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LEARNING ABOUT INTERVENTION TARGET ZONES

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ABSTRACT

This paper provides a framework for evaluating how market participants' beliefs about foreign exchange target zones change as they learn about central bank intervention policy. In order to examine this behavior, we first generalize the standard target zone model to allow for intra-marginal intervention. Intra-marginal intervention implies that the position of market participants' beliefs about the target zone can be determined from their beliefs about the likelihood of intervention. As an application of this model, we estimate a probability of intervention model using daily exchange rates and market observations of central bank interventions following the Louvre Accord. Interestingly, even over this relatively stable Louvre Accord period, we find that the market's views of intervention target zones would have varied quite a bit over time.

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Exchange rates depend strongly upon the foreign exchange market's expectations of future policy. These expectations have by now become central to any explanation of exchange rate determination. Therefore, most international economists would probably agree that if variables that affect the exchange rate behave differently at particular exchange rate levels, then exchange rates should incorporate expectations of these events. Krugman (forthcoming) has recently shown a forceful example of these type of effects.[1] Krugman points out that if monetary policy acts to contain the exchange rate within particular target bands, these expectations will help stabilize the exchange rate.

The more controversial issue is how the foreign exchange market actually views the central bank's intervention policy and, in turn, how these expectations affect the exchange rate on a practical level. Our goal in this paper is to shed some light on this difficult question. In particular, we focus on the effects of the market's perceptions of target zones on exchange rate determination. Three important results arise from our analysis. First, the likelihood of intra-marginal intervention directly affects the relationship between exchange rates and fundamentals. This result is important since intra-marginal interventions are a notable characteristic of actual exchange rate regimes, even those with well-defined bands such as the European Monetary System (EMS). Second, within any fixed exchange rate band, the presence of intra-marginal intervention allows fundamentals, such as the money supply, to vary within a wider range than with no intra-marginal intervention. Third, the framework presented in this paper demonstrates how the position of the target zone can be determined directly from

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[1]Other research on target zone policies include Bertola and Caballero (1989), Flood and Garber (1989), Froot and Obstfeld (1989, forthcoming), Klein (1989, 1990), Miller and Weller (1989), Spencer (1990), and Svensson (1989, 1990).

the market's beliefs about the intervention policy.

These three points lay the groundwork for analyzing how the target zone relationship would evolve over time as the market learns about intervention policy. As market participants observe central banks' actions, their beliefs about policy goals change. Since the exchange rate depends upon expectations about the intervention process, learning about this process implies that the position of the target zone varies over time. As an application of this framework, we evaluate a learning-about-intervention process during the period from the Louvre Accord in February 1987 to the October 1987 stock market crash. We focus upon this period since market observers seemed to believe that major central banks were targeting the dollar exchange rate within unannounced bands. To implement our estimation, we use daily exchange rate data together with data identifying days when there was intervention in the foreign exchange market by the central banks of the United States, Germany, and Japan (the so-called G-3 countries). We evaluate the market's perceptions of the target zones and targeted exchange rate levels for the Deutschemark/dollar and yen/dollar exchange rates. Interestingly, we find that during the Louvre period, the market's perceptions about the intervention policy varied considerably over time. This result appears particularly noteworthy since most observers would consider this period to have the most stable intervention policy in recent managed float experience.

The rest of the paper is organized as follows. The first part of Section I develops the target zone model with a continuous probability of intervention within the margin. In this section we also discuss the three results listed above. The latter part of Section I describes the learning process and the implied evolution of the exchange rate solution. Section II uses the model to evaluate the G-3 intervention policy over the period from September 1985 to October 1987. Concluding remarks follow.

I. INTRA-MARGINAL INTERVENTION AND TARGET ZONES

In this section, we develop our framework for analyzing target zones based upon market beliefs about intra-marginal intervention policy. This framework will allow us to evaluate the effects of learning about intervention target zones in sections II and III below. To illustrate key features of our model, we begin in Part A by reviewing the determination of the exchange rate under two different sets of assumptions about intervention. First, we present the solution for the exchange rate under a pure float without intervention. Second, we briefly describe the solution when the market believes intervention will occur only at known target bands. In Part B, we present the solution for the exchange rate when the market believes intra-marginal intervention will occur with greater frequency as the exchange rate nears the target bands. Part C contains a discussion of the learning process.

A. The Exchange Rate Solution Under Two Beliefs About Intervention

According to the standard forward-looking asset pricing model, the exchange rate depends upon its current fundamental value and its expected future change:

(1) $e(t) = f(t) + \alpha E(de(t))/dt$

where e is the logarithm of the exchange rate (domestic currency per unit of foreign currency), f is a linear combination of the "fundamental" variables that affect demand and supply of foreign exchange, and α parameterizes the sensitivity of the asset price to its own expected change. In general, f is the incipient excess supply of currency at time t. Thus, it summarizes the effects upon demand

and supply for foreign exchange arising from all variables that influence the market at time t. More specifically, in a monetary model it represents excess domestic money supply relative to foreign money supply.[2] For expositional simplicity, we will refer to this variable as the "fundamental" below, even though f captures the effects of all variables that influence excess supply for foreign exchange.

Solving (1) forward, the basic solution to the exchange rate is given by:

$$(2) \quad e(t_0) = (1/\alpha) \int_{t_0}^{\infty} \exp[(t_0 - t)/\alpha] \; E(f(t) \mid \Omega(t_0))dt$$

where Ω_t is the information set at time t that includes all current information as well as market beliefs about intervention policy.

