

Noise Trading Channel and Timing of Effective Central Bank Intervention

기술적 매매 채널에 근거한 중앙은행의 효과적인 외환시장 개입 시기 분석

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This study is to test if sterilized intervention by central banks in the foreign exchange market tends to be more effective when the timing of intervention is consistent with the noise-trading or coordination channel hypothesis. For the test, I use a three-regime threshold model and daily data on actual intervention by US and German central banks. The main finding is that if central banks choose the optimal timing in light of the trend-chasing behaviors of noise traders, such strategic intervention can be more effective in countering the exchange rate trend.

Key words: central bank intervention, noise trading channel, threshold model
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I. INTRODUCTION

Numerous empirical studies have investigated the issue of whether sterilized intervention by central banks is effective or not. A central bank intervenes in the foreign exchange market, usually in the local market, by buying or selling a foreign currency. When the central bank intervenes by buying the foreign currency, it pays home currency and consequently increases the money supply. Similarly, sales of foreign currency decrease the money supply. Change in money supply then affects the interest rate and international investment flows, which eventually has a significant impact on the exchange rate. Since this change in money supply may be in conflict with the established monetary policy, however, central banks of major currencies are known to routinely sterilize their intervention through simultaneous open market operation in the opposite direction and keep the level of money supply intact. Sterilized intervention, therefore, cannot affect the exchange rate through changes in money supply and interest rate. In the early literature, two theories have been proposed about how sterilized intervention may affect the exchange rate: portfolio balance channel and signaling channel. The portfolio balance channel hypothesis asserts that sterilized intervention changes the relative share of foreign currency denominated assets in investors' portfolios and thus their relative risk. Investors, then, adjust their holdings of foreign assets, and the resulting foreign exchange transactions affect the exchange rate. The signaling channel hypothesis, on the other hand, claims that sterilized intervention can be interpreted as a signal about the central bank's view of the current exchange rate and the direction of future monetary policy. The market participants adjust their expectations based on the signal, which is accompanied by changes in the demand for foreign exchange and the exchange rate.

Many studies have tried to empirically test, based on the two hypothesized channels, if sterilized intervention is effective. The majority of those studies, particularly the early studies with the notable exception of Dominguez and Frankel (1993), fail to find substantial evidence for its effectiveness. In fact, the lack of evidence for effectiveness is quite prevalent that only a few studies define effectiveness in terms of the *direct* response of the exchange rate to the intervention operations. Nevertheless, some studies, especially recent studies with new approaches, report more favorable results. For example, Kearns and Rigobon (2005) find that the partial effects of intervention by the Reserve Bank of Australia and the Bank of Japan are significant when policy endogeneity is addressed. Fatum and Hutchison (2003 and 2006) show that intervention is effective when it is measured by episode, rather than daily amount of purchase or sale. Taylor (2004 and 2005), with Markov-switching models and real exchange rate data, reports that intervention increases the probability of switching from a nonstationary exchange rate regime to a stationary regime when the exchange rate is substantially misaligned.

Given the mixed empirical results so far, however, a fair summary seems that intervention can be sometimes effective but not always. Then, a relevant question to ask is “under what conditions intervention becomes effective” rather than “whether intervention is effective or not.” This paper, therefore, follows a “conditional effectiveness” approach to examine the possibility that intervention operations can be effective if certain conditions are satisfied but ineffective otherwise.

One advantage of this approach is that it can explain the mixed results in previous studies. Suppose that the majority of the intervention operations in a given sample period fail to satisfy the conditions under which intervention becomes effective. Then, an empirical study will find

the intervention operations ineffective on average during the sample period. Nonetheless it may be the case that the conditions are satisfied in some sub-periods. A study that focuses or puts more weights on these sub-periods will find intervention to be effective. In addition, if the conditional efficacy hypothesis holds, it follows that the monetary authorities may increase the probability of success in their future operations by learning from past experience.

Concerning the specific conditions for effective intervention, it has been shown in the previous literature that joint intervention by two or more central banks tends to be more effective. Also, the Japanese intervention since 1995, which is noticeable for its unprecedentedly large size, suggests that the size of intervention relative to the market volume is an important factor (see Fatum 2002, for example).

In the current paper, the focus lies on the optimal timing of intervention which has been recognized as an important issue but relatively ignored in the previous literature. Although intervention operations with sufficiently large size are likely to be effective, they can be quite costly to the monetary authorities given that the available foreign reserve under a floating system is quite small relative to the volume of daily trading in the foreign exchange market. Moderate size operation at the right timing can be a more efficient alternative, if effective.

I characterize the appropriate timing based on the 'noise-trading channel' hypothesis of Hung (1997), who analyzes the effect of this channel on the volatility but not on the level of the exchange rate. Noise traders or chartists are those who make trading decisions based on technical trading rules rather than economic fundamentals. With regard to the relative importance of noise traders in the markets, Frankel and Froot (1990) note that the majority of the foreign exchange forecasting firms switched from fundamental analysis to technical analysis around the mid-

1980s. Taylor and Allen (1992) also report that about 90 percent of the traders in London were relying on some form of technical analysis in early 1990's. Building on these findings, Hung claims that since noise traders may be the main source of short-term exchange rate instability, central banks might improve the effectiveness of intervention by entering the market at the optimal moment implied by the trading rules that are popular in the market. In particular, Hung suggests that the monetary authorities should wait until noise traders drive the exchange rate sufficiently up or down before intervening in the market. This is because breaking the trend is easier in a relatively thin market where more traders agree that the exchange rate has overshot some threshold level, and consequently the momentum toward further deviation is relatively weak.

