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Solving Endogeneity in Assessing the Efficacy of Foreign Exchange Market Interventions

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Abstract

This paper evaluates the efficacy of the sterilized foreign exchange rate intervention while mitigating the pervasive endogenous bias in the intervention literature. In an attempt to solve the endogeneity problems, this paper utilizes customer trade data to identify the system of equations. By estimating the various model specifications, including the Markov-switching policy function, the results show that the interventions undertaken by the Bank of Korea were effective during 2001 and 2002. Specifically, the volatile market induced the Bank of Korea to intervene, and the interventions decreased the standard deviation of the changes in the Korean won rate from 5.683~5.793 to 5.676.

Keywords: Sterilized intervention; Endogeneity; Customer trade; Markov-switching policy function

JEL classification: F31; E58; G15

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1 Introduction

The effectiveness of foreign exchange market interventions has been one of the most intensively discussed topics in central bank policy analysis. After reviewing the extensive research on this topic, one could take a skeptical viewpoint and state that the sterilized interventions do not meaningfully impact the nominal exchange rate (Craig and Humpage, 2001). At best, the results are mixed.[1] However, due to the endogeneity problems within the previous research on the topic, the debate on the subject cannot yet be concluded. The objective of this paper is to assess the effect of the interventions while minimizing the endogeneity bias by which the existing intervention literatures are plagued. Specifically, this paper identifies a system of equations with valid and unique instrumental variables (IVs) from the market microstructure finance data.

The first endogeneity problem stems from the simultaneity between the intervention decision and the contemporaneous exchange rate. This problem occurs because while the intervention may have an impact on the current spot rate, the current spot rate movement may also trigger an intervention. If we regress the rate movements on interventions with a single equation, such as

$$\Delta S_t = \beta_0 + \beta_1 INT_t + \boldsymbol{\beta}_2 \mathbf{X}_t + \varepsilon_t \tag{1}$$

where ΔS_t is the difference in the exchange rate, INT_t is the central bank intervention and $\mathbf{X}_t$ includes the vector of the other explanatory variables, then the well-known simultaneity between ΔS_t and INT_t implies that INT_t is endogenous. Thus, we will have an inconsistent estimator for β_1 (Neely, 2005; Kearns and Rigobon, 2005).

Endogeneity also occurs due to the omitted variables in equation (1). For the sake of argument, assume that the interventions are decided regardless of the current spot rate. Although INT_t is exogenous in this case, it is still debatable whether $\mathbf{X}_t$ catches all of the other factors that are to be controlled. If $\mathbf{X}_t$ fails to include the variables which have an

[1] See the literature review of Galati et al. (2005)

explanatory power on ΔS_t, β_1 will be inconsistent. Of course, most empirical research contains the omitted variable problem. However, it is particularly difficult to find a valid $\mathbf{X}_t$ to be used for the daily nominal exchange rate models. Existing papers have included the news and/or day of the week dummy variables, as well as macroeconomic variables, such as the interest rate spread, as explanatory variables $\mathbf{X}_t$[2]. However, in many cases the coefficients are not statistically significant. Meese and Rogoff (1983) showed that macroeconomic models underperform on simple random walk models in monthly out-of-sample predictions. In addition, I focus on the daily horizon, for which the macroeconomic variables are likely to be less relevant than on the longer horizons in regard to the exchange rate determination.

In order to avoid the endogeneity problems from the simultaneity, researchers need to take into account an intervention policy reaction function, such as

$$INT_t = \alpha_0 + \alpha_1 \Delta S_t + \boldsymbol{\alpha}_2 \mathbf{Y}_t + u_t \tag{2}$$

where $\mathbf{Y}_t$ includes factors that explain intervention decisions (Neely, 2005). In order to estimate these equations, valid instrumental variables must be available. However, similar to the difficulties in finding a relevant $\mathbf{X}_t$, a lack of valid IVs can be problematic.[3] In this paper, customer trade data from the market microstructure finance are used as IVs and the empirical results verify that these IVs are valid. In addition, customer trades data are shown to be closely related to the spot rate movements and, thus, the data are used in order to resolve the omitted variable bias.

In order to illustrate that the endogeneity bias may mislead researchers when assessing

[2] Bonser-Neal and Tanner (1996) used the macroeconomic news announcement dummy variables and the surprise component of the announced variables; Dominguez (1993, 1998) used the interest rate spread and day dummy variables; Galati et al. (2005) used macroeconomic announcements; Ito (2002) used only US interventions; Rogers and Siklos (2003) used macroeconomic variables, such as changes in stock market prices, interest rate spreads and relevant news dummy variables. Bonser-Near and Tanner (1996) and Rogers and Siklos (2003) regressed the implied volatility on the explanatory variables.

[3] Kearns and Rigobon (2005) identified a system with the intervention regime change of the Reserve Bank of Australia and the Bank of Japan using a simulation method. Hillebrand et al. (2007) estimated a system with the returns of the yen rate, realized volatility and the interventions.

the effect of interventions, a simple GARCH(1,1) specification was estimated for the market condition (1) in Korea. This specification showed that the USD buying intervention appreciated the Korean won, and that the interventions increased the volatility of the won rate in the GARCH model. However, within six different specifications, which will be discussed below, the results were reversed when the systems of equations were estimated. Specifically, the standard deviation of the changes in the won decreased from 5.683~5.793 to 5.676 with the interventions in the sample period, and the 100 million dollar buying intervention depreciated the Korean won by 0.006%~0.132%.

The estimation strategy used within this paper is as follows. First, a simple linear specification with equations (1) and (2) was used. Then, market condition (1) was divided into demand and supply curves. As the linear systems of the equations were estimated, the Generalized Method of Moments (GMM) was attempted. Next, in regard to the nonlinear specification, the Markov-switching type policy reaction function was estimated with the Maximum Likelihood Estimation method. Then, the market demand/supply curves were estimated by the GMM. After estimating the coefficients, the hypothetical exchange rate was calculated in order to show what the rate would be if no interventions were to exist. Finally, the standard deviations in the hypothetical rate were compared to those within the actual rate.