Solving equation (2) requires first specifying a law of motion for the fundamental. A convenient law of motion studied by Krugman (forthcoming), Froot and Obstfeld (1989) and others is:

$$(3) \quad df = \mu dt + \sigma dz$$

where μ is the drift in f(t) and dz is the increment of the standard Weiner process.

Given this evolution of fundamentals, equation (2) has a basic solution. If we define this function as G(f) and assume that it is continuous and twice differentiable, Ito's Lemma implies that the exchange rate solution must satisfy,

$$(4) \quad G(f) = f + \alpha\mu \, G'(f) + (1/2) \, \alpha \, \sigma^2 \, G''(f).$$

Equation (4) is a second-order differential equation and, therefore, its solution depends upon two boundary conditions. These boundary conditions depend upon

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[2]See, for example, Mussa (1982) and Frenkel and Mussa (1980). In a monetary model, α is the semi-elasticity of money demand with respect to the nominal interest rate.

particular assumptions about intervention policy as the following two examples illustrate.

First, suppose that market traders believe the authorities are allowing the exchange rate to float freely. In this case, the solution to the exchange rate depends linearly upon the fundamental variable, f.

(5) $e(t) = f(t) + \alpha\mu$.

This solution is depicted in Figure 1 as the line FF.

Second, suppose that traders believe that central banks will intervene at boundaries around the exchange rate. Specifically, suppose that the authorities announce (credibly) that they will intervene whenever the exchange rate reaches an upper limit, $e_u(f_u)$, or a lower limit, $e_l(f_l)$. In this case, imposing the boundary conditions that $G'(f_u) = G'(f_l) = 0$ yields the exchange rate solution ZZ in Figure 1.[3] The exchange rate function bends away from the known intervention points because the expectation of no depreciation at e_u, say, makes foreign exchange traders bid up the value of the currency at every smaller value of fundamentals.[4]

B. The Exchange Rate With Continuous Intra-Marginal Intervention

The common unifying feature of the solutions discussed above is that, except for two boundary points, fundamentals evolve freely according to equation (3). However, in many exchange rate systems, the authorities intervene at points

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[3]As in the free float case, equation (3) has a convenient closed form solution. See, for example, Svensson (1989) and Froot and Obstfeld (1989).

[4]Other assumptions about intervention imply other boundary conditions and therefore provide alternative solutions to the exchange rate. For example, Flood and Garber (1989) solve for equation (4) assuming that large interventions take place at the boundaries so that the authorities move f discretely. Froot and Obstfeld (1989) provide an overview of these issues.

other than the boundaries. For example, most of the intervention by EMS countries does not take place at the margins.[5] Also, interventions took place within the unofficial target bands during the post-Louvre period.

We characterize the market's expectations about intra-marginal intervention in the following simple way. Participants in the foreign exchange market recognize that central banks care about a number of different targets, such as interest rates and inflation, in addition to the exchange rate. In their view, exchange rate policy becomes more important to central banks relative to other objectives as the exchange rate deviates from its target level. Thus the market views the probability that the authorities will intervene as increasing in the exchange rate's deviation from its target level. We therefore specify the market's beliefs concerning the probability of intra-marginal intervention policy as:

$$\pi(|f(t) - f_o|), \quad \pi' > 0, \tag{6}$$

where π is the probability that the central bank will intervene at that level of fundamentals $f(t)$ and f_o is the fundamental level associated with the target level of the exchange rate, $e_o(f_o)$. These interventions serve to momentarily stop the movement of the exchange rate. When central banks intervene, they temporarily offset the incipient excess supply for foreign exchange and therefore do not allow fundamentals to change.

For expositional simplicity, we will set f_o equal to zero and consider positive values of fundamentals, therefore restricting the discussion to the upper half of the target zone depicted in Figure 1. Given the symmetry of the probability function in (6), the lower half will be symmetric.

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[5]See, for example, the evidence and discussions in Mastropasqua, Micossi, and Rinaldi (1988), and Giavazzi and Giovannini (1989).

With intra-marginal intervention, the appendix shows that the solution to (2) is given by:

(7) $G(f) = f + \alpha\,[\,(1 - \pi(f))\mu - \pi'(f)\,\sigma^2\,]\,G'(f) + (1/2)\,\alpha\,\sigma^2\,(1 - \pi(f))\,G''(f)$

Equation (7), like the standard solution (3), is a second-order differential equation and, therefore, depends upon two boundary conditions. In the case of (7), these boundary conditions arise naturally from the form of the probability distribution. In particular, as fundamentals grow away from f_0, the probability of intervention increases to one. Further inspection reveals that, but for the term $-\pi'(f)\,\sigma^2$, equation (7) only differs from the standard solution by the presence of the term $(1 - \pi(f))$ on the first and second derivatives of G. This term weights the standard evolution of the exchange rate by the probability that no intervention will take place. The term $-\pi'(f)\,\sigma^2$ captures the interaction between changes in fundamentals and the feed-back to changes in the probability of intervention.[6]

We can compare this solution with the solution obtained when intervention only occurs at the boundaries.[7] To illustrate, suppose that the level of fundamentals where intervention occurs with probability one are the same for both solutions. Specifically, the fundamentals bands in the standard target zone model, f_l and f_u in Figure 1, are the same fundamentals where the probability of

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[6]In particular, this term reflects the assumption that central bankers are part of the market and view the direction of incipient foreign exchange demand before deciding to intervene. The underlying stochastic process for fundamentals remains Markovian in this case because the process with intervention remains at its original position. If the probability of intervention depended only upon the current level of fundamentals instead, the π' term would not appear and the all of the essential results in the text would continue to hold.