More recently, Sarno and Taylor (2001) propose a similar transmission mechanism, termed the 'coordination channel', through which intervention can be effective even when the traditional *signaling channel and portfolio balance channel* fail to work. They claim that the central bank may serve as a coordinator for those market participants who are aware of severe misalignment but reluctant to bet individually against a sustained trend.

This paper tests the implications of the noise-trading/coordination channel on the level, rather than the volatility, of the exchange rate. Some studies in the literature, such as Dominguez (1998) and Beine et al. (2007), adopt volatility reduction on a daily basis as the measure of efficacy of intervention. At a first glance, this approach seems to be consistent with the general purpose of intervention, i.e., stabilization of exchange rate. However, it is not clear whether the central banks should buy or sell foreign currency in order to reduce *daily* volatility. Moreover, daily volatility may increase immediately after intervention even if the intervention has the desirable effect of stabilizing *longer-run* volatility of

the exchange rate. For instance, suppose that the daily Deutsche Mark per US dollar rate has increased continuously for a few weeks, and the selling US dollar operation by the Federal Reserve and Deutsche Bundesbank is accompanied by a substantial drop of the exchange rate. In this case, the sudden drop of the exchange rate would *increase* the measured daily volatility. On a *weekly* or *monthly* basis, however, the intervention has *decreased* the volatility by countering sustained upward trend in the exchange rate movement. To avoid this ambiguity accompanying the volatility measure, in terms of the appropriate choice of instrument (buying or selling) and the interpretation of the effect (success or failure), I choose to focus on the effect of intervention on the level of the exchange rate.

Whether the goal of intervention is to reduce volatility by countering trends in the exchange rate movements or to change it for the purpose of improving trade balance, efficacy of intervention requires the exchange rate to fall after selling foreign currency operations and rise after buying operations. Therefore, a direct and intuitive measure of the effectiveness, i.e. the response of the daily log return of the exchange rate, is employed instead of some indirect measures of previous studies. In order to allow the effect to vary depending on the timing of intervention, a three-regime threshold model is adopted. Both the noise-trading channel and the coordination channel suggest that intervention will be effective on days with sufficient appreciation (lower regime) or depreciation (upper regime), but ineffective otherwise (middle regime).

I use the data on the actual daily intervention in the Deutsche mark/U.S. dollar (DM/USD) market during 1987-1989. This is a period characterized by relatively frequent intervention and used in many previous studies which fail to find evidence for the overall effectiveness. Given the overall inefficacy during this period as documented in previous

studies, and the moderate sizes of daily operations relative to the sizes of the more recent Japanese intervention, it seems interesting to see if some of the operations consistent with the noise-trading/coordination channel hypothesis were successful. The empirical results with a linear model confirm the well-known *leaning against the wind effect* that the overall effectiveness of intervention on the daily log return of the exchange rate is statistically insignificant. However, the conditional efficacy is significant in the upper and lower regimes of the threshold model, as suggested by the noise-trading/coordination channel hypothesis.

With an extended data covering about six years from January 1987 to January 1993, similar results are obtained although the evidence is a bit weaker in this case presumably because daily intervention during the additional sample period is less frequent relative to the three years between 1987 and 1989.

The rest of this paper is organized as follows. Section 2 discusses some issues specific to modeling the effects of intervention within a threshold-model framework. Section 3 describes the data. Estimation and test results are presented in Section 4 and Section 5 concludes.

II. MODELING THE EFFECTIVENESS OF INTERVENTION

1. Linear model for overall effectiveness

Let S_t be the DM/USD spot exchange rate. Then the log-return y_t is defined as

$$y_t \equiv 100 [\ln(S_t) - \ln(S_{t-1})], \quad (1)$$

which is approximately the percentage change of the exchange rate between the market opening time of day $t-1$ and the market opening time of day t . The linear effect model can be written as

$$y_t = c + \theta \text{intv}[n]_{t-2} + u_t, \quad (2)$$

where c is a constant, and the explanatory variable $\text{intv}[n]_{t-2}$, measured in 100 million U.S. dollars, is the average amount of daily intervention carried out for n days, from day $t-n-1$ to day $t-2$. Thus, the coefficient θ shows the response of the exchange rate, between day $t-1$ and day t , to the average of the previous n -day intervention. The daily amount of intervention is the sum of U.S. dollars purchased by the Federal Reserve and the Bundesbank. The amount is positive when U.S. dollars are purchased against Deutsche mark and negative when U.S. dollars are sold.

