main concern of the BOJ is to deal with deflation and to revive its domestic economic activity, and there does not seem to be any major structural change in its policy.

Before introducing our model in details in next section, we briefly describe the monetary policy practice of the Bank of Japan (BOJ) during the 1990s, a period when the BOJ explicitly uses a short-term nominal interest rate (the overnight inter-bank call rate) as the policy instrument. In the late 1990s, the BOJ adopted what they call “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 the BOJ's 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 is to move nominal interest rates down to a level as low as possible by satiating the money market with excess supply of funds. One important aspect of the zero interest rate policy is that an exogenous monetary easing will not result in any further movement in the

interest rate when the rate is already on the zero lower bound. Therefore, while 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.

2.2. The Interest Rate As a Censored Variable

To model the behavior of the monetary authority in Japan described above, we make the following specification. Let $R_i$ be the short-term nominal interest rate and $R^*_i$ be a latent variable measuring the true stance of monetary policy. $R^*_i$ is in general not observable by an econometrician. However, as long as the central bank uses the short-term interest rate as the operating target, $R^*_i$ is directly linked to $R_i$ through the relation

$$R_i = \begin{cases} R^*_i & \text{if } R^*_i \geq c \\ c & \text{otherwise} \end{cases}$$

where $c$ is a lower bound on the nominal interest rate at which $R_i$ is regarded as essentially zero.

In general, as discussed in details in Okina and Oda (2000), the call rate cannot become exactly zero due to the existence of various transaction costs. So the choice for the value for $c$ should also be made to best describe the BOJ's policy rule. The BOJ has set the un-collateralized overnight call rate guideline at 0.50% for 1995-1998 and at 0.25% after September 1998. Between February 1999 and July 2000, this lower bound was further pushed down to about 0.02 - 0.03%. It therefore appears to be a good approximation to the actual policy behavior to model the rate as being censored, or equivalently $R^*_i \leq R_i$, as long as the actual rate
$R_t$ is less than 50 basis points.\textsuperscript{11} Accordingly, throughout this paper, we choose the lower bound $c$ to be 0.50%, and use the terms such as 'zero interest rate' or 'zero lower bound' even when the actual lower bound is not necessarily exactly equal to zero.

Equation (1) treats $R_t$ as a censored variable. It implies that, when used by the monetary authority as the policy instrument, the short-term interest rate provides a direct measure of the stance of monetary policy. However, if the monetary policy drives the interest rate down to zero, a further monetary easing will not affect the interest rate. $R_t^*$ can be thought of as the interest rate level the monetary authority would have set according to its policy rule if there were no zero lower bound on the interest rate.

To connect the above scheme to the macroeconomic shocks, consider a standard money market model. When the interest rate is the operating target, we can describe the determination of the interest rate and money growth in terms of fundamental macroeconomic shocks by (we abstract from all the lagged variables that may also enter the equations)

\begin{align}
R_t^* &= \beta_1^t \epsilon_t^y + \beta_2^t \epsilon_t^z \\
\Delta m_t &= \alpha_1^t \epsilon_t^y - \alpha_2^t \epsilon_t^z + \alpha_3^t \epsilon_t^d
\end{align}

where $\Delta m_t$ is the growth rate of money at time $t$. Note that the short-term interest rate $R_t$ is determined jointly by (1) and (2).

Equation (2) represents the monetary policy reaction function (or policy rule), where $\epsilon_t^y$ is a vector of innovations to the macroeconomic variables to which the central bank responds contemporaneously when setting the short-term interest rate. $\epsilon_t^z$ is an exogenous monetary

\textsuperscript{11} 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.”
policy shock due to any discretionary actions that are not captured by the systematic monetary policy rule, and \( \varepsilon_t^d \) in equation (3) stands for an exogenous money demand shock. When the interest rate is the policy instrument, the monetary authority fully accommodates money demand shocks so that \( \varepsilon_t^d \) only affects money growth without having any immediate effect on the interest rate. On the other hand, the exogenous monetary policy shock \( \varepsilon_t^s \) affects both the interest rate and money growth.