The remainder of this paper is organized as follows. Part Two describes the Korean foreign exchange market and the data set used within this paper. Part Three illustrates the model set-up which specifies the interactions between the interventions, market participants' behaviors and the exchange rate. Part Four explains the empirical results of the study and Part Five concludes the findings and the paper.

2 Facts and Data

This paper utilizes daily data from 2001 to 2002. During this sample period, the Bank of Korea "allowed the Korean won to fluctuate freely according to demand and supply conditions in the foreign exchange market" (The Bank of Korea, 2002, page 46). However, the Bank of Korea intervened "to avoid abrupt fluctuations of the exchange rate within a short-term period" (The Bank of Korea, 2003, page 46). In addition, "the objective [was] to mitigate short-term exchange rate volatility, ... rather than to maintain a certain exchange rate target" (Rhee and Lee, 2005, page197), most of the intervention transactions occurred within the spot market and the impact of these transactions on the money supply was sterilized (Rhee and Lee, 2005). Due to the above reasoning, this paper focuses on the effects of the sterilized interventions on the foreign exchange rate volatility in the Korean won spot market. For the intervention data, I used the daily change in the foreign exchange position of the Bank of Korea as a proxy variable, since the Bank of Korea kept the intervention data confidential.

The Korean won spot is not internationalized and, therefore, is only traded within the Korean foreign exchange market. Specifically, the Korean won spot rate is determined by the Korean interbank (or interdealer) market, which is organized as a limit order book market. That is, the market participants' (or dealers') limit orders to buy (or sell) at certain prices are matched electronically without a market maker. The market participants are mainly commercial banks chartered by the government and, thus, other entities who wish to trade the Korean won spot do so with the participant banks. I refer to these other entities as customers.

The customers include a wide range of entities, such as enterprises selling the USD (export companies) or buying the Korean won (import companies); individuals exchanging the Korean won for the USD at a bank's window; foreign investors who need to trade the USD/KRW spot in order to finance their investments in Korean securities; and other trading desks of the banks such as the non-deliverable forwards (NDF) desks whose positions are frequently hedged by spot transactions. The data for the daily demand and supply trades from the customers were accumulated by surveying the participant banks. The basic descriptive statistics for the customer trades are provided in Table 1. While the daily average of total turnover in the interbank market amounts to 2.6 billion dollars, the customer demand trades amount to 836 million dollars and the customer supply trades amount to 862 million dollars on daily average. On average, the price of the US dollar falls (the mean of ΔS_t is -0.141), and this feature is consistent with the higher selling pressure from the customers.

[Insert Table 1 here]

3 The Model

Lyons (1997) proposed a market microstructure model for the foreign exchange markets in which the foreign exchange rate is determined by public information on the rate, such as interest rate differentials and the order flow. The order flow in the foreign exchange market refers to "the net of buyer-initiated and seller-initiated orders" (Evans and Lyons, 2002, page 171). In the empirical findings of Evans and Lyons (2002), the order flow was estimated to be highly significant in determining the foreign exchange rate return.

In Lyons' (1997) simultaneous trading model, the order flow is a determinant of the rate because the order flow conveys the private information which is relevant to the rate movement. The private information of each dealer is the customer trade. Therefore, customer trade is the main exogenous determinant factor that affects the rate in Lyons' model. This paper follows Lyons' approach to the foreign exchange rate in the sense that customer trade is the main driving force in the foreign exchange market.

3.1 The Behavior of Market Participants

Assume that the interbank foreign exchange market consists of two representative decision-making agents: a demander and a supplier. Based on their information sets ($\Omega_{D(S)t}$ denotes the information set for the demander(supplier) at day t), the demander(supplier) forms a demand(supply) curve. Let's suppose that the demander receives CD_t (customer demand for the USD) and the supplier receives CS_t (customer supply for the USD) at day t. This supposition means that $CD_t \in \Omega_{Dt}$, $CS_t \in \Omega_{St}$.

With the agents' speculative views, the agents maximize the expected utility from wealth as defined as:

$$W_{Dt} \equiv (\Delta S_{t+1} - \Delta S_t) Q_{Dt}^{spec}, \quad (3)$$

$$W_{St} \equiv (\Delta S_t - \Delta S_{t+1}) Q_{St}^{spec}, \quad (4)$$

where $W_{Dt}(W_{St})$ is the wealth of the demander(supplier), $Q_{Dt}^{spec}(Q_{St}^{spec})$ is the quantity demanded(supplied) from the speculative incentives, ΔS_t is $S_t - S_{t-1}$, and S_t is the spot rate of the Korean won against the USD at the end of day t.[4] For tractability, the model assumes that the expected utility function of the agents is a negative exponential with the constant absolute risk averse coefficients, γ_D (for the demander) and γ_S (for the supplier). Additionally, for a simple closed form objective function of the maximization problem, the model assumes that ΔS_{t+1} follows the normal distribution conditional on the agents' information set. In order to show this normality, it becomes necessary to partition the time interval from t to $t+1$ into N sub-intervals, $t = k_0 < k_1 < k_3 < ... < k_N = t+1$, i.e. the time index t is for the day-by-day index and k is for the tick-by-tick index. Therefore, if the rate differentials for a small fraction of time during day $t+1$ are independent and identically distributed conditional on the information at day t, as given by the Central Limit Theorem, then we

[4] This definition of wealth is implicit in assuming that the demander and the supplier know that they will switch roles in near future and, thus, trade with each other at ΔS_t on day t.