Note that intervention is measured as the n -day average amount rather than the daily amount based on the assumption that intervention carried out on *multiple* days can be more effective than an isolated single-day intervention. Additionally, the average amount may capture *delayed effects* of intervention. The delayed effects can be substantial since intervention is frequently unannounced and small in size and thus full reaction in the market may take time. Alternatively, the average amount $\text{intv}[n]_{t-2}$ may be replaced by the amount of intervention on day $t-2$ and its lags. However, since daily intervention is serially correlated, the alternative multivariate model is likely to suffer from multicollinearity, such that the daily variables may not be significant individually even if significant jointly. In this respect, the more parsimonious model is preferred. Since the value of n is unknown, the range of 1 through 5 days will be considered.

The slope coefficient θ in the linear model (2) measures the overall effect of intervention. If intervention is effective on average for the entire sample period, θ should be positive: buying USD against DM increases the DM/USD rate and selling USD decreases the rate. If θ is negative or zero, on the other hand, it means intervention is ineffective, at least on average.

2. Threshold model for conditional effect

If the noise-trading/coordination channel exists, intervention could be effective if the exchange rate is sufficiently above or below some threshold levels. These conditional effects can be specified with a three-regime threshold model as

$$y_t = 1(q_t \leq \gamma_1)(c_1 + \theta_1 \text{intv}[n]_{t-2}) + 1(\gamma_1 < q_t \leq \gamma_2)(c_2 + \theta_2 \text{intv}[n]_{t-2}) + 1(q_t > \gamma_2)(c_3 + \theta_3 \text{intv}[n]_{t-2}) + u_t, \quad (3)$$

where $1(\cdot)$ is the indicator function. The threshold variable q_t is defined as the percentage deviation of the exchange rate on day $t-n-1$ from its previous m -day moving average:

$$q_t = 100 \left(\log(S_{t-n-1}) - \log \left(m^{-1} \sum_{i=1}^m S_{t-n-1-i} \right) \right). \quad (4)$$

The m -day moving average serves as the time-varying point of reference in judging whether the exchange rate has been following a rapid upward or downward trend recently. As an alternative to the moving average, we may consider a proxy for the equilibrium exchange rate such as the purchasing power parity (PPP) level, in which case the threshold variable has an attractive economic meaning: the degree of misalignment of the exchange rate. However, the moving average is

employed in this paper for two reasons. First, it is available at daily frequency, while the data on price levels are available only at monthly frequency. The moving average is also widely used by noise-traders to form short-term trading rules. Thus, it reflects the market conditions better than the monthly PPP rate on a daily basis. Second, as long as the moving average order m is not too large, the deviation from the moving average is stationary. Stationarity is required for the threshold variable in a regime-switching model in order to ensure that all the regimes of the model are observed. In contrast, the deviation from PPP (the real exchange rate) is known to be highly persistent and thus nearly nonstationary. Although m is unknown, it can be estimated once the upper and lower bounds are given. In this paper, up to six months ($m = 120$ days) of moving averages are considered, starting from one month ($m = 20$ days), with the step length of one week (5 days).

In the threshold model of (3), the regime is determined by the size of q_t relative to the two thresholds γ_1 and γ_2 , which will be estimated together with the other parameters in the model. Since each regime shows the reaction of log-return y_t to previous n -day intervention, q_t is assumed to be known before the central banks start the n -day intervention session, i.e., at the beginning of day $t - (n + 1)$.

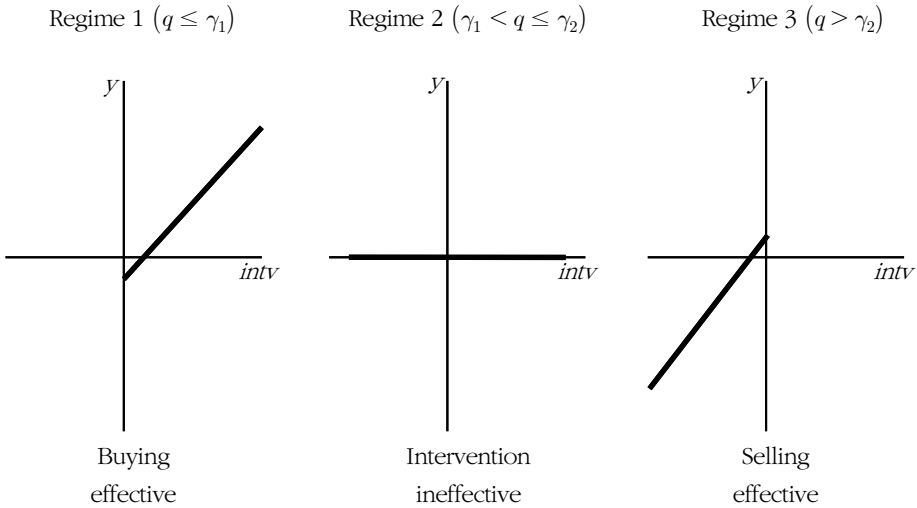
The conditional efficacy of intervention implied by the noise-trading/coordination channel is illustrated in Figure 1 within the context of the three-regime threshold model.