More specifically, equations (1) – (3) together imply that, when the interest rate is positive, an expansionary policy shock \( (\varepsilon_t^s < 0) \) lowers the interest rate and raises money growth. When the interest rate is initially on the zero bound, however, an expansionary policy shock \( (\varepsilon_t^s < 0) \) does not generate any movement in the interest rate, but leads to an increase in money growth. In other words, when the interest rate is positive, both the interest rate and money growth contain information about monetary policy actions in either direction. But under the zero interest rate regime, exogenous monetary expansions can only be reflected in the corresponding movements of money growth, while the interest rate remains on its lower bound.\(^{12}\)

### 2.3 FX Intervention Policy Shock

To examine the effectiveness of FX intervention, most studies regress the exchange rate change on a measure of interventions, usually the net amount of foreign currency purchases,  

\(^{12}\) The maintained assumption is that there is no structural change in the policy rule during the whole sample period. This allows us to address the central issue of how the monetary policy effects are altered when the interest rate reaches its lower bound but the central bank continues to follow the same policy rule.
along with other control variables. This standard practice is a sensible way for the investigation when high frequency (e.g. daily) data are used. With longer 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, while whether and when to intervene is affected by the level of the exchange rate. This endogenuity 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 including 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 inter-bank call rate, $R$) and the growth rate of aggregate money ($\Delta m$). These variables contain information about the stance of monetary policy. The last group includes foreign exchange market variables, namely the
yen/dollar nominal exchange rate \((x)\) and the amount of net dollar purchases by the BOJ \((f)\).

These are the variables are of central interest in this paper and play an important role, particularly when the nominal interest rate is on the zero bound.

Denote three groups of variables mentioned above by \(Y_t, W_t^*, X_t\), respectively, where \(Y_t, W_t^*\) and \(X_t\) are all 2×1 vectors. The VAR system is then given by

\[
\begin{bmatrix}
Y_t \\
W_t^* \\
X_t
\end{bmatrix} = B(L) \begin{bmatrix}
Y_t \\
W_t \\
X_t
\end{bmatrix} + \mu + u_t
\]  

(4)

Where \(Y_t = (y_t, p_t)'\), \(W_t^* = (R_t^*, \Delta m_t)'\), \(W_t = (R_t, \Delta m_t)'\), \(X_t = (x_t, f_t)'\), \(B(L) = B_1 L - \cdots - B_p L^p\)

with \(L\) being the lag operator, and \(\mu\) is a vector of constants. \(R_t, \Delta m_t\) and \(R_t^*\) are defined in Equations (1) - (3) above. \(x_t\) is the yen/dollar nominal exchange rate. \(f_t\) is the amount of net dollar purchases by the BOJ. \(Y_t\) contains log output and log price level. The term \(u_t\) stands for a vector of one-step-ahead forecast errors and is assumed to be distributed as \(N(0, \Sigma)\) where \(\Sigma\) is a symmetric positive definite matrix. It is important to note that in equation (4), \(W_t^*\) on the left hand side of the equation includes the latent variable \(R_t^*\), while \(W_t\) 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 (4) can be written as

\[
A_0 Z_t^* = A(L) Z_t + A_0 \mu + \varepsilon_t
\]

(5)
where $\mathbf{Z}_i^* = [Y_i', W_i', X_i']'$, $\mathbf{Z}_i = [Y_i', W_i', X_i']'$ and $\mathbf{e}_i = [e_i^r, e_i^M, e_i^X']'$ stands for the fundamental macroeconomic shocks. Note that $e_i^M = (e_i^r, e_i^d)'$ and $e_i^X = (e_i^r, e_i^{f})'$ where $e_i^r$ is the exogenous monetary policy shock, $e_i^d$ is the exogenous money demand shock, $e_i^X$ is the exogenous foreign exchange shock, and $e_i^{f}$ is the exogenous intervention policy shock. We assume that $e_i \sim N(0, \mathbf{I}_m)$.

We impose the following restrictions to identify the model. First, we assume that the exogenous money market shock $e_i^M$ and the foreign exchange market shock $e_i^X$ do not affect output and price level ($Y_i$) 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 $\mathbf{X}_i$ 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 by the macroeconomic nor money market shocks contemporaneously. This is because there is no evidence that the BOJ had 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 responds to the FX intervention shock through either the signaling channel or the portfolio balance channel, while it does not respond directly to exchange rate shocks. Fifth, the exchange rate movements is assumed to reflect exogenous shocks of all variables.