have,

$$\sum_{n=1}^{N} \Delta S_{k_n} \quad | \quad \Omega_{Dt} = \Delta S_{t+1} \mid \Omega_{Dt} \sim N(\mu_{Dt}, \sigma^2_{Dt}), \tag{5}$$

$$\sum_{n=1}^{N} \Delta S_{k_n} \quad | \quad \Omega_{St} = \Delta S_{t+1} \mid \Omega_{St} \sim N(\mu_{St}, \sigma^2_{St}), \tag{6}$$

where $\mu_{D(S)t} = E[\Delta S_{t+1} \mid \Omega_{D(S)t}]$, $\sigma^2_{D(S)t} = Var[\Delta S_{t+1} \mid \Omega_{D(S)t}]$. These assumptions generate the maximization problems for the demander and supplier as follows:

$$\max_{Q_{Dt}} \{E[W_{Dt} \quad | \quad \Omega_{Dt}] - \frac{\gamma_D}{2} Var[W_{Dt} \mid \Omega_{Dt}]\}, \tag{7}$$

$$\max_{Q_{St}} \{E[W_{St} \quad | \quad \Omega_{St}] - \frac{\gamma_S}{2} Var[W_{St} \mid \Omega_{St}]\}. \tag{8}$$

From the first order conditions, we have the optimal quantity to trade of the demander and the supplier from the speculative incentives as follows:

$$Q^{spec}_{Dt} = \frac{\mu_{Dt} - \Delta S_t}{\gamma_D \sigma^2_{Dt}}, \tag{9}$$

$$Q^{spec}_{St} = \frac{-\mu_{St} + \Delta S_t}{\gamma_S \sigma^2_{St}}. \tag{10}$$

Other than the speculative incentives, the dealers in the foreign exchange market trade with each other in order to manage their inventory. That is, when a dealer purchases the USD from a customer (CS_t) and the dealer's desired position is a zero position, then the short position of the dealer is an unwanted inventory. In this case, in order to return to the desired zero position, the dealer should buy the USD. Considering this inventory management trading, the total amount of desired trading quantity of the agents is as follows:

$$Q_{Dt} = CD_t + \frac{\mu_{Dt} - \Delta S_t}{\gamma_D \sigma^2_{Dt}}, \tag{11}$$

$$Q_{St} = CS_t + \frac{-\mu_{St} + \Delta S_t}{\gamma_S \sigma^2_{St}}. \tag{12}$$

where $Q_{D(S)t}$ is the total quantity demanded(supplied).

The expected values and variances of the future exchange rate differentials, which are conditional to the participants' information, can be modeled. For tractability, the model assumes that the conditional variances are fixed. In the next section, a few linear specifications for the conditional expectations will be suggested.

3.2 Empirical Model Specification

This section describes the three suggestions for the empirical model specifications. The first specification proposes a linear system that contains the market condition and policy reaction function. The second specification divides the market condition into the linear demand and supply curves. Finally, in the third suggestion, the policy reaction function becomes nonlinear with the Markov-switching intervention probability.

The crucial issue when estimating a system of equations is the availability of valid instrumental variables. Thus, the identification assumption used within this model will, first, be explained and, then, in subsequent sections, tested. One of the issues in this paper is the inclusion of the Japanese yen exchange rate as an exogenous variable. As illustrated in Figure 1, the Korean won was synchronized with the Japanese yen for the sample period and, thus, the yen rate will be a 'strong' instrumental variable. However, the exogeneity may be questioned as there might be other unknown factors that influenced both rates. Therefore, this paper will contain a variation of each model to be tested with the Japanese yen rate.

[Insert Figure 1 here]

3.2.1 Linear Specification (1)

In linear specification (1), the change in the exchange rate is modeled as a linear combination of the current and lagged customer trades and the current interventions. That is, equations

(11) and (12) are simultaneously solved by equating Q_{Dt} to Q_{St}, and the conditional expectations are assumed to be linear combinations of current and past customer trades and the interventions. Then, the current intervention is modeled as a linear combination of the lagged interventions and the current change in the exchange rate. The negative coefficient for ΔS_t in policy equation (14) means that the central bank leans against the wind because the positive INT_t refers to the USD buying intervention. This model can be found as follows,

$$\Delta S_t = \beta_{m0} + \sum_{k=0}^{3} \beta_{m1k} CD_{t-k} + \sum_{k=0}^{3} \beta_{m2k} CS_{t-k} + \beta_{m3} INT_t + \varepsilon_{mt}, \text{ (Market)} \quad (13)$$

$$INT_t = \alpha_0 + \sum_{k=1}^{3} \alpha_k INT_{t-k} + \alpha_4 \Delta S_t + \varepsilon_{pt}, \text{ (Policy)} \quad (14)$$

where the ε terms denote the serially uncorrelated error terms. In this specification, the lagged interventions are used as excluded instrumental variables in market condition (13) and customer trades are excluded in the policy function in order to identify ΔS_t in (14). In addition, the yen variation model includes the difference in the yen rate in the market condition, but not in the policy function.

3.2.2 Linear Specification (2)

Next, I will introduce demand and supply. With the division of the market condition, this model contains a four equation system as follows,

$$Q_{Dt} = \beta_{d0} + \sum_{k=1}^{3} \beta_{d1k} Q_{t-k} + \sum_{k=0}^{3} \beta_{d2k} CD_{t-k} + \beta_{d3} \Delta S_t + \beta_{d4} INT_t + \varepsilon_{dt}, \text{ (Demand)} \quad (15)$$

$$Q_{St} = \beta_{s0} + \sum_{k=1}^{3} \beta_{s1k} Q_{t-k} + \sum_{k=0}^{3} \beta_{s2k} CS_{t-k} + \beta_{s3} \Delta S_t + \beta_{s4} INT_t + \varepsilon_{st}, \text{ (Supply)} \quad (16)$$

$$Q_{Dt} = Q_{St}, \quad (17)$$

$$INT_t = \alpha_0 + \sum_{k=1}^{3} \alpha_k INT_{t-k} + \alpha_4 \Delta S_t + \varepsilon_{pt}. \text{ (Policy)} \quad (18)$$

where Q_t is the quantity traded. Equations (15) and (16) are the estimation equations for (11) and (12), while equation (18) is the linear policy function that illustrates the intervention decision. The lagged quantity traded is used in order to capture the unknown factors that influence the quantity demanded and supplied in an autoregressive manner. In this system, ΔS_t and INT_t are endogenous variables in the demand and supply curves. When identifying the demand curve, it is assumed that the customer supply and lagged interventions can be excluded. Similarly, customer demand is used in order to identify the supply curve. When identifying the policy function, the customer trades are used as excluded IVs. The variation of this model occurs due to the inclusion of the differenced yen rate in the demand and supply curves. This rate is also used as an instrumental variable in the policy function in the variation model.