In Figure 1, y is the daily log return of the DM/USD rate, $intv$ is the average daily purchase of the USD during the previous n -days, and q measures the deviation of the exchange rate from previous m -day moving average. In Regime 1, where the USD is sufficiently undervalued, buying intervention appreciates USD. In Regime 3, where USD is quite overvalued, selling intervention depreciates USD. In Regime 2, where USD

is neither overvalued nor undervalued, intervention has little effect on the level of the exchange rate.

Noise traders tend to sell a currency when it is depreciating and buy when it is appreciating. If the traders already sold enough of a currency

〈Figure 1〉 Hypothesized conditional effectiveness of intervention



following a depreciating short-term trend, such that the exchange rate is sufficiently below the lower threshold ($q \leq \gamma_1$), then buying intervention is likely to be effective, as shown in the far-left panel in Figure 1. In the opposite situation, shown in the far-right panel, when the noise traders are in a heavily overbought position ($q > \gamma_2$), selling intervention is expected to be effective. Note that this three-regime model allows the partial effect of intervention to be asymmetric ($\theta_1 \neq \theta_3$). In the middle case, in which any upward or downward trend is in its early stage with strong momentum, intervention with limited resources is hypothesized to be ineffective.

3. Estimation and inference

The linear effect model of (2) can be estimated by ordinary least squares (OLS). The parameters of the threshold model in (3), including the two thresholds γ_1 and γ_2 , and the moving-average order m in (4) can be estimated by the method of sequential conditional least squares as explained in Hansen (2000). The overall effectiveness of intervention can be tested with the null hypothesis of $\theta \leq 0$ in (2) against the alternative of $\theta > 0$. The conditional effectiveness implied by the noise-trading/coordination channel can be tested with the null hypothesis of $\theta_i \leq 0$ against the alternative of $\theta_i > 0$ for $i = 1, 3$ in (3). However, any test involving the parameters of the threshold model is valid only if the thresholds exist. Therefore, the t-tests should be accompanied by an additional test for nonlinearity with the null hypothesis of $c_1 = c_2 = c_3$ and $\theta_1 = \theta_2 = \theta_3$ in (3) in order to see whether significant threshold effects exist.

A simple test for nonlinearity is to compare the values of an information criterion, such as Akaike Information Criterion (AIC) and Schwartz Bayesian Criterion (SBC), between the linear model and the nonlinear model. A more formal test relies on a test statistic such as

$$F = T(SSR_1 - SSR_3) / SSR_3, \quad (5)$$

where SSR_1 is the sum of squared residuals of the linear model, SSR_3 is the sum of squared residuals of the three-regime model and T is the sample size. When the threshold is known, the asymptotic distribution of this statistic is the Chi-square distribution. However, the thresholds (γ_1, γ_2) are unknown and unidentified under the null hypothesis of no threshold effect while SSR_3 depends on the value of the thresholds. Thus, the

asymptotic distribution is not the Chi-square distribution.

The distribution of the F -statistic in (5) can be approximated by a bootstrap procedure described in Hansen (1999), with minor modification to reflect the fact that the log-return of the exchange rate series has the GARCH property. Thus random draws in each bootstrap replication will not be from the residuals of the linear model (2) but rather from the standardized residuals of $\hat{z}_t = \hat{u}_t / \hat{\sigma}_t$ that can be computed after the joint estimation of (2) with a GARCH model for the conditional variance (σ_t^2) by the method of maximum likelihood (ML). Then the bootstrap data in each replication will be generated as

$$\tilde{u}_t = \tilde{z}_t \hat{\sigma}_t, \tag{6}$$

and

$$\tilde{y}_t = \hat{c} + \hat{\theta} \text{intv}[n]_{t-2} + \tilde{u}_t, \tag{7}$$

where $\hat{\sigma}_t$, \hat{c} and $\hat{\theta}$ are the ML estimates and \tilde{z}_t , \tilde{u}_t and \tilde{y}_t are bootstrap series.

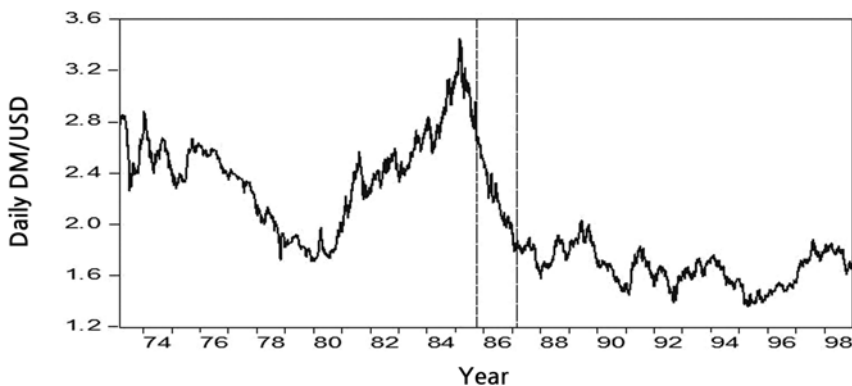
Although the bootstrap data will be generated based on the ML estimates of the parameters, the test statistic in (5) will be computed based on the least-squares estimation in each replication, without explicit consideration of the GARCH property of the errors. This is for two reasons. First, it is computationally easier to implement, given that the bootstrap procedure involves millions of regressions. Note that the OLS estimators are still consistent and asymptotically normal albeit inefficient. Second, once the GARCH specification is included in the multi-regime model, the regimes may be determined largely by the GARCH parameters rather than by the coefficients in the conditional-mean equation. This