Under these restrictions, we can rewrite (5) as

$$\mathbf{Z}_i^* = \mathbf{B}(L)\mathbf{Z}_i + \mathbf{\mu} + \mathbf{C}e_i$$

(6)
\[ C = A_0^{-1} \] is the matrix of the impact multipliers, which is expressed as

\[
C = \begin{bmatrix}
c_{11} & 0 & 0 & 0 & 0 & 0 \\
c_{21} & c_{22} & 0 & 0 & 0 & 0 \\
c_{31} & c_{32} & c_{33} & 0 & 0 & 0 \\
c_{41} & c_{42} & c_{43} & c_{44} & 0 & c_{46} \\
c_{51} & c_{52} & c_{53} & c_{54} & c_{55} & c_{56} \\
0 & 0 & 0 & 0 & c_{65} & c_{66}
\end{bmatrix}
\] (7)

In the above matrix, “0” indicates zero restriction and “c_{ij}” indicates a free parameter. This form imposes sufficient identifying restrictions to investigate the dynamic response of \( \textbf{Z}_t \) to an intervention shock \( \varepsilon_t^f \) as well as a monetary policy shock \( \varepsilon_t^s \). The system (6) subject to (1) and (7) can be estimated by the maximum likelihood method. The Akaike's information criterion (AIC) is used to choose the number of lags in (6). The derivation of the likelihood function is provided in the Appendix.

When the economy is in liquidity trap with zero interest rates, money demand is likely to behave quite differently than in the normal environment with positive interest rates. We therefore allow for the possibility that when the nominal interest rate is zero, money growth \( \Delta m_i \) responds differently to \( \varepsilon_t^Y \), \( \varepsilon_t^M \) as well as \( \varepsilon_t^s \). We also allow for different intercept term for \( \Delta m_i \) in model (6) when the zero bound is approached.\(^{13}\)

\(^{13}\) Since ML estimation of our model with nonlinearity and many parameters is already quite complicated, we tried only limited number of different specifications. First, there is a concern that the BOJ might have switched its policy instrument to monetary base around 2001. To take into account this possibility, we relaxed the restriction \( c_{34} = 0 \) but imposed \( c_{45} = 0 \). The result turned out to be quite similar to the case of the original specification, but with a little 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 the impulse response functions behave in unnatural way with excessive jags.
4. Empirical Results

4.1. UIP with Zero Interest Rates

Even though UIP is a key relation in many theoretical models and plays a central role in the debate between McCallum and Christiano, it has been strongly rejected in countless empirical studies. Engle (1996) provides an excellent survey on the subject.

In general, UIP is the link between the expected exchange rate change and the interest rate differential between two countries given by

\[ E_t(s_{t+1}) - s_t = i_t - i^*_t \]  

where \( s_t \) is the spot exchange rate at time \( t \), \( i_t \) and \( i^*_t \) are the domestic and foreign interest rates, and \( E_t(\cdot) \) stands for the expectations given the information up to time \( t \). To examine this relationship empirically, one can run the regression

\[ s_{t+1} - s_t = \alpha + \beta(i_t - i^*_t) + u_t. \]  

If the UIP is true, it should be the case that \( \alpha = 0 \) and \( \beta = 1 \). However, most studies get a significantly negative estimate of \( \beta \). This is often referred to as the forward premium puzzle.

We repeat the standard regression on the Japanese data during 1990s. Table 1 reports the estimated regression coefficients in two cases: (i) the regression using the entire observations within the sample period; (ii) the two separate regressions were run under the zero-interest-rate regime and the positive-interest-rate regime. The results show that in both cases the estimates of \( \beta \) are negative and significantly different from 1. Therefore we do not impose UIP relation in our empirical model described in (6) - (7).
4.2. The Effects of FX Interventions

To investigate the effects of FX intervention, we compute the impulse response functions of the estimated VAR system specified in (6) – (7). This approach allows us to focus on the effects of exogenous FX intervention shocks. In general, the impulse response function (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 same 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 \( \Omega_{t-1} \) stands for the information set at t-1, and \( h = 1, 2, \cdots \) is the time horizon. In a standard linear model, this difference reduces to the h-th 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 the size and direction of the shock.\(^{14}\) This state-dependent feature of the IRF allows us to analyze the policy effects conditional on the current state of the system. In particular, impulse response functions under the zero-interest-rate regime and positive-interest-rate regime can be computed separately (Iwata and Wu 2006).