[7]The differential equation (3) has an analytical solution in the class of hypergeometic functions. See Froot and Obstfeld (forthcoming). Lewis (1990) describes numerical solutions of the function (7) for various forms of the $\pi(f)$ function.

intervention reaches 1 in our model so that $\pi(|f_u - f_o|) = \pi(|f_l - f_c|) = 1$. Figure 2 depicts this relationship by comparing the line OZ, the standard target zone solution, to the lower line OA, the solution with the probability of intervention function π^A (the results for the negative quadrant are symmetric to those shown for the positive quadrant). Intuitively, OA lies everywhere below OZ because the expected present value of fundamentals in (2) is lower when there is intra-marginal intervention as compared to when intervention occurs only at the boundary. Since in both cases the market knows central banks will intervene at f^A, the slope of the exchange rate functions OA and OZ are both zero at the level of the fundamental f^A.

Figure 2 also shows the relationship between a standard target zone solution and one with intra-marginal intervention when both types of policies contain the exchange rate within an upper band e^B. The probability of intervention occurring at any level of the fundamental in this case is given by the function π^B. The possibility of intramarginal intervention bids up the price of the currency before the band is reached. The exchange rate function OB has a zero slope at f^B where the probability of intervention is one. This point lies to the right of f^A. For a given exchange rate band, fundamentals fluctuate within wider bands when there is intra-marginal intervention than when intervention occurs only at the boundary.

Figure 2 demonstrates how the probability assigned by the market to the likelihood of intervention affects the relationship between the exchange rate and fundamentals. The exchange rate is contained in a tighter band when the probability of intervention as a function of fundamentals increases more quickly. As depicted in the lower panel of Figure 2, the probability function π^A lies everywhere above π^B since it represents a greater likelihood of intervention at any level of fundamentals. Consequently, the exchange rate relationship corresponding to π^A lies everywhere below the one corresponding to π^B since the higher probability of intervention translates into a lower expected value of fundamentals. Thus, the market's expectations of intra-marginal intervention policy determines the relationship between the exchange rate and its fundamentals.

C. Learning About Intervention

The solution in Figure 2 depends upon how the market believes central bankers will intervene as parameterized by $\pi(f)$. In many situations, however, the market may not know the intervention policy sufficiently to hold firm views about $\pi(f)$. For example, after a period of policy directed towards dollar depreciation beginning with the Plaza Meeting in September 1985, exchange-rate policy appeared to shift significantly towards currency stabilization following the Louvre Meeting in February 1987. Details of actual policy implementation were kept confidential at that time.[8]

During such periods when foreign exchange market participants are learning about intervention policy, they update their beliefs about the probability of intervention function based upon observing central bank behavior. Therefore, instead of a time-invariant exchange rate solution as in Figure 2 depending upon a given $\pi(f)$ function, the exchange rate at any point in time depends upon the current estimate of the probability-of-intervention function. The exchange rate solution evolves over time with the market's beliefs about this function. In

[8]Similar changes in intervention policy may also occur in fixed rate arrangements such as the EMS after realignments. Edison and Kaminsky (1990) examine evidence of Bank of France interventions and find significant evidence of intra-marginal intervention. The behavior of this intervention policy appears to have differed between realignment periods.

particular, if the market is uncertain about the exchange rate bands, the learning process yields a time series of S-shaped curves like the one in Figure 2. As the market learns the true probability distribution over time, the solution converges to a single S-shaped curve. As the market's beliefs about intervention policy evolve over time, there will be a corresponding evolution of the relationship between fundamentals and the exchange rate.

To illustrate the learning process, consider the following situation.[9] Suppose the market observes whether central banks intervene. Define this intervention series I_t with entries equal to 1 on days when intervention occurs and equal to 0 on days when intervention does not take place. Furthermore, the market also observes the fundamentals, f_t. For purposes of illustration, suppose further that agents use a linear probability model to determine how likely intervention will be given current fundamentals. This probability can be written[10]

(8) $I_t = f_t\beta + \epsilon_t$.

In this case, the probability of intervention is $f_t\beta$.

When the market does not know the intervention policy process, then the market will not know the true probability distribution, parameterized by β. Agents may learn this process over time. That is, suppose that market traders have a prior distribution of the parameter that includes a prior mean, $\hat{\beta}_t$ and a prior precision estimate given by H_t. Their parameter estimates evolve with

[9]The market may also learn about monetary policy under the free float without bands. However, this type of regime has quite different implications for the exchange rate behavior during learning than when authorities follow a target zone. See, for example, Lewis (1989).

[10]As is well-known, this type of probability model has some undesirable features including probability estimates that may be negative. We therefore use this model only for expositional simplicity. In Section II below, we estimate instead a probability function in logistic form.

each additional observation of f_t according to the Bayesian rule:[11]

(9) $\hat{\beta}_t = [H_{t-1} + f_t'f_t]^{-1}[H_{t-1}'\hat{\beta}_{t-1} + f_t'I_t]$.

As the number of observations increase, the markets estimate of ß converges to the true parameter. In this way, the market learns the true probability distribution, $\pi(f)$.

During the learning process, the exchange rate solution in Figure 2 depends upon the market's current estimate of the probability distribution, $\hat{\pi}_t(f_t)$. Therefore, the exchange rate solution evolves over time with the market's beliefs about the probability distribution.[12] In particular, if the market is uncertain about the bands as under the managed float, the learning process yields a time series of these S-shaped curves. As the market learns the true probability distribution over time, the solution converges to a single S-shaped curve.