3.2.3 Nonlinear Specification

Policy reaction functions are notoriously difficult to estimate due to the complexity of policy implementations. Thus, the linear specification within this model may be too simplistic. One of the most notable nonlinear features of the intervention process is the excess zeros in the series. That is, when the desired intervention is small, the central banks may not intervene at all, instead of frequently intervening in small amounts. Therefore, the intervention behavior is modeled in the nonlinear specification as follows,

$$INT_t = d_t(\alpha_0 + \sum_{k=1}^{3} \alpha_k INT_{t-k} + \alpha_4 \Delta\tilde{S}_t + \varepsilon_{pt}),\ \varepsilon_{pt} \tilde{} N(0, \sigma^2) \tag{19}$$

where $d_t = 1$ occurs when the central bank decides to intervene, $d_t = 0$ occurs when the central bank does not intervene and $\Delta\tilde{S}_t$ is the central bank's projected rate change on the current date.

At this point, the projected rate must be further explained. When the central bank decides to intervene on day t, it is realistic to assume that the bank cannot exactly know

ΔS_t, as the closing rate for day t has not yet been decided. Instead, the bank will attempt to guess the ΔS_t, and the intervention decision will, therefore, be based on this guess. In this paper, this guess is assumed to be a linear projection of ΔS_t on the customer trades. In the variation model with the yen rate, ΔS_t is projected on the customer trades and the changes in the yen rate.

In order to model the binary choice d_t, assume a Markov-switching probability as follows,

$$p_t \equiv \Pr(d_t = 1 \mid d_{t-1} = 0) = \frac{\exp(\gamma_0 + \gamma_1(|\tilde{S}_t - S_t^{trend}|))}{1 + \exp(\gamma_0 + \gamma_1(|\tilde{S}_t - S_t^{trend}|))}, \tag{20}$$

$$q_t \equiv \Pr(d_t = 1 \mid d_{t-1} = 1) = \frac{\exp(\gamma_2 + \gamma_3(|\tilde{S}_t - S_t^{trend}|))}{1 + \exp(\gamma_2 + \gamma_3(|\tilde{S}_t - S_t^{trend}|))}, \tag{21}$$

where p_t is the probability of switching from the 'no intervention regime' to the 'intervention regime,' q_t is the probability of remaining in the 'intervention regime,' and S_t^{trend} is a moving average trend of the exchange rate. That is, according to this reaction function, it is more probable that the central bank will intervene when the projected rate deviates from the moving average trend, and that the magnitude of the intervention will depend upon the lagged interventions and $\Delta\tilde{S}_t$.

Then, the likelihood function to be maximized is,

$$\begin{aligned} f(\alpha, \gamma \mid \{INT_t\}_{t=1}^T) = \prod_{t=4}^{T} \phi(\alpha_0 + \sum_{k=1}^{3} \alpha_k INT_{t-k} + \alpha_4 \Delta\tilde{S}_t) \times \{(p_t I_{\{d_{t-1}=0\}} + q_t I_{\{d_{t-1}=1\}}) I_{\{d_t=1\}} \\ +((1 - p_t) I_{\{d_{t-1}=0\}} + (1 - q_t) I_{\{d_{t-1}=1\}}) I_{\{d_t=0\}}\} \end{aligned} \tag{22}$$

where $\phi(\cdot)$ is a standard normal probability density function and $I_{\{.\}}$ is an indicator function.

As the policy function does not depend on ΔS_t, the model estimates the demand and supply curves separately from the policy function. Specifically, after estimating the nonlinear policy function and generating the predicted value $\widehat{INT}_t$ from equation (19), the predicted intervention values are used in equations (23) and (24) as the generated regressors CD_t^* and

CS_t^*. The demand and supply functions are as follows,

$$Q_{Dt} = \beta_{d0} + \sum_{k=1}^{3} \beta_{d1k} Q_{t-k} + \sum_{k=0}^{3} \beta_{d2k} CD_{t-k}^* + \beta_{d3} \Delta S_t + \varepsilon_{dt} \text{ (Demand)} \tag{23}$$

$$Q_{St} = \beta_{s0} + \sum_{k=1}^{3} \beta_{s1k} Q_{t-k} + \sum_{k=0}^{3} \beta_{s2k} CS_{t-k}^* + \beta_{s3} \Delta S_t + \varepsilon_{st} \text{ (Supply)} \tag{24}$$

where CD_t^* is generated as $CD_t + \widehat{INT_t}$ when $\widehat{INT_t} > 0$, $CS_t^* = CS_t - \widehat{INT_t}$ if $\widehat{INT_t} < 0$. In this model, the assumption in regard to the agents' information sets becomes more realistic. In the linear specifications, it was assumed that the agents knew the intervention. However, as the interventions are generally kept secret, this model assumes that the demander(supplier) only knew the sum of the customer demand(supply) and the net buying(selling) intervention. Therefore, the interventions in this model are one of the factors in the customer trades. This assumption means that the only endogenous variable is ΔS_t, the current and lagged CS_t^* can be used to identify the demand function and CD_{t-k}^* can be used to identify the supply function. In addition, the yen rate variation incorporates the changes in the yen rate in both equations.