possibility itself is interesting. However, the main interest of this study lies in the effect of intervention on the level of the exchange rate. By adopting a threshold model with four or more regimes, it is possible at least theoretically to allow nonlinearity both in the volatility and in the conditional mean. However, such higher-order threshold models can easily become intractable in terms of securing minimum sample size to obtain a consistent estimator in each regime or achieving convergence in the ML estimation.

III. DATA

The data set used for this study contains daily observations on the DM/USD exchange rate and official intervention by the Federal Reserve and the Bundesbank for about six years, from January 5, 1987 through January 22, 1993. The exchange rates are observed at 9:30 AM Paris time and originally recorded by Olsen and Associates of Zurich, Switzerland.

〈Figure 2〉 Daily DM/USD exchange rate (3/2/1973-12/31/1998)



The choice of this particular sample period has a threefold justification. First, although more recent data would be preferable, the fact of the matter is that the two central banks have virtually stopped intervening since September 1995. Specifically, the Federal Reserve intervened only twice between September 1995 and June 2010, i.e., in the yen/USD market on June 17, 1998 and in the euro/USD market on September 22, 2000¹⁾. The Deutsche Bundesbank did not intervene from September 1995 until the advent of euro in 1999. The European Central Bank (ECB) intervened on three days in 2000 but then never intervened until May 2010²⁾.

Second, the chosen sample period is quite stable in terms of intervention policy of the monetary authorities because intervention operations since 1987 were governed by the Louvre Accord, signed by G6 on February 22, 1987. While the goal of the preceding Plaza Agreement, signed by G5 on September 22, 1985, was to depreciate USD through joint intervention and help the United States cut the mounting current account deficit following the sustained appreciation of USD, as shown in Figure 2, the main goal of the Louvre Accord was to prevent further decline of USD and stabilize its value around the level that was prevalent in early 1987³⁾. It is notable that intervention following the Plaza Agreement (first vertical line in Figure 2) was to enhance the preexisting trend of depreciating USD, hence termed in the literature as the “leaning-*with*-the-wind” type intervention, while intervention following the Louvre Accord (second vertical line in Figure 2) was to stabilize the

1) The official intervention records of the Federal Reserve since September 1995 are available at www.newyorkfed.org/newsevents/news/markets.html

2) See the news article of Financial Times available at ftalphaville.ft.com/blog/2010/05/21/238771/a-quick-guide-to-ecb-intervention

3) The Plaza agreement was signed by G5: the United States, Germany, the United Kingdom, France and Japan. The Louvre Accord was signed by G5 and Canada.

value of USD by countering upward or downward trends, hence termed as the “leaning-against-the-wind” type intervention.

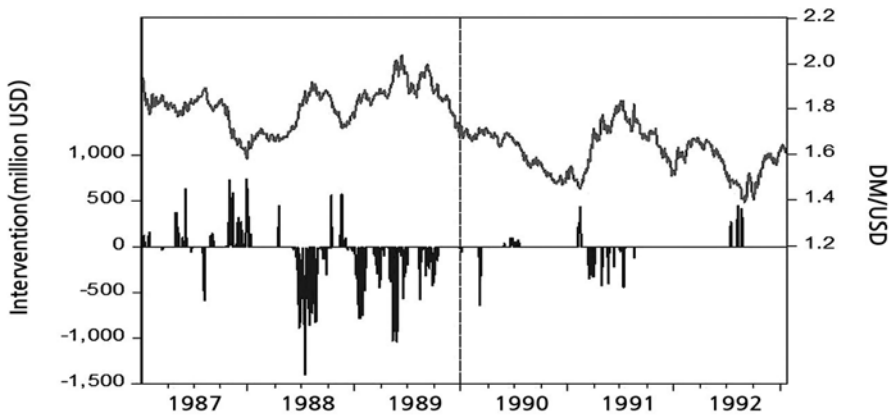
Third, in contrast to the success, albeit arguable, of intervention based on the Plaza Agreement, many studies have found that the intensive intervention following the Louvre Accord is not effective, at least on the average, whether the effectiveness is measured in terms of volatility or the return of the exchange rate. As reported in the next section, I also find that the intervention by the Federal Reserve and Bundesbank has insignificant effect on the daily exchange rate return on average. Therefore, the six years of post-Louvre era is appropriate sample period for the purpose of testing the noise-trading hypothesis, i.e., timely intervention could be effective even if the intervention operations are not effective on average.