Figure 2 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

\(^{14}\) Following the literature on nonlinear impulse response [Koop et al (1996), Gallant et al (1993), and 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 \( \Omega_{t-1} \) stands for the information set at t-1, and \( h = 1, 2, \cdots \) is the time horizon. To calculate the conditional expectations, we simulate the model in the following manner. First, we draw the model parameters from the sampling distribution of the ML estimates. Second, we draw \( \varepsilon_{t+j} \) from \( N(0, I_m) \) for \( j = 1, 2, \cdots, h \). 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 \( \varepsilon_t \). This process is repeated 200 times for generating parameters, 500 times for generating shocks. The estimated conditional expectation is obtained as the average of the outcomes.
intervention shock when the interest rate is on the zero bound (solid line) and when it is positive (wide broken line). The shock is standardized to one standard deviation. The 90 % error bands are drawn with the dotted lines for the zero bound case and the narrow broken lines for the positive interest case.

As we can see clearly from Figure 2, 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 2(e)). Since money also increases significantly in response to the FX intervention shock (see Figure 2(d)), it suggests that the FX intervention to a large extent is not sterilized or only partially sterilized. The rise of money supply lowers the nominal interest rate (see Figure 2(c)) and raises the price level (see Figure 2(b)). As a result, the yen depreciates in real term and the real interest rate falls as well, leading to an increase in output (see Figure 2(a)). These dynamic responses to an exogenous foreign exchange intervention shock when the interest rate is positive are entirely consistent with the predictions of the standard economic theory and the results of previous empirical studies on the effects of unsterilized FX interventions.

When the interest rate is at zero, however, an exogenous FX intervention shock produces quite different responses from the economic variables. First, from Figure 2(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 2(c)), and there is only a marginal increase in money growth (see Figure 2(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 2(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 on the effect of official FX interventions. There are three main channels discussed in the literature through which the interventions can affect exchange rates: (a) the interest rate channel, (b) the portfolio balance channel, and (c) the signaling channel. These three channels are not necessarily mutually exclusive but are supposed 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 its 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 being confirmed by the impulse response functions 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 would be changed, and hence, the interest rate channel would 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 since sterilized interventions effectively replaces foreign bonds by 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 adjusting 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 in money supply will affect the exchange rate now.

Empirical results in the existing literature are not conclusive about the effectiveness of the above two channels. Early studies are mostly negative on the effectiveness of sterilized intervention (Edison 1993). The quality of the data used in those studies is, however, somewhat questionable. Since direct data on interventions were not available, those studies infer intervention activities from movements in international reserves. However, the latter represents a very inaccurate proxy for intervention activities since there are a variety of other reasons for which reserves may change. Recent studies using the new direct data released by the governments of the US and Japan tend to find more positive evidence for the effectiveness of sterilized interventions [see Dominguez (1990, 1998, 2003), Dominguez and Frankel (1993 a, b), Ito (2003), Kim (2003), Chaboud and Humpage (2005) among others].

The finding in the current paper not only confirms the results from these recent studies of unsterilized interventions, but also offers a direct measure of importance 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 2(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 compared to that when the interest rate is positive. The difference in the impulse response functions 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.

Some 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 it has some effect. The results in the current paper 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 in, say, daily frequency.

Figure 2(a) and 2(b) also report the dynamic responses of output and price to an exogenous FX intervention shock at zero interest rates. 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 impulse response functions under the positive interest rate regime,
however, the increase 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 2 suggest that while an exchange-rate-based monetary policy rule might be a feasible alternative, its effectiveness regarding 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 impulse response functions from our empirical model in Figure 2 and McCallum’s (2000) impulse response functions based on the simulations of his theoretical model (see Figures 4 and 5 of McCallum, 2000). In the next section, we provide an econometric evaluation of the exchange-rate-based policy strategy proposed by McCallum using our empirical model.