II. AN APPLICATION: THE LOUVRE ACCORD

Exchange rate policy among the United States, West Germany and Japan in the wake of the Louvre Meeting on February 21-22, 1987 was characterized by some of the key features of the model developed above. First, foreign exchange intervention policy during this period was based upon the stabilization of currencies within implicit exchange rate bands. This corresponds to the increasing probability of intervention as the exchange rate moves away from its target level in the model. Second, policies agreed upon at the Louvre Meeting were widely perceived as representing a break from the past. Third, actual

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[11]See Zellner (1971), for example. For illustration, we are assuming ϵ_t is normally distributed and that the prior has a natural conjugate form.

[12]A standard result of learning models, such as the one we develop, is that agents are rational only in the long-run. See Bray and Savin (1986) or Taylor (1975).

details of intervention policies and exchange rate band widths were not explicitly announced. Thus market participants only learned about the true width of the bands over time as observations of intervention revealed policy intentions. In view of these characteristics, we apply our model of intramarginal intervention with learning to daily data drawn from the period following the Louvre Accord. Our sample runs for eight months since policy probably shifted focus after the worldwide stock market crash on October 19, 1987.

Empirical implementation of the model requires two slight modifications of the analysis. The first modification arises from the nature of fundamentals variables, summarized in f_t. In principle, if we could identify all of the variables responsible for determining the demand and supply of foreign exchange, we could use this series to directly estimate $\pi(f)$. However, studies have not found strong empirically-reliable relationships between the exchange rate and variables commonly viewed as its important determinants. One explanation may be that the econometrician cannot identify all of the variables that affect the exchange rate.

On the other hand, the current exchange rate contains all current information about fundamentals as equation (2) describes.[13] Therefore, in order to identify the probability of intervention function without knowing all of the fundamentals, we may consider the probability in terms of the equilibrium exchange rate. Namely, define equation (6), the exchange rate solution, to be $e = G(f)$ and its inverse function to be $f = G^{-1}(e)$. Then there is an equilibrium relationship between the probability to intervene as a function of the exchange

[13]This point has been made, for example, by Campbell and Shiller (1987) in the context of stock prices.

rate and the probability to intervene as a function of fundamentals. That is,

$$\pi(f) = \pi(G^{-1}(e)) \equiv \pi^*(e).$$

In order to allow easy comparison with the data, we transform π to be a function of the exchange rate level, defining the exchange rate to be the prices of foreign currency.

$$\pi^*(e) \equiv \pi^*(\log(s)) = \hat{\pi}(s),$$

where $s = (1/\exp(e))$, the price of dollars in terms of foreign currency. Since the exchange rate depends upon fundamentals, it contains all information considered relevant to the market.

The second modification necessary to implement the learning model is to specify an appropriate probability model. Although the linear form in (8) provided a simple illustration, this model implies undesirable features as a probability function, as is well known.[14] Therefore, we assume the probability-of-intervention function is a logistic distribution function. To motivate this form further, we first describe the data more fully.

A. The Probability of Intervention

In this section, we develop and estimate an intervention probability function for the period from the February 1987 Louvre Meeting to that year's October stock market crash. The estimates presented in this section show that the intervention function we specify adequately characterizes the data in our complete sample. In the next section we estimate this intervention function within a learning model to track the evolution of the market's perceived target zones.

The data required for our analysis includes daily exchange rate series and daily intervention data. The daily exchange rate data represent spot rates at

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[14]For example, see Dhrymes (1986), pages 1568 - 1572 or Maddala (1983).

9:00 AM Eastern Standard Time.[15] The intervention series identify days when G-3 central banks were observed intervening by traders after the opening of the New York market. These series were compiled from daily newspaper accounts from the *New York Times*, *Wall Street Journal* and the *London Financial Times*. From these accounts, dummy variables were constructed for days when intervention was observed. These variables were further decomposed into interventions of dollar sales or purchases. Specifically, these variables were defined as:

$I_t = 0$,	No Intervention
$I_t = 1$,	Intervention with Dollar Sales
$I_t = -1$,	Intervention with Dollar Purchases.

For the purpose of the empirical estimation, we define s_t as the price of dollars in terms of foreign currency. The probability of intervention may then be characterized as:[16]

$$\text{(10a)}\quad \text{Prob}(I_t = 0 \mid s_{t-1}) = \left[\frac{\exp(g_o + g_1 s_{t-1})}{1 + \exp(c_o + c_1 s_{t-1}) + \exp(g_o + g_1 s_{t-1})} \right]$$

$$\text{(10b)}\quad \text{Prob}(I_t = 1 \mid s_{t-1}) = \left[\frac{1}{1 + \exp(c_o + c_1 s_{t-1}) + \exp(g_o + g_1 s_{t-1})} \right]$$

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[15]These data were kindly provided by Kathryn Dominguez.