4 Results

4.1 Estimation of Coefficients and Identification Tests

The simple descriptive statistics for the variables are shown in Table 1. According to the Augmented Dickey-Fuller test, none of the variables were shown to have a unit root. Before proceeding to the estimation of the suggested models, I estimated a simple GARCH(1,1) model for the market condition in order to illustrate the potential endogeneity problems. In the conditional mean equation, ΔS_t was regressed on the current customer trades, the changes in the Japanese yen rate and the interventions. Following Dominguez' (1998) example, the day of the week and the holiday dummy variables were included. The conditional variance equation has the absolute value of the intervention and Table 2 shows that the interventions are positively correlated to the conditional variances, and the coefficient is strongly significant. These results may show that the intervention increases the volatility of the rate in the sample period. However, these results may not be maintained after controlling for the endogeneity in the intervention.

[Insert Table 2 here]

First, the linear specifications (1) and (2) were estimated using the GMM. In order to detect the weakness of the instrumental variables, partial F statistics and Cragg-Donald minimum eigenvalue statistics were calculated (Stock and Yogo, 2002). For the exogeneity of the IVs, Hansen's J statistic was calculated. Then, for the estimation of the nonlinear specifications, the Maximum Likelihood Estimation (MLE) was implemented for the nonlinear policy function. The GMM estimation with generated regressors was implemented for the demand and the supply curves. In order to produce the predicted value of the intervention, a threshold of 0.5 for p_t and q_t was used in calculating $\hat{d}_t$.

Tables 3 through 5 summarize the estimation results. According to the test statistics, in most cases, the IVs were strong and exogenous. The test statistics for rejecting the null hypothesis that IVs were weak were always significant under the 1% level. The inclusion of the Japanese yen into the model deteriorated the exogeneity of the IVs for ΔS_t, but strengthened the IVs relevance. However, even with the yen rate, the null hypothesis that IVs were exogenous was still, in most cases, acceptable at the 5% significance level. The only case in which the null hypothesis was not accepted was the supply curve in a nonlinear specification without the Japanese yen. Nevertheless, it can be concluded that the identification assumptions within these specifications were valid and robust.

The signs of the coefficients corresponded to the intuition, and were strongly significant.

First, the coefficient for the intervention in the market condition was found to be significantly positive in linear specification (1). (β_{m3} was 0.0164 in the specification without the yen and 0.0104 in the specification with the yen.) As the intervention variable is the net USD buying intervention, the above result confirms the intuition that when the central bank buys the USD, its price will increase (the Korean won depreciation). However, in the GARCH(1,1) estimation, the USD buying intervention was shown to significantly decrease ΔS_t. (The coefficient was -0.1417.) Due to the potential endogeneity bias, the sign of the key parameter was estimated to be reversed in the GARCH model.

Additionally, when the market condition was divided into the demand and supply curves in linear specification (2), the interventions were shown to decrease both the demand and supply quantities. However, the coefficients of the interventions in the demand curves were insignificant, but were significant in the supply curves.

Second, the demand(supply) curves were estimated to be downward(upward) sloping. In addition, when the price of the USD, as denominated by the Japanese yen, increased, the expected USD price, as denominated by the Korean won (i.e. $E[\Delta S_{t+1} \mid \Omega_{D(S)t}]$), also increased in both equations. The customer demand(supply) trades have positive relationships with the quantity demanded(supplied) in the same day, but the effects were reversed in the consecutive days. In regard to the policy functions, ΔS_t and $\Delta \tilde{S}_t$ were negatively related to the net buying intervention, which means that the central bank sold the USD when its price (or, guessed price) increased.

[Insert Table 3, 4, 5 here]

4.2 The Hypothetical Rate and the Effect of the Interventions

What would have happened in the foreign exchange market if no interventions existed? This paper tackles this question by calculating the 'hypothetical rate' and comparing it to the actual rate. The hypothetical rate is the rate which assumes that there are no interventions. The rate was calculated by subtracting the intervention terms and, then, solving the estimated equations for ΔS_t. The hypothetical rate is the accumulation of the impulse responses to the shocks in the interventions.

As it is assumed that the Bank of Korea tried to minimize the abrupt changes in the rate, the sample standard deviation of ΔS_t becomes a criterion for assessing the efficacy of the intervention operations. Table 6 summarizes the final results. Interestingly, the hypothetical rate argument can be used to identify the causal relationship between the volatile market and the interventions. That is, in the hypothetical world, the sample standard deviations were higher in the days with interventions than in the days without interventions. This result means that the Bank of Korea intervened because the market was volatile.

On the other hand, the standard deviations of the hypothetical rate were always higher than those of the actual rate. Specifically, the standard deviation of ΔS_t was calculated to be 5.676 for the whole sample in the actual rate, and the standard deviation was always higher than 5.676 in the hypothetical rate in every specification ranging from 5.683 to 5.793. This result shows that the volatility decreased with the interventions. Therefore, the high volatility ignited the interventions and the interventions decreased the volatility. As the high volatility and interventions occur simultaneously, the interventions may appear to increase the volatility as in the example of the GARCH(1,1) model. However, this paper has shown that the causality may be opposite once the simultaneity bias is controlled.

[Insert Table 6 here]

In addition, the intervention elasticity of the exchange rate was calculated. That is, the percent change in the rate induced by the 100 million dollar intervention was calculated and the average of the elasticity is summarized in Table 7. The average varied from 0.006% (the nonlinear specification with the yen) to 0.132% (linear specification (1)). The Kearns and

Rigobon (2005) study shows that the result is 0.2% for the Japanese yen rate. Although the variability is quite large, a caveat should be given to the interpretation of the elasticity in the nonlinear specification. That is, the elasticity was calculated only for the days with the interventions and, thus, cannot capture the dynamics of the effects in total. As the lagged intervention affects the rate in the nonlinear model, the elasticity may not be a proper measure. However, it is still apparent that the effectiveness was smaller within the more complicated and realistic models. For example, the difference in the standard deviation between the hypothetical rate and the actual rate was largest in linear specification (1) and smallest in the nonlinear model. This result suggests that the effectiveness of the foreign exchange rate intervention could be overestimated in the simpler models.