Figure 3 depicts the exchange rate movements and the sum of daily intervention amounts by the two central banks during the sample period. In this figure, the amount of the USD purchased against the DM by either the Federal Reserve or Bundesbank is measured in millions of USD along the left vertical axis. Negative values are for selling USD intervention. The exchange rate of DM per USD is measured on the right vertical axis. Since there is no official record of when the Louvre Accord was rescinded, and it is not clear how long the Accord practically influenced the intervention decisions of the two central banks, I consider a sub-sample period of 1987-89 covering the first three years immediately following the Accord, as well as the whole available sample period of 1987-93. As show in Figur 3, intervention becomes less frequent in the early 1990s.

Excluding holidays and weekends, the sub-sample includes 723 daily observations with 220 days of intervention, and the entire sample has 1464 observations with 272 days of intervention. More details classified by

bank and type of intervention are given in Table 1, first for the sub-sample period and then for the whole period.

〈Figure 3〉 Daily DM/USD exchange rate and amount of intervention



〈Table 1〉 Days of Intervention in DM/USD market

	First 3 years (Jan, 1987 - Dec, 1989)			
	Federal Reserve	Bundesbank	Either bank	Both banks
Buy USD	36	48	59	25
Sell USD	101	132	161	72
Total	137	180	220	97
	Whole sample period (Jan, 1987 - Jan, 1993)			
	Federal Reserve	Bundesbank	Either bank	Both banks
Buy USD	65	56	88	33
Sell USD	109	155	184	80
Total	174	211	272	113

Both in the linear model and the threshold model, the dependent variable y_t is the percentage change in the DM/USD rate from 9:30 AM on day $t-1$ in Paris to 9:30 AM on day t . To avoid correlation between

the errors and the explanatory variable, y_t is matched with interventions before 9:30 AM on day $t-1$. Thus, for example, when the 3-day average amount of intervention is chosen as the measure of intervention ($n=3$), the explanatory variable $intv3_{t-2}$ is the daily average amount of US dollars purchased between day $t-4$ and $t-2$. The amount of intervention on day $t-i$ for $i=2,3,4$ is the amount of US dollars purchased between the market closing time on day $t-i-1$ and the market closing time on day $t-i$. With this transformation of the data, four observations are lost and the number of usable observations in the regression is 719 for the sub-sample and 1460 for the entire sample. The 3-day moving average of intervention ($intv3_{t-2}$), as it turns out, gives the highest R^2 to the linear effect model for both sample periods. The variable $intv3_{t-2}$ has 344 nonzero observations, with 105 positive values (buying-USD intervention) and 239 negative values (selling-USD intervention), in the sub-sample, and 440 nonzero observations, with 151 positive values and 289 negative values, in the entire sample.

The threshold variable q_t is the deviation of the exchange rate on day $t-n-1$ from the previous m -day moving average. To compute q_t , it is necessary to have $m+n+1$ observations on the exchange rate before the first observation in the sample. Since maximum value of m considered is 120, this means that the usable sample size will be reduced by more than 120 observations. In order to avoid this loss in sample size, the exchange rate data are augmented by the additional observations available from the Federal Reserve Bank of New York website (www.newyorkfed.org/markets/foreignex.html). The supplementary data are the buying USD rate against DM at noon in New York. Although the exchange rates from the two sets of data may differ on a daily basis, the difference cannot affect the empirical results substantially, as the supplementary data are used only to compute the moving averages of the

exchange rate.

IV. RESULTS

1. Sub-sample period (Jan. 1987 – Dec. 1989)

The estimation results for the first three years of the sample are reported in Table 2: the linear model in the second column and the three-regime threshold model in the last three columns. With the linear-effect model, the estimated slope parameter is 0.014. That is, the exchange rate is expected to rise by 0.014% when the central banks buy 100 million U.S. dollars against Deutsche mark. The estimate has the expected positive sign but it is not statistically different from zero at any conventional significance level. This result suggests that intervention in this period is not effective on average, which is consistent with the findings in previous empirical studies.

For the three-regime threshold model, the estimates of θ are 0.246 in regime 1 and 0.062 in regime 3. Both estimates have positive signs and are statistically significant. Thus, each of the null hypotheses of $\theta_1 \leq 0$ and $\theta_3 \leq 0$ is rejected against the alternative hypothesis of $\theta_i > 0$, with p-values 0.0003 and 0.03, respectively. In contrast, the slope estimate is negative in regime 2, implying that intervention is ineffective in that middle regime. The standard errors reported in Table 2 are computed using White's correction, and thus are robust to heteroskedasticity. In fact, the three types of additional adjustments to the White's formula are considered as suggested in the econometrics literature (see Davidson and MacKinnon 2004, p.100), and those reported in Table 2 are the most conservative of the three. The Ljung-Box tests indicate that there is no

remaining serial correlation.

The estimated conditional effect of buying intervention is not only statistically significant but also practically substantial. In regime 1, buying an additional 60 million USD, which is the median of the explanatory variable for buying intervention, is expected to appreciate USD against DM by about 0.15%. This is approximately 1/3 of the sample standard deviation, 0.48, of the positive values of the dependent variable. The conditional effect of selling intervention is estimated to be much weaker but still nontrivial. With the sale of 98 million USD, the median value of the explanatory variable for selling intervention, the expected depreciation of USD in regime 3 is about 0.06%. This is approximately 1/8 of the sample standard deviation of the negative values of the dependent variable (0.47).