[16]This is a multi-nomial logistic distribution. On the estimation of this model, see Maddala (1983).

$$(10c)\ \mathrm{Prob}(I_t = -1 \mid s_{t-1}) = \left[\frac{\exp(c_o + c_1 s_{t-1})}{1 + \exp(c_o + c_1 s_{t-1}) + \exp(g_o + g_1 s_{t-1})} \right]$$

As the exchange rate moves away from the target level, the probability of intervention increases. To see how this relates to the parameters, it is useful to rewrite equations (10) in terms of the logarithms of the odds ratios:

$$(11a)\quad \log(\mathrm{Prob}(I_t = -1)\ /\mathrm{Prob}(I_t = 1) \mid s_{t-1}) = c_o + c_1 s_{t-1}$$

$$(11b)\quad \log(\mathrm{Prob}(I_t = 0)\ /\mathrm{Prob}(I_t = 1) \mid s_{t-1}) = g_o + g_1 s_{t-1}.$$

$$(11c)\quad \log(\mathrm{Prob}(I_t = -1)\ /\mathrm{Prob}(I_t = 0) \mid s_{t-1}) = (c_o - g_o) + (c_1 - g_1) s_{t-1}.$$

In (11a), a fall in the price of dollars to foreign currency will increase the probability of intervention to buy dollars relative to selling dollars. Therefore, we should find $c_1 < 0$. In (11b), a fall in the price of dollars will reduce the probability of dollar selling intervention relative to no intervention. Therefore, we should find $g_1 < 0$. Finally, in (11c), a fall in s should increase the probability of buying dollars relative to no intervention. Therefore, we should find $(c_1 - g_1) < 0$, that is $|c_1| > |g_1|$.[17] Similar arguments apply to the constant coefficients that determine the probabilities when s_{t-1} equals zero. At this low value for the dollar, we should find that the probability of intervention to buy dollars is greater than the probability of no

[17]Later we demonstrate how the coefficient estimates allow us to calculate a central target rate as well as exchange rate target bands.

intervention. The probability of no intervention at low values of the dollar exceeds the probability of dollar sales. Therefore, we expect to find $c_o > g_o$ and $c_o > (c_o - g_o)$.

Table 1 reports the results of estimating this model for the Deutschemark/dollar and the yen/dollar rates from just after the Louvre Meeting on February 22, 1987 to just before the October 19, 1987 stock market crash.[18] The model was estimated for the Deutschemark/dollar rate using a combined series that equaled 1, 0, or -1 when either the Fed or the Bundesbank intervened. Similarly, the probability model for the yen/dollar rate was estimated with a series when either the Fed or the Bank of Japan intervened. As the estimates show, c_1 and g_1 are significantly negative in both equations. Also, $|c_1| > |g_1|$, $c_o > g_o$ and $c_o > (c_o - g_o)$ in all cases. Finally, a high percent of the intervention events are correctly predicted by the model indicating that the equations characterize the data fairly well.

B. The Probability of Intervention and G-3 Intervention Target Zones

As shown in the model in Section I, market participants' view of the probability distribution for intervention determines the target zone. We can use the probability model discussed above to estimate the market participants' perceptions of the probability function. Using these estimates we can calculate the evolution of the midpoint and the upper and lower boundaries of the target zone.

The midpoint of the target zone can be calculated as the level of the exchange rate that minimizes the probability of intervention. Maximizing the

[18]The results in Table 1 are robust to a variety of central bank intervention series, such as intervention by one central bank alone.

TABLE 1
Multinomial Logisitic Intervention Estimation
Louvre Meeting to Stock Market Crash:
February 22, 1987 to October 18, 1987

Exchange Rate	c_0	c_1	g_0	g_1	% Correctly Predicted
DM / Dollar	122.7	-66.7	80.7	-42.0	79.3
	(28.7)	(15.7)	(22.3)	(12.0)	
Yen / Dollar	76.7	-0.51	51.7	-0.33	72.8
	(22.0)	(0.15)	(20.9)	(0.14)	

Numbers in parenthesis are estimated standard errors. Intervention is by either the Federal Reserve or the Bundesbank for the DM/Dollar rate, and by either the Federal Reserve or the Bank of Japan for the Yen/Dollar rate.

probability-of-no-intervention equation (10a) and solving for the exchange rate yields a target level of the exchange rate, s_0, as:

$$(13) \quad s_0 = \frac{\log[g_1/(c_1-g_1)] - c_0}{c_1}$$

This exchange rate maximizes the probability of no intervention but is well defined only when $c_1 < g_1 < 0$. These conditions imply that the probability of intervention is increasing as the exchange rate deviates from s_0.

In general, we would estimate the upper and lower boundaries of the target zone by determining the level of the exchange rate that sets the probability of intervention equal to one (given our estimates of c_0, c_1, g_0 and g_1). The logistic form that we employ for empirical tractability, however, implies that the probability of intervention only approaches one asymptotically. Therefore, target zones where the probability of intervention equals one cannot be calculated. Fortunately, we are able to calculate target zones associated with any given probability of intervention less than one. These target zone estimates allow us to track the evolution of the target zone over time.

C. Learning About G-3 Intervention Target Zones

The Louvre Accord represented the "most serious attempt to implement systematic currency stabilization"[19] among the major industrial nations since the advent of floating exchange rates. The communique issued after the Louvre Meeting on February 22, 1987 stated that finance ministers and central bank

[19] Funabashi 1988, page 177.

governors of the G-6[20] feared that "Further substantial exchange rate shifts among their currencies could damage growth and adjustment prospects in their countries. In current circumstances, therefore, they agreed to cooperate closely to foster stability of exchange rates around their current levels." (quoted from the G-6 communique). This quest for currency stability represented a shift from the previous policy of dollar-depreciation pursued since the September 1985 Plaza Meeting. A statement by then British Chancellor of the Exchequer Nigel Lawson at the conclusion of the Louvre Meeting exemplifies this change in policy stance. Lawson stated that "[at the Plaza Meeting] we all agreed that the dollar should fall, now we all agree we need stability."[21]

In this section we evaluate the foreign exchange market's daily view of the target zone and the target level for the Deutschemark/dollar and yen/dollar exchange rates following the Louvre Accord. Our evaluation of target zones is based on the analysis represented by Figure 2. The market's perceptions of the target zone maps directly into a solution for the exchange rate. A probability function for intervention that increases quickly with deviations from the target level implies a relatively tight target zone, and conversely. The exchange rate that minimizes the probability of intervention provides an estimate of the target level of the exchange rate. We estimate an updating learning process. The logistic probability model requires a non-linear estimation technique in contrast to equation (8). Details of the learning estimation are provided in an appendix.