[Insert Table 7 here]

5 Conclusion

Endogeneity problems impede the analysis of the effectiveness of the interventions. In most studies, the researchers had to estimate only a reduced form equation in which the endogenous variables were used as regressors and the regressors were insignificant. Therefore, the results of their analyses were obscure. The main motivation of this paper was to clarify the causality between interventions and the exchange rate volatility. For this task, systems of equations were specified and estimated with a unique data set that included the customer trade data. Specifically, market participants were modeled to solve the utility maximization problems, and the central bank was modeled to intervene to affect the exchange rate. However, the central bank also reacted to the exchange rate movements. To consistently estimate the equations, valid IVs were necessary. In order to fulfill this requirement, I used customer trade as the IVs.

This paper reports three main results. First, the models, which are based on the observational relationship between volatility and the interventions, may mislead researchers when assessing the causal relationship between volatility and the interventions. For example, the GARCH(1,1) specification showed that the interventions were positively related to market volatility with the same data set. However, this result should not be interpreted to mean that the interventions caused the high volatility because, within the various specifications controlling the endogeneity, it was shown that the high volatility ignited the intervention, and that the intervention indeed decreased the volatility. In addition, the effectiveness was numerically measured as 0.006%~0.132% of the depreciation according to the 100 million dollar purchases in the sample period in Korea.

The second finding showed that customer trades can be used as valid IVs, and have explanatory powers in regard to the change in the exchange rate. Throughout the specifications, the customer trades were exogenous and valid IVs, and the results were very robust. Also, customer trades were significant in most of the cases in determining the quantity demanded, quantity supplied and the exchange rate differential. The final result shows that the numerical effect of the intervention decreased with the complication of the model specifications. Therefore, a more careful interpretation of the effect of the interventions should be undertaken numerically with a simple set-up.

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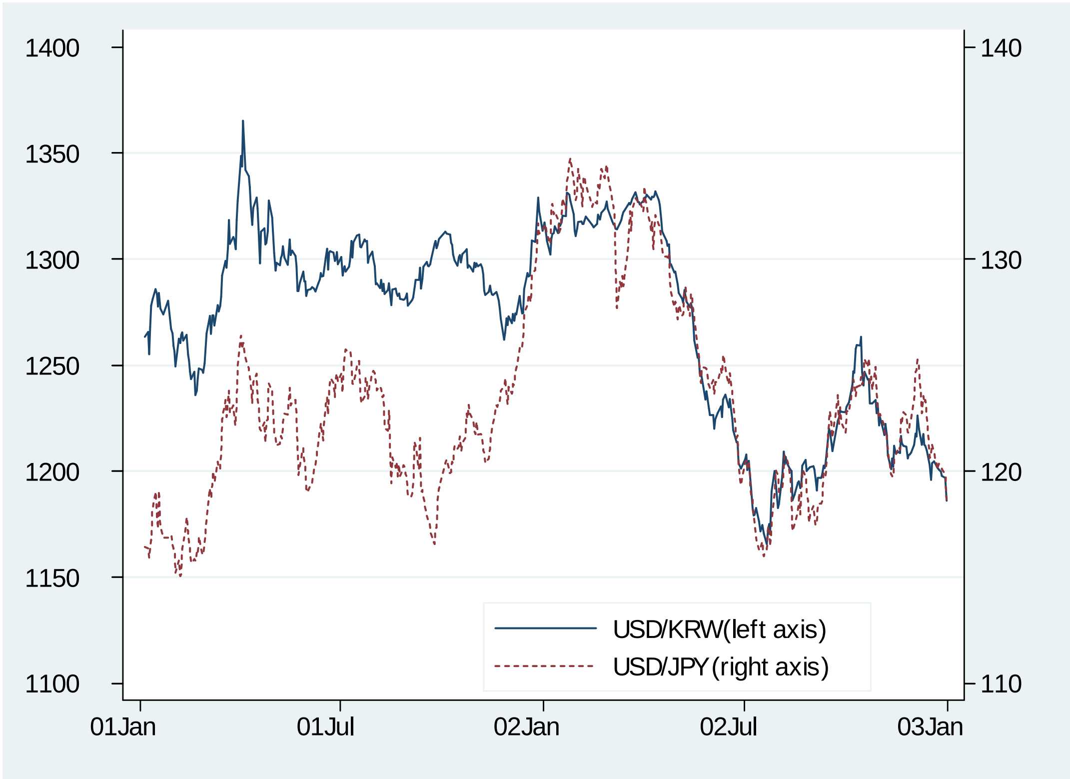
Figure 1. The Korean won and the Japanese yen rate in the sample period



a) source: The Bank of Korea.

Table 1. Descriptive statistics for the variables

	$Q_t^{a)}$	ΔS_t	ΔJPY_t	$CD_t^{a)}$	$CS_t^{a)}$
Mean	2,635	-0.141	0.010	836	862
Standard deviation	561	5.684	0.771	247	237
Skewness	0.230	0.192	-0.148	0.863	0.506
Kurtosis	2.950	4.385	4.096	4.321	3.224
ADF statistics	-11.04	-22.44	-22.36	-14.80	-15.51
(p-value)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)

a) Q_t (traded quantity), CD_t (customer demands) and CS_t (customer supply) are expressed in millions of dollars.

b) ΔS_t is the daily change in the Korean won rate and ΔJPY_t is the daily change in the Japanese yen rate.

Table 2. GARCH(1,1) estimation

$$\begin{aligned}
\Delta S_t &= \beta_{m0} + \beta_{m1} CD_t + \beta_{m2} CS_t + \beta_{m3} INT_t + \sum_{k=1}^{4} \beta_{m4k} D_{kt} + \beta_{m5} h_t + \beta_{m6} \Delta JPY_t + u_t \\
u_t &= \sigma_t \epsilon_t, \ \epsilon_t \sim N(0,1) \\
\sigma_t^2 &= \phi_0 + \phi_1 u_{t-1}^2 + \phi_2 \sigma_{t-1}^2 + \phi_3 h_t + \phi_4 |INT_t|
\end{aligned}$$

where D_{kt} are the day of week dummy variables and h_t is a holiday dummy variable.