〈Table 2〉 Results with sub-sample (Jan. 1987 - Dec. 1989)

	Linear Model	Threshold Model		
		Regime1	Regime2	Regime3
constant	0.014 (0.028)	0.213 (0.149)	0.063 (0.031)	0.173 (0.071)
$intv3_{t-2}$	0.014 (0.024)	0.246 (0.072)	0.097 (0.044)	0.062 (0.033)
Obs.	719	62	471	186
Buy	105	38	67	0
Sell	239	0	108	131
Thresholds		4.84		1.71
R ²	0.001		0.039	
AIC	4276.4		4248.2	
SBC	4289.6		4287.6	
Q(20)	19.5		20.7	

Note: 1) In parentheses are heteroskedasticity-consistent standard errors.

2) Q(20) is the Ljung-Box statistic. The p-values are 0.49 and 0.42, hence no remaining serial correlation in both models.

The threshold model is estimated with the restriction that each regime should contain at least 5%, or 36 days, of the total observations. Table 2 shows that 62 days belong to regime 1 and 186 to regime 3. Since USD is depreciating in regime 1, all the observations with intervention are buying operations in this regime. Similarly in regime 3 where USD is appreciating, all the observations with intervention are selling operations. Therefore, the threshold variable, which is estimated to be the deviation of the exchange rate from previous 45-day moving average, is consistent with the leaning-against-the-wind type intervention. The estimated thresholds are $\hat{\gamma}_1 = -4.84\%$ and $\hat{\gamma}_2 = 1.71\%$.

Concerning the existence of threshold effects, both AIC and SBC reported in Table 2 suggest that the three-regime nonlinear model explains the data better than the linear model: the three-regime model has lower AIC and SBC than the linear model. The bootstrap test for nonlinearity based on the F -statistic in (6) also suggests that the multi-regime model is better than the linear model. The F -statistic is 28.84 with a bootstrap p -value of 0.017. Thus the null hypothesis of no threshold effect is rejected at 5% or lower level. The bootstrap p -value is computed from 1,000 replications, in each of which the bootstrap data are generated with the following estimated Linear-GARCH model:

$$\begin{aligned} y_t &= -0.01 + 0.006intv3_{t-2} + u_t, \\ u_t &= \sigma_t z_t, \text{ and} \\ \sigma_t^2 &= 0.019 + 0.088u_{t-1}^2 + 0.879\sigma_{t-1}^2. \end{aligned}$$

The above empirical results provide strong evidence for the conditional efficacy of intervention and the existence of the noise-trading/coordination channel. However, since intervention is found effective only after the exchange rate is substantially appreciated or depreciated, one may claim

that the effects are not caused by intervention but by the increased pressure towards the purchasing power parity. This is a plausible assertion and there is plenty of evidence in the literature supporting this claim. For example, see the survey of Taylor (2003).

Interestingly, however, the estimated intercepts of the threshold model in Table 2 lead to a notable counter-argument. In Regime 1, the estimate of the constant is -0.213, which is significant at 10% level with a one-tailed test. The implication is that without intervention, the USD is expected to further depreciate in this regime where the USD is already depreciated substantially. If the PPP claim holds, the opposite should be true. Similarly, the estimated intercept in Regime 3, which is positive and significant at the 1% level, implies that without intervention, the USD is expected to appreciate further rather than depreciate. One explanation for this result is that the regimes of the threshold model are determined by the deviation of the exchange rate from the 45-day moving average which is quite different from the PPP level or the long-run equilibrium level of the exchange rate.

2. Whole sample period (Jan. 1987 – Jan. 1993)

Estimation results with all available observations, which is about six years between 1/5/1987 and 1/22/1993, are reported in Table 3. For the linear model, the estimates are quite similar to those in Table 2. Despite the additional observations, both the intercept and the slope coefficient are statistically insignificant, implying that intervention by the Federal Reserve and Bundesbank is still not effective on average in the extended sample period.

The results for the threshold model are somewhat different from those with the smaller sample. Notwithstanding the differences, the threshold

effect implied by the noise-trading channel is still maintained in the extended period. Specifically, The estimated marginal effect of 3-day intervention is 0.152 in Regime 1, which is smaller than the estimate of 0.246 for the sub-sample case, and 0.154 in Regime 3, which is larger than 0.062 in Table 2. Both are significant with p-values of 0.034 and 0.004, respectively. As expected, the marginal effect in the middle regime is not significantly different from zero at any conventional significance level. The threshold variable is estimated to be the deviation of the exchange rate from previous 90-day average instead of 45-day moving average. The estimates of the thresholds (-8.18% and 7.64%) are similar in size and much larger relative to the estimates in Table 2 (-4.845 and 1.71%).