Figures 3 and 4 present the exchange rate and days of intervention as well

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[20]The countries that issued this communique were the United States, West Germany, Japan, Great Britain, France, and Canada.

[21]Quoted in Funabashi (1989), page 177. Dominguez (1988) also describes policy shifts during this period.

as the estimated target level and target zone for the yen/dollar and Deutschemark/dollar rates, respectively. In these figures, the lower boundary of the target zone depicts the level of the exchange rate where the probability of intervention to support the dollar is 50% and the upper boundary is the exchange rate where the probability of intervention to weaken the dollar is 50%. (We also discuss below some results for 90% probability-of-intervention target zones.) The solid line in the figures depicts the exchange rate. The solid circles or triangles on the exchange rate line represent days when there was intervention to weaken or strengthen the dollar, respectively. The dashed line is the estimated target level of the exchange rate and the overlapping circles represent the upper and lower boundaries of the 50%-probability-of-intervention target zone boundary.[22]

The Louvre Accord refers to stabilizing exchange rates around "current levels." The exchange rates that constitute these levels were those on the last trading day before the Louvre Meeting. These exchange rates were 1.825 Deutschemarks per dollar and 153.5 yen per dollar. By March 12, when our estimates begin, the Deustchemark stood at 1.856 to the dollar and the yen at 153.5 to the dollar.

Figure 3 shows that the initial estimated target level for the yen was 153.1 yen/dollar, with 50%-probability-of-intervention boundaries at 150.1 to 156.8 yen/dollar (a 4.5% target zone width). The upper boundary of the target zone decreased with intervention to weaken the dollar at the outset of our estimates. Subsequent intervention to strengthen the dollar against the yen when the currency was below the estimated midpoint occurred on twenty-three of the

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[22]The estimates of the target exchange rate level and the target zone boundaries do not begin immediately after the Louvre Meeting since some observations are required to estimate initial prior distributions.

first forty observations shown in Figure 3. This intervention signalled to markets that authorities desired an appreciation of the dollar. Despite this goal, the dollar remained weak during March and April, plunging at one point to a 40-year low of 137.9 yen. Even in the face of the weak dollar, our estimates of the lower boundary of the 50%-probability-of-intervention target zone remained relatively stable since extensive intervention signalled a policy stance to defend the dollar. For example, after intervention on 23 of 32 trading days, on May 5, 1987 the target zone was 146.2 to 155.1 yen/dollar, a range of 6.1%. The estimated target level on this day was 152.5 yen/dollar while the actual exchange rate was 138.2 yen/dollar.

Intervention efforts stalled for two weeks after May 5. With a dollar substantially below the estimated midpoint and no further intervention during this fortnight the lower boundary of the target zone fell to 140.4 yen/dollar. A dollar-weakening intervention on June 23, when the target level exceeded the actual exchange rate, raised the upper boundary from 155.1 to 161.2 yen/dollar. The 50%-probability-of-intervention target zone at this time was 134.8 - 161.2 yen/dollar, a 19.6% spread (the 90%-probability-of-intervention target zone at this time was 106.6 - 178.9 yen/dollar, a 67.8% range). The target zone remained close to this range until early August when intervention to weaken the dollar on four out of five consecutive days lowered the target level of the exchange rate to 149.7 yen/dollar and narrowed the target zone to 136.8 - 158.6 yen/dollar (a 15.9% range). A 5% decline in the exchange rate in less than a week in mid-August, and a subsequent 2.5% further decline by the beginning of September, did not widen the target zone since there was intensive intervention to strengthen the dollar in response; from August 19 to September 11, intervention occurred on all but five of the trading days. This intervention activity maintained the 50%-

probability-of-intervention exchange rate target zone close to the approximately 13% range of 140 - 158 yen/dollar over the final part of our sample.

Figure 4 shows an initial estimate of the target level of 1.847 Deutschemarks/dollar on March 12 with 50%-probability-of-intervention target zone of 1.801 to 1.856 DM/dollar (a range of 3.1%). After an initial intervention to weaken the dollar, intervention to strengthen the dollar was undertaken as the dollar began to fall against the Deutschemark throughout late March. This intervention maintained a stable Deutschemark target zone from March to mid-May as downward movements in the exchange rate were met with dollar-strengthening intervention. On May 21, however, in the face of a declining dollar, there was intervention to further weaken the dollar. The target zone went from 1.741 to 1.856 Deutschemarks/dollar (a 6.6% range) on the day before this intervention to 1.736 to 1.906 Deutschemarks/dollar (a 9.8% range) on May 21 (the 90%-probability-of-intervention range increased from 1.64 to 1.86 Deutschemarks/dollar, a range of 13.4%, to 1.62 DM/dollar to 1.97 DM/dollar, a range of 21.6%). Twice in June the upper boundary of the target zone fell in response to dollar-weakening interventions that occurred when the exchange rate exceeded its estimated target level. By early July, the target zone had narrowed to the 7.5% range of 1.74 - 1.87 Deutschemarks/dollar. A purchase of dollars when the exchange rate exceeded the target level on July 15, however, began a period of a rapidly rising upper boundary. Within two weeks, by the end of July, the target zone had widened to 1.73 - 1.93 DM/dollar (an 11.6% range). Five straight days of dollar-weakening intervention narrowed the target zone to 1.73 - 1.88 Deutschemarks/dollar. During the remainder of the sample the 50%-probability-of-intervention target zone stayed close to the 9.8% range of 1.73 - 1.90 Deutschemarks/dollar (during this time the 90%-probability-of-intervention target zone was close to 1.62 - 1.95 Deutschemarks/dollar; a 20.4% range).