$N = 489$, $\ln L = -1368.043$
Wald $\chi^2(9) = 411.37$, p-value: 0.0000

	Coefficient	Standard Error	z stat.	p-value
β_{m0}	0.6902	0.8667	0.80	0.426
β_{m1}	0.0053	0.0010	5.42	0.000
β_{m2}	-0.0057	0.0011	-5.19	0.000
β_{m3}	-0.1417	0.0047	-3.00	0.003
β_{m41}	0.0792	0.5952	0.13	0.894
β_{m42}	-0.9838	0.5776	-1.70	0.089
β_{m43}	-0.7441	0.5573	-1.34	0.182
β_{m44}	-0.3580	0.5555	-0.64	0.519
β_{m5}	1.2709	1.0311	1.23	0.218
β_{m6}	3.9454	0.2303	17.13	0.000
ϕ_0	0.3410	0.3340	1.02	0.307
ϕ_1	0.0944	0.0238	3.96	0.000
ϕ_2	0.7966	0.0450	17.70	0.000
ϕ_3	1.1056	0.5662	1.95	0.051
ϕ_4	0.0051	0.0007	3.96	0.000

Table 3. Estimation results for linear specification (1)

	Market condition			Policy function	
	without JPY	with JPY		without JPY	with JPY
β_{m0}	2.1789	1.5801	α_0	2.2016	1.6002
	(1.3355)	(1.0321)		(3.0755)	(1.1597)
$\beta_{m10}(CD_t)$	0.0097**	0.0072**	$\alpha_1(INT_{t-1})$	0.2993**	0.2917**
	(0.0021)	(0.0017)		(0.0634)	(0.0606)
$\beta_{m11}(CD_{t-1})$	-0.0024	-0.0021	$\alpha_2(INT_{t-2})$	0.0929	0.0588
	(0.0016)	(0.0013)		(0.0623)	(0.0406)
$\beta_{m12}(CD_{t-2})$	-0.0002	-0.0003	$\alpha_3(INT_{t-3})$	0.1053	0.0628
	(0.0015)	(0.0012)		(0.0848)	(0.0612)
$\beta_{m13}(CD_{t-3})$	0.0009	-0.0005	$\alpha_4(\Delta S_t)$	-6.2991	-0.7550*
	(0.0017)	(0.0012)		(3.5393)	(0.3444)
$\beta_{m20}(CS_t)$	-0.0096**	-0.0078*			
	(0.0021)	(0.0016)			
$\beta_{m21}(CS_{t-1})$	0.0020	0.0018			
	(0.0018)	(0.0015)			
$\beta_{m22}(CS_{t-2})$	0.0001	0.0010			
	(0.0016)	(0.0012)			
$\beta_{m23}(CS_{t-3})$	-0.0030	-0.0014			
	(0.0018)	(0.0013)			
$\beta_{m3}(INT_t)$	0.0164*	0.0104			
	(0.0074)	(0.0078)			
$\beta_{m4}(\Delta JPY_t)$		4.5673**			
		(0.2606)			
partial R^2 b)	0.1745	0.1747		0.0713	0.4457
partial F b)	13.07**	12.97**		2.71**	40.68**
C-D c)	103.39**	103.52**		37.55**	393.14**
Hansen's J d)	0.801(0.670)	0.489(0.783)		1.992(0.960)	14.885(0.061)

a) ** denotes significance at the 1% level. * denotes significance at the 5% level. Standard errors are in parentheses.

b) Shea's partial R^2 and partial F test statistics

c) Cragg-Donald chi-squared test statistic for identification

d) Hansen's J statistic

Table 4. Estimation results for linear specification (2)

	Demand curve			Supply curve	
	without JPY	with JPY		without JPY	with JPY
β_{d0}	395.53*	484.79**	β_{s0}	277.51	246.42
	(165.42)	(160.94)		(150.94)	(167.64)
$\beta_{d11}(Q_{t-1})$	0.3680**	0.3749**	$\beta_{s11}(Q_{t-1})$	0.4741**	0.4673**
	(0.0598)	(0.0577)		(0.0522)	(0.0550)
$\beta_{d12}(Q_{t-2})$	0.2193**	0.2414**	$\beta_{s12}(Q_{t-2})$	0.2124**	0.1994**
	(0.0606)	(0.0580)		(0.0563)	(0.0592)
$\beta_{d13}(Q_{t-3})$	0.2316**	0.1834**	$\beta_{s13}(Q_{t-3})$	0.1124*	0.1447*
	(0.0646)	(0.0583)		(0.0559)	(0.0562)
$\beta_{d20}(CD_t)$	0.9721**	0.9292**	$\beta_{s20}(CS_t)$	0.9479**	1.0059**
	(0.1123)	(0.1135)		(0.1017)	(0.1107)
$\beta_{d21}(CD_{t-1})$	-0.4540**	-0.4844**	$\beta_{s21}(CS_{t-1})$	-0.5134**	-0.5070**
	(0.0979)	(0.0992)		(0.1062)	(0.1104)
$\beta_{d22}(CD_{t-2})$	-0.2560*	-0.2357*	$\beta_{s22}(CS_{t-2})$	-0.1447	-0.1915
	(0.1161)	(0.1166)		(0.1097)	(0.1133)
$\beta_{d23}(CD_{t-3})$	-0.1767	-0.1793	$\beta_{s23}(CS_{t-3})$	0.0130	-0.0012
	(0.1139)	(0.1103)		(0.1063)	(0.1099)
$\beta_{d3}(\Delta S_t)$	-54.180**	-75.416**	$\beta_{s3}(\Delta S_t)$	38.073**	58.229**
	(16.460)	(20.885)		(14.512)	(21.238)
$\beta_{d4}(INT_t)$	-0.4457	-0.3264	$\beta_{s4}(INT_t)$	-1.2060*	-1.1467
	(0.6031)	(0.6544)		(0.5580)	(0.6765)
$\beta_{d5}(\Delta JPY_t)$		368.60**	$\beta_{s5}(\Delta JPY_t)$		-246.23*
		(102.37)			(100.93)
partial $R^2(\Delta S_t)$	0.0545	0.0593		0.0549	0.0538
partial F(ΔS_t)	3.65**	3.90**		3.26**	3.08**
partial $R^2(INT_t)$	0.2199	0.2324		0.2196	0.2301
partial F(INT_t)	8.60**	8.61**		8.67**	8.66**
C-D	26.81**	29.29**		27.27**	26.82**
Hansen's J	4.828(0.437)	2.427(0.787)		10.322(0.067)	7.649(0.177)
	Policy function				
	without JPY	with JPY		without JPY	with JPY
α_0	2.8936	0.8468	$\alpha_3(INT_{t-3})$	0.1046	0.0578
	(2.6691)	(1.0482)		(0.0796)	(0.0607)
$\alpha_1(INT_{t-1})$	0.2934**	0.3023**	$\alpha_4(\Delta S_t)$	-5.5066*	-0.7787*
	(0.0620)	(0.0595)		(2.5918)	(0.3443)
$\alpha_2(INT_{t-2})$	0.0982	0.0724			
	(0.0580)	(0.0391)			
partial R^2	0.0836	0.4479	C-D	44.63**	396.68**
partial F	2.54**	30.63**	Hansen's J	3.016(0.981)	19.486(0.053)