4.3. An Econometric Evaluation of the Exchange-Rate Policy Rule

Using various versions of a fully fledged dynamic general equilibrium models under stochastic shocks, studies of monetary policy at zero interest rates often evaluate the performance of alternative monetary policy rules through numerical simulations (Fuhrer and Madigan 1997, Orphanides and Wieland 1998, Clouse et al. 2000, Reifschneider and Williams 2000, Wolman 1998 and others). One advantage of these studies is that they are immune to the Lucas Critique as expectations are endogenously determined. We conduct an analogous evaluation of the exchange-rate-based monetary policy proposed by McCallum (2000), using the econometric model estimated above. Had the Bank of Japan adopted such a policy once the
nominal short-term interest rate reached zero, what differences would it make? How would this alternative monetary policy strategy perform when the economy is under further adverse macroeconomic shocks in a zero-interest-rate environment? Of course, it is well understood that such an econometric evaluation is subject to the Lucas Critique since we assume the parameters in the VAR model remain the same except those governing the monetary policy. However, one advantage of our approach is that the policy evaluation is done based on an empirically estimated model.

To conduct such an evaluation, we need to assign the values of \( c_{61} \) and \( c_{62} \), the elements in the last row of the matrix \( C \) of the impact multipliers given in equation (7). These two parameters play roles analogous to \( \mu_1 \) and \( \mu_2 \) in the McCallum’s exchange-rate-based Taylor rule given by

\[
\Delta x_t = \mu_0 - \mu_1 (\Delta p_t - \pi^*) - \mu_2 E_{t-1} (y_t - y^*) + e_t, \tag{10}
\]

where \( \Delta x_t \) stands for the rate of depreciation of the yen, and \( \pi^* \) and \( y^* \) stand for the optimal inflation and the natural rate of output, respectively. A little algebra shows that they are linked by the relation \( c_{61} = (c_{61} c_{66} / c_{56}) \cdot \mu_2 \) and \( c_{62} = (c_{22} c_{66} / c_{56}) \cdot \mu_1 \). We assign the values of \( c_{61} \) and \( c_{62} \) implied by those of \( \mu_1 \) and \( \mu_2 \) used by McCallum (2000) and the estimated values of other c’s. Since the exchange rate is the policy instrument under this rule, we also set \( c_{54} = 0 \) to make the exchange policy to fully accommodate money demand shocks. After imposing these values on \( C \), we conduct two types of exercises. In the first exercise, we suppose that the BOJ adopted the exchange-rate-based monetary policy in September 1995 when the policy interest rate hit the zero lower bound. The levels of output and price that might have been experienced in the following years are computed from our estimated VAR model with a modified \( C \) matrix.
imbedding the exchange-rate-based monetary policy. These counterfactual paths of output and price are then compared with the actual paths for policy evaluation. In the second exercise, we assume the situation in which a negative output shock with one-standard-error size hits the economy in two consecutive months when the policy interest rate is on the zero bound. Since the conventional interest rate monetary policy is no longer capable of handling the situation, our interest is in whether the exchange-rate-based monetary policy can do better than the actual policy of the BOJ.

Figure 3 shows the counterfactual paths of output and price if the BOJ adopted the exchange-rate-based monetary policy after 1995, computed from our estimated VAR model, together with the actual paths of output and price. The computation is based on $\mu_1 = \mu_2 = 0.5$, the base line case of McCallum (2000). While there appears to be some improvement in the price level over time, not much difference is found in output improvement when the exchange-rate-based policy replaces the actual BOJ policy.

Figure 4 displays the dynamic responses of output, price, the interest rate, money growth, the exchange rate and foreign exchange intervention to an exogenous negative output shock in two consecutive periods. The curve in the solid line in each diagram corresponds to the exchange-rate-based monetary policy and the curve in the wide broken line to the actual BOJ policy. During the first two months, output declines by about 2.5% but the interest rate cannot move from the zero level in both cases. Under the BOJ’s actual policy, there is no policy response of FX intervention to the negative output shock and hence the exchange rate moves little after the shock. Instead, the BOJ apparently keep increasing monetary base in response to the shock, which appears to result in a mild increase in money supply. However, an increase in money supply is very weak and the price level continues to decline for about 18 months after
the shock, which produces a higher real interest rate. This makes the recovery weak and slow. It takes about 3 years to fully recover output under the BOJ’s active policy. On the other hand, under the exchange-rate-based monetary policy, the negative output shock triggers massive FX interventions by the BOJ, which raise money supply and help the home currency to depreciate. This in turn raises the price level, and hence, lowers the real interest rate and brings in a real depreciation of the home currency. All this leads to a stronger and faster recovery from the output decline, compared to the active BOJ’s policy. It takes only two years to fully recover output under this monetary policy.