It is interesting to compare these estimates of the evolution of the target zone for the dollar against the Deutschemark and the yen with information now available about policy at that time.[23] The confidential joint proposal worked out at the Louvre Meeting specified central target rates of 1.825 Deutschemarks/dollar and 153.5 yen/dollar. Intervention was to begin with a 2.5 percent deviation from these parities and was to intensify up to a 5 percent deviation. Consultation on policy adjustment was obligatory when the deviation exceeded 5 percent. Extensive central bank intervention demonstrated commitment to this policy. The Federal Reserve spent $4.06 billion on dollar purchases and the Bank of Japan and the Bundesbank (as well as other European central banks) also "bought dollars in 'extraordinary' amounts" (Funabashi 1988, page 191) between the Louvre Meeting and the end of April.

Relatively tight estimates of the target zones at the beginning of the sample reflects central bank actions in support of the Louvre Accord. The intensive intervention to weaken the yen that we observed at the beginning of our sample also reflects the politically-sensitive threshold of 150 yen/dollar facing Japanese policy-makers. The failure to hold this line led to a rebasing of the central parity of the yen to 146 in early April, a move supported by the United States and European countries, but initially resisted by Japan. This change in the yen target is reflected in our estimates when, in May, intervention to weaken the dollar halted for a time and the lower boundary of the target zone fell. By the time of a G-5 meeting in Washington in September 1987, divergent views on the intensity of the commitment to the Louvre Accord were becoming evident. Our

[23]This information comes from Funabashi (1988) who interviewed officials who participated in exchange rate policy during this period.

estimates of target zones depict much wider boundaries at the end of the sample than at its outset. Overall, our estimates are consistent with a review of the evolution of the target zone for this period drawn from interviews with the participating policy-makers.

III. CONCLUDING REMARKS

In this paper, we consider how the market's beliefs about interventions to target exchange rates within bands will directly affect the relationship between the exchange rate and fundamentals. When there is stochastic intramarginal intervention, the relationship between fundamentals and the exchange rate depends upon the function relating the probability of intervention to the level of the exchange rate. More importantly, as the market learns about the nature of intervention policy, this non-linear relationship will evolve over time. These results have implications for research on the effects of target zones on the relationship between fundamentals and exchange rates when policy has recently changed and market participants are learning about policy. Since the form of the non-linearity changes over time during the learning process, detecting a particular empirical non-linear relationship can be illusive. The evolution of a target zone over time due to learning may help explain why empirical studies have been not been successful in finding non-linearities in the exchange rate.[24]

We use data on daily intervention observations for the G-3 country central banks together with exchange rates to evaluate the learning model for the period from the Louvre Accord to the stock market crash in 1987. This period is

[24]For example, see Meese and Rose (1990) and Flood, Rose, and Mathieson (1990).

generally viewed as one of successful international coordination on exchange rate policy. Our results suggest, however, that the market's perceptions of the target zone shifted significantly during this period.

Our approach to modeling intra-marginal intervention policy can also be applied to other regimes. For example, the market may believe that realignments are possible at particular points such as at the bands.[25] The framework with intra-marginal intervention developed above can incorporate these beliefs through different boundary conditions. Overall, therefore, the results in this paper should prove useful in future research on exchange rate regimes.

[25]See, for example, Bertola and Caballero (1990).

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FIGURE 1
Known-Width Target Zone