〈Table 3〉 Results with whole sample (Jan. 1987 - Jan. 1993)

	Linear Model	Threshold Model		
		Regime1	Regime2	Regime3
constant	0,010 (0,021)	0,107 (0,150)	0,039 (0,021)	0,297 (0,129)
$intv3_{t-2}$	0,013 (0,022)	0,152 (0,083)	0,025 (0,023)	0,154 (0,058)
Obs.	1460	74	1306	80
Buy	151	26	125	0
Sell	289	2	252	35
Thresholds		8,18		7,64
R ²	0,000		0,016	
AIC	9946,4		9922,6	
SBC	9961,0		9966,4	
Q(20)	19,4		22,6	

Note: 1) In parentheses are heteroscedasticity-consistent standard errors.

2) Q(20) is the Ljung-Box statistic. The p-values are 0.50 and 0.31, hence no remaining serial correlation in both models.

As a consequence, only a small fraction of the 1460 observations belong to the outer regimes: 74 days in regime 1 and 80 days in regime 3. Most of the interventions in regime 1 are buying operations (26 out of 28) and all the interventions in regime 3 are selling operations (35 out of 35).

The information criteria show that the relative advantage of the three-regime threshold model is weaker with the whole sample. Although the AIC value is still smaller for the threshold model (9922.6 versus 9946.4), the linear model is better by the SBC criterion (9961.0 with the linear model and 9966.4 for the threshold model). However, this is not because intervention in the outer regimes is ineffective but because two of the six parameters (intercept in regime 1 and slope coefficient in regime 2) are quite insignificant. Re-estimation excluding the intercept of regime 1, i.e. restricting it to be zero, reduces the SBC value of the threshold model to 9960.2, which is slightly smaller than the value of the linear model. More importantly, the formal test for nonlinearity confirms that strong threshold effect exists even with the extended sample. The F -statistic defined in (6) is 23.96 and the bootstrap p -value is 0.028. The bootstrapping for the whole sample period is based on the following GARCH model, which is re-estimated with the entire sample but quite similar to the GARCH model for the sub-sample:

$$\begin{aligned} y_t &= -0.02 + 0.004 \text{intv}3_{t-2} + u_t, \\ u_t &= \sigma_t z_t, \text{ and} \\ \sigma_t^2 &= 0.017 + 0.080 u_{t-1}^2 + 0.894 \sigma_{t-1}^2. \end{aligned}$$

V. CONCLUSION

This paper examines the hypothesis that sterilized intervention in the

foreign exchange market could be effective under certain conditions but ineffective otherwise. In order to identify the potential conditions for effective intervention, it is first assumed that trend-chasing noise-traders are the main source of short-run fluctuations in the exchange rate. With the further assumption that intervention is effective only if the noise-traders are in heavily overbought or oversold positions, a three-regime threshold model is adopted as the appropriate description of the nonlinear relationship between intervention and the exchange rate return.

The estimation and test results, with the daily data on the actual intervention in the DM/USD market between 1987 and 1989, strongly support the noise-trading/coordination channel hypothesis, and thus the conditional efficacy of intervention. I obtain similar results with a longer sample period from January 1987 to January 1993, even though the evidence is somewhat weaker presumably because intervention was less frequent in early 1990s relative to the three years following the Louvre Accord. Overall, the results suggest that the central banks may increase the effectiveness of intervention by waiting until the exchange rate appreciates or depreciates beyond the estimated thresholds, instead of attempting to counter new trends immediately or when the momentum is at its peak.

The approach taken in this paper can serve as a practical guide for future studies aiming to evaluate the performance of observed intervention operations, and also for the monetary authorities who want to develop more effective intervention strategies.

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요 약

외환시장에 대한 중앙은행의 개입과 동시에 정부채 매입 또는 매도를 통하여 국내 통화량 및 이자율에 대한 영향을 상쇄시키는 sterilized intervention의 경우, 일반적으로 환율에 미치는 영향이 미약하나 특정한 조건하에서는 환율안정을 위한 효과적인 수단이 될 수 있는 것으로 알려져 있다. 이와 관련하여 본 연구에서는 중앙은행이 시장상황을 감안하여 적절한 개입시기를 선택할 경우 sterilized intervention을 통해서도 환율안정을 이룰 수 있다는 가설(noise-trading channel or coordination channel hypothesis)을, 통상적으로 sterilization을 수반하는 것으로 알려진 미국과 독일의 마르크/달러 시장에 대한 개입 데이터 및 삼단계 모형(three-regime threshold model)을 사용하여 검증코자 하였다. 실증분석의 결과, 마르크/달러 환율의 상승 또는 하락 추세가 기술적 분석에 의존하는 시장 참여자들(noise-traders)에 의해 더욱 강화되는 시점에서는 기존의 연구결과와 마찬가지로 sterilized intervention이 추세를 둔화 또는 반전시키는 효과가 없는 것으로 나타났다. 그러나 상승 또는 하락추세가 어느 정도 지속되어 추가적인 상승 또는 하락의 동력이 약화된 시점에서 중앙은행이 개입할 경우, noise-trading/coordination channel 가설이 주장하는 바와 같이 추세의 둔화 또는 반전을 통해 환율의 안정이라는 목표를 달성할 수 있다는 결론을 도출하였다.

※ 국문 색인어: 기술적 매매, 다단계 모형, 채널외환시장개입