The above observation appears to provide a strong support to the exchange-rate-based monetary policy. However, there is a problem in the size of intervention. In response to the 2.5% output decline, the policy rule (10) with $\mu_i = \mu_z = 0.5$ suggested by McCallum requires two-month-long interventions with 3.5 trillion yen each, which is twice as large as the maximum monthly intervention undertaken by the BOJ within our sample period, namely in September 2001. Even this size of intervention can produce only the maximum 6% of currency depreciation. Another problem is the political feasibility of this policy strategy. A substantial and purposeful exchange rate devaluation by the government would elicit strong protests from trading partners, and hence pressure for reversal as pointed out by Auerbach and Obstfeld (2003).

5. Conclusion

This paper uses a nonlinear structural vector auto-regression model to empirically investigate the effectiveness of official foreign exchange (FX) interventions in an economy when interest rates are constrained at the zero level, based on the 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 while 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.
Appendix

Derivation of the likelihood function:

We first rearrange the order of the variables in $Z_t^*$. Define

$$J = \begin{bmatrix} 0 & 1 & 0 \\ I_k & 0 & 0 \\ 0 & 0 & I_{n+1} \end{bmatrix}$$

so that $J'J = I_m$. Rewrite (1) as

$$JB(L)J'JZ_t^* = J\mu + JC_0J'J\varepsilon_t$$

or

$$\tilde{B}(L)\tilde{Z}_t^* = \tilde{\mu} + \tilde{C}_0\tilde{\varepsilon}_t$$

where $\tilde{B}(L) = JB(L)J'$, $\tilde{C}_0 = JC_0J'$, $\tilde{\mu} = J\mu\mu$, $\tilde{Z}_t^* = [R_t^*, [Y_t', X_t']]'$ = $[Z_t^*, Z_{2t}^*]'$ and

$$\tilde{\varepsilon}_t = [e_t^M, e_t^Y, e_t^X]' \sim N(0, I_m).$$

Write $\tilde{B} = [\tilde{B}_1, \cdots, \tilde{B}_p, \tilde{\mu}]$ and $\tilde{Z}_t^* = [\tilde{Z}_{t-1}, \cdots, \tilde{Z}_{t-p}, 1]'$. Then we have

$$\tilde{Z}_t^* = \tilde{B}\tilde{Z}_t^* + \tilde{u}_t$$

with $E(\tilde{u}, \tilde{u}') = \Sigma = \begin{bmatrix} \tilde{\Sigma}_{11} & \tilde{\Sigma}_{12} \\ \tilde{\Sigma}_{21} & \tilde{\Sigma}_{22} \end{bmatrix} = \tilde{C}_0\tilde{C}_0' = JC_0C_0'J'$. The likelihood function conditional on $(\tilde{Z}_0, \cdots, \tilde{Z}_{t-p})$ is given by

$$L = \prod_{R_t^*} f(\tilde{Z}_{1t}, Z_{2t}) \prod_{R_t^*} \int f(\tilde{Z}_{1t}, \tilde{Z}_{2t}) d\tilde{Z}_{1t}$$