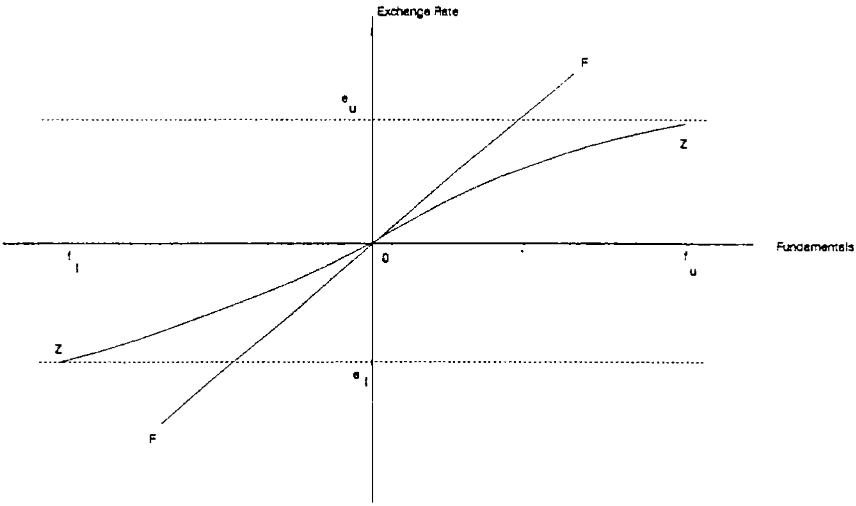

FIGURE 2
Intra-Marginal Intervention Target Zone

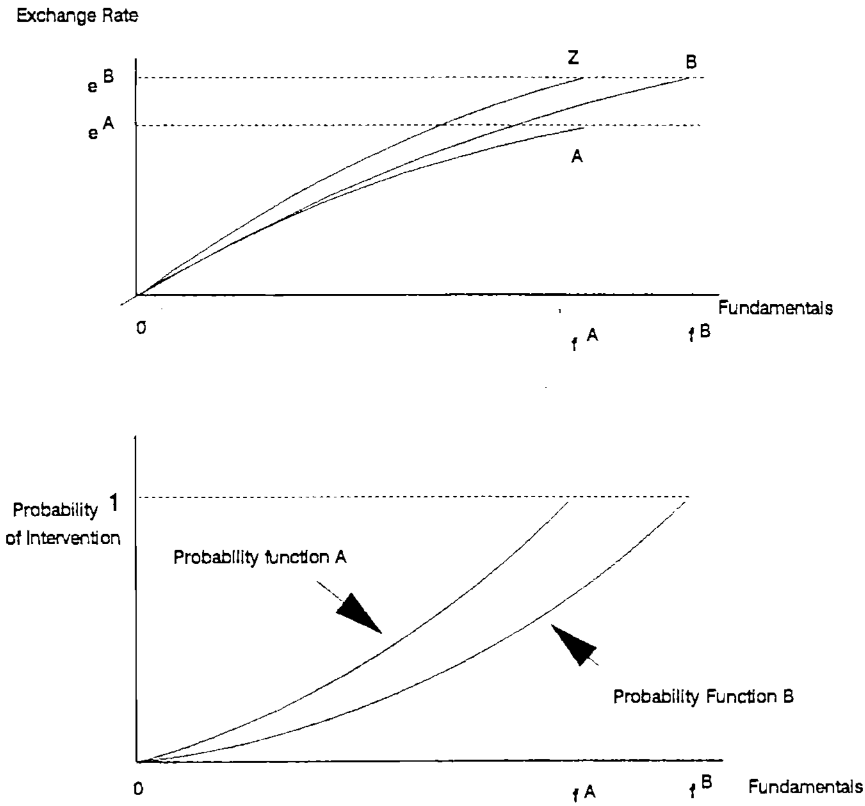

FIGURE 3: YEN / DOLLAR

Louvre Meeting to October Stock Market Crash

Yen/$, Target Level, Target Zone, Intervention

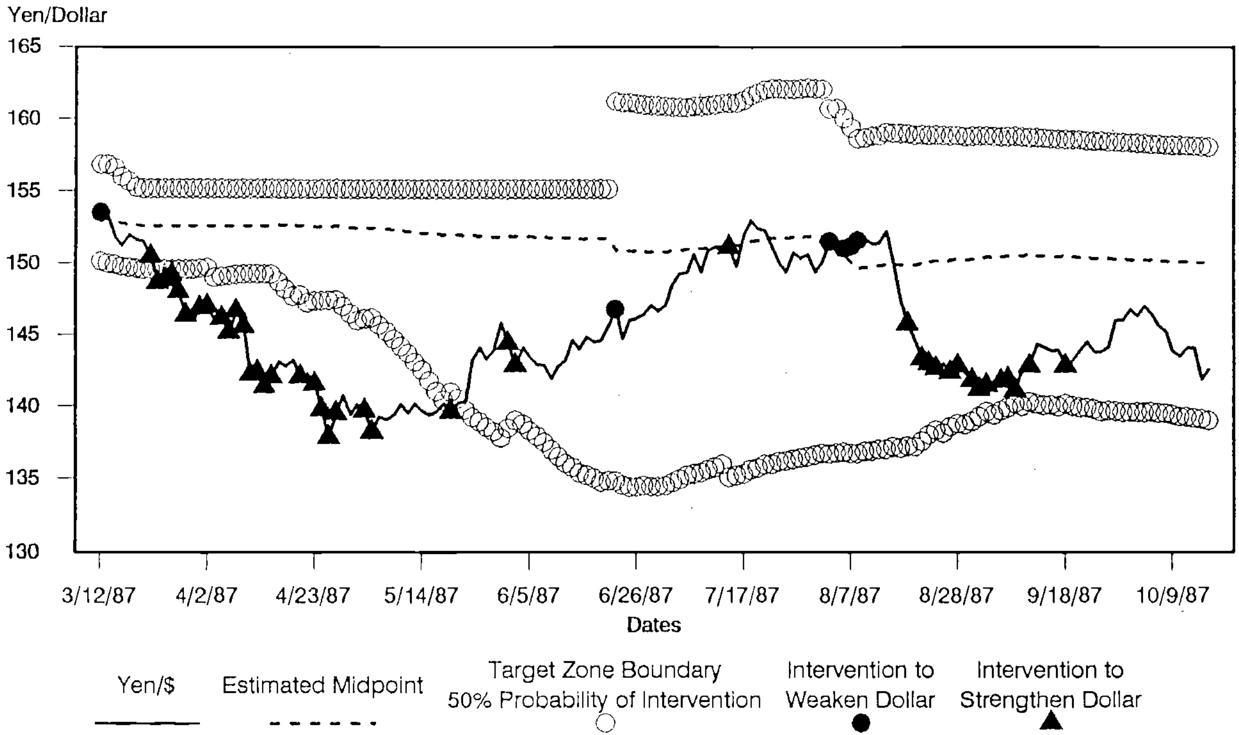

FIGURE 4: DEUTSCHEMARK / DOLLAR

Louvre Meeting to October Stock Market Crash

DM/$, Target Level, Target Zone, Intervention