Table 5. Estimation results for the nonlinear specification

	Demand curve			Supply curve	
	without JPY	with JPY		without JPY	with JPY
β_{d0}	361.74*	469.57**	β_{s0}	265.38	237.55
	(157.72)	(157.42)		(160.11)	(182.06)
$\beta_{d11}(Q_{t-1})$	0.3628**	0.3723**	$\beta_{s11}(Q_{t-1})$	0.4741**	0.4688**
	(0.0583)	(0.0571)		(0.0552)	(0.0598)
$\beta_{d12}(Q_{t-2})$	0.2280**	0.2460**	$\beta_{s12}(Q_{t-2})$	0.2250**	0.2031**
	(0.0572)	(0.0568)		(0.0593)	(0.0634)
$\beta_{d13}(Q_{t-3})$	0.2356**	0.1860**	$\beta_{s13}(Q_{t-3})$	0.1081	0.0510*
	(0.0624)	(0.0577)		(0.0588)	(0.0608)
$\beta_{d20}(CD_t^*)$	0.9750**	0.9384**	$\beta_{s20}(CS_t^*)$	0.9722**	1.0331**
	(0.1092)	(0.1126)		(0.1100)	(0.1210)
$\beta_{d21}(CD_{t-1}^*)$	-0.4532**	-0.4840**	$\beta_{s21}(CS_{t-1}^*)$	-0.4978**	-0.5153**
	(0.0955)	(0.0998)		(0.1130)	(0.1223)
$\beta_{d22}(CD_{t-2}^*)$	-0.2523*	-0.2418*	$\beta_{s22}(CS_{t-2}^*)$	-0.1596	-0.1966
	(0.1149)	(0.1162)		(0.1166)	(0.1218)
$\beta_{d23}(CD_{t-3}^*)$	-0.1713	-0.1794	$\beta_{s23}(CS_{t-3}^*)$	-0.0292	-0.0456
	(0.1106)	(0.1108)		(0.1078)	(0.1151)
$\beta_{d3}(\Delta S_t)$	-50.200**	-76.272**	$\beta_{s3}(\Delta S_t)$	51.386**	76.818**
	(15.211)	(22.018)		(16.283)	(24.594)
$\beta_{d4}(\Delta JPY_t)$		380.42**	$\beta_{s4}(\Delta JPY_t)$		-326.25**
		(107.90)			(118.93)
partial R^2	0.0647	0.0630		0.0612	0.0549
partial F	5.57**	5.32**		4.79**	4.10**
C-D	33.62**	32.70**		31.70**	28.21**
Hansen's J	5.312(0.150)	2.755(0.431)		8.415(0.038)	5.287(0.152)
	Policy function				
	without JPY	with JPY		without JPY	with JPY
α_0	1.0479	2.3931	σ	53.192**	55.404**
	(2.4332)	(2.5250)		(1.7009)	(1.7716)
$\alpha_1(INT_{t-1})$	0.3202**	0.2835**	γ_0	-2.9064**	-3.2270**
	(0.0430)	(0.0443)		(0.3205)	(0.3400)
$\alpha_2(INT_{t-2})$	0.0958*	0.1260**	γ_1	0.0484**	0.0658**
	(0.0440)	(0.0456)		(0.0170)	(0.0164)
$\alpha_3(INT_{t-3})$	0.1785**	0.1589**	γ_2	-0.8295	-0.9831*
	(0.0426)	(0.0442)		(0.4364)	(0.4423)
$\alpha_4(\Delta\tilde{S}_t)$	-10.686**	-2.1545**	γ_3	0.0641**	0.0699**
	(1.4670)	(0.6643)		(0.0161)	(0.0137)
$\ln L$	-2814.2	-2828.3	Wald χ^2	175.39**	123.42**

Table 6. Sample standard deviations of ΔS_t in the actual and hypothetical rate

		Hypothetical rate		
		Whole sample	Intervention day	No intervention day
Linear(1)	w/o yen	5.793	7.647	5.075
	w yen	5.729	7.450	5.075
Linear(2)	w/o yen	5.714	7.380	5.086
	w yen	5.698	7.352	5.076
Nonlinear	w/o yen	5.689	7.298	5.089
	w yen	5.683	7.291	5.083
		Actual rate		
		Whole sample	Intervention day	No intervention day
		5.676	7.286	5.075

Table 7. Estimated intervention elasticity of the exchange rate

		Intervention elasticity[a)]
Linear(1)	w/o yen	0.132
	w yen	0.083
Linear(2)	w/o yen	0.067
	w yen	0.051
Nonlinear	w/o yen	0.010
	w yen	0.006

a) Average % change in S_t with 100 millions dollar intervention