$$= \prod_{R_t^*} f(\tilde{Z}_{1t}, \tilde{Z}_{2t}) \prod_{R_t^*} \int f(\tilde{Z}_{1t} | \tilde{Z}_{2t}) f(\tilde{Z}_{2t}) d\tilde{Z}_{1t}$$
Noting that \( \tilde{u}_{1t} = \Sigma_{12} \tilde{\Sigma}_{22}^{-1} \tilde{u}_{2t} + e_t \) where \( e_t \sim \mathcal{N}(0, \tilde{\sigma}_{112}^2) \) with \( \tilde{\sigma}_{112}^2 = \tilde{\sigma}_{11}^2 - \Sigma_{12} \tilde{\Sigma}_{22}^{-1} \tilde{\Sigma}_{21} \), we find
\[
\tilde{Z}_{1t} \mid \tilde{Z}_{2t} \sim \mathcal{N}(\mu_{12}, \tilde{\sigma}_{112}^2)
\]
where \( \mu_{12} = (\tilde{B}_1 - \Sigma_{12} \tilde{\Sigma}_{22}^{-1} \tilde{B}_2) \tilde{Z}_t + \Sigma_{12} \tilde{\Sigma}_{22}^{-1} \tilde{Z}_{2t} \) and \( \tilde{B} = [\tilde{B}_1', \tilde{B}_2']' \). Hence, the log likelihood function takes the form as
\[
\ln L \propto -(T_1 / 2) \ln |\tilde{C}_0 \tilde{C}_0'| - (1 / 2) \sum_{R_t > c} (\tilde{Z}_t - \tilde{B}\tilde{Z}_t)'(\tilde{C}_0 \tilde{C}_0')^{-1}(\tilde{Z}_t - \tilde{B}\tilde{Z}_t) - (T / 2) \ln |\tilde{\Sigma}_{22}|
\]
\[
- (1 / 2) \sum_{R_t = c} (\tilde{Z}_{2t} - \tilde{B}_2 \tilde{Z}_t)'(\tilde{\Sigma}_{22}^0)^{-1}(\tilde{Z}_{2t} - \tilde{B}_2 \tilde{Z}_t) + \sum_{R_t > c} \ln \Phi \left( \frac{c - \mu_{12}^0}{\tilde{\sigma}_{112}^0} \right)
\]
where \( T_1 \) stands for the number of observations for which \( R_t > c \).
References


Table 1: The UIP Regression Coefficient Estimates

<table>
<thead>
<tr>
<th>Variable</th>
<th>Regression (1)</th>
<th>Regression (2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant (0.396)</td>
<td>-0.632</td>
<td>-0.691</td>
</tr>
<tr>
<td>Int. differential (0.168)</td>
<td>-0.182</td>
<td>-0.202</td>
</tr>
<tr>
<td>Zero int. dummy ------</td>
<td>0.538</td>
<td>0.120</td>
</tr>
<tr>
<td>(0.976)</td>
<td></td>
<td>(0.234)</td>
</tr>
<tr>
<td>Int. diff * dummy ------</td>
<td>0.120</td>
<td></td>
</tr>
<tr>
<td>(0.234)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>R-squared</td>
<td>0.027</td>
<td>0.030</td>
</tr>
<tr>
<td>D-W</td>
<td>1.344</td>
<td>1.337</td>
</tr>
</tbody>
</table>

Note: “Regression (1)” is the OLS regression of the actual rate of depreciation of the yen against the dollar on the interest differentials of two countries, given in equation (10) in the text. Regression (2) adds the dummy of the zero-interest-rate regime and the interaction term of the dummy and the interest differentials to Regression (1).
Figure 1: Exchange rates, FX Interventions and Monetary Policy

Money Supply Growth

Industrial Product

 Wholesale Price Index

Exchange Rates

FX Interventions

Call Rates
Figure 2: Dynamic Responses of an FX Intervention Shock

Note: This figure 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. In each diagram, the solid line indicates the response when the interest rate is on the zero bound while the wide broken line indicates the response when the interest rate is positive. The shock is standardized to one standard deviation. The 90% error bands are drawn with the dotted lines for the zero bound case and the narrow broken lines for the positive interest case.
Note: The broken lines correspond to the counterfactual paths of output and price level that would occur if the BOJ adopted exchange-rate-based monetary policy after 1995, while the solid lines correspond to the actual paths of output and price level.
Figure 4: Dynamic Responses of an Adverse Output Shock

Note: The figure displays the dynamic responses of output, price, the interest rate, money growth, the exchange rate and foreign exchange intervention to an exogenous negative output shock in two consecutive periods. The curve in the solid line in each diagram corresponds to the exchange-rate-based monetary policy and the curve in the wide broken line to the actual BOJ policy.