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Learning about intervention target zones

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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. We generalize the standard target-zone model to allow for intra-marginal intervention. Intra-marginal intervention implies that market participants' beliefs about the target zone can be determined from their beliefs about the likelihood of intervention. We then estimate a daily probability of intervention model for the period following the Louvre Accord. We find that the market's views of intervention target zones would have varied quite a bit over time even over this relatively stable period.

1. Introduction

Recent research demonstrates the sensitivity of the predictions of target-zone models to the manner in which the foreign exchange market views the central bank's intervention policy. In the basic target-zone model of Krugman (1991), the commitment by monetary authorities to maintain the exchange rate within a certain band stabilizes the exchange rate because of the effects of this policy on market participants' expectations. Variants of this

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model consider the consequences of alternative types of target-zone intervention rules for the determination of the exchange rate.[1]

Our goal in this paper is to shed some light on the question of how the foreign exchange market actually views the central bank's intervention policy and, in turn, how these expectations affect exchange rate determination. We first extend the basic target-zone model, in which intervention only occurs when the exchange rate reaches the edge of the target zone, by considering the consequences of stochastic intra-marginal intervention. This is an important extension since actual target-zone regimes, even those with well-defined bands such as the European Monetary System, are characterized by intra-marginal intervention.[2] The likelihood of intra-marginal intervention directly affects the relationship between exchange rates and fundamentals in this framework, as we describe in subsection 2.1.

Based upon this stochastic intra-marginal intervention framework, we develop a learning model, presented in subsection 2.2. The premise of this model is that the actual target zone is not known to market participants but information about it is learned over time through the market's observations of intervention policy. The assumption that market participants learn about the target-zone policy over time and that their beliefs about policy goals evolve as they observe central banks' actions introduces further realism into the model. The presence of learning in this model implies that the position of the perceived target zone varies over time.

The model of stochastic intra-marginal intervention with learning provides a framework in which to address the practical effects of expectations upon target-zone policies.[3] In section 3 we apply our theoretical framework of a learning-about-intervention process to an empirical study of the period from the Louvre Accord in February 1987 to the October 1987 stock market crash. This period is particularly well-suited for our study since market observers at that time 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). Using a Bayesian empirical approach, we ask whether market perceptions of the target zone converged over time, as a stable intervention policy would imply. Interestingly, we find that the market's estimated perceptions about intervention policy varied considerably over time, even though most observers consider this period to have exhibited the most stable intervention in recent managed float experience.

[1]These target-zones models include Klein (1990, 1992), Flood and Garber (1991), Froot and Obstfeld (1991a, b), Miller and Weller (1991), Svensson (1991a) and Bertola and Caballero (1992).

[2]See Mastropasqua et al. (1988) and Giavazzi and Giovannini (1989).

[3]Empirical applications of target-zone models include work by Edison and Kaminsky (1990), Flood et al. (1990), Lewis (1990) and Svensson (1991b).

2. Target zones with intra-marginal intervention

In this section we develop a model of exchange rate determination when authorities defend a target zone with intra-marginal intervention. This intervention occurs in a stochastic fashion which is described by a likelihood-of-intervention function. In subsection 2.1 we develop the model for a known probability-of-intervention function. We discuss the implications of learning about the probability-of-intervention function in subsection 2.2.

2.1. Stochastic intra-marginal intervention

The starting point for our analysis is the standard continuous-time, forward-looking, asset pricing model of the exchange rate. In this model, the logarithm of the exchange rate at time t, $e(t)$, depends upon its expected future change and the value of a fundamental at that time:

$$e(t) = f(t) + \alpha \mathrm{E}\left(\frac{\mathrm{d}e(t)}{\mathrm{d}t}\right), \tag{1}$$

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, $f(t)$ is the incipient excess supply for 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.[4] More specifically, in a monetary model it represents excess domestic money supply relative to foreign money supply.[5]

Solving (1) forward yields the following expression:

$$e(t_0) = \frac{1}{\alpha} \int_{t_0}^{\infty} \exp\left[\frac{(t_0 - t)}{\alpha}\right] \mathrm{E}(f(t) \mid \Omega(t_0))\, \mathrm{d}t, \tag{2}$$

where Ω_t is the information set at time t that includes all current information as well as market beliefs about interventional policy. A solution to eq. (2) requires first specifying a law of motion for the fundamental. A convenient law of motion studied by Krugman (1991), Froot and Obstfeld (1991a) and others is

$$\mathrm{d}f = u\, \mathrm{d}t + \sigma\, \mathrm{d}z, \tag{3}$$

[4]For simplicity of exposition in what follows we will refer to this variable as the 'fundamental', even though f captures the effects of all variables that influences excess demand for foreign exchange.

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

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

We define the function that solves eq. (2) as $G(f)$ and assume that it is continuous and twice differentiable. By Itô's lemma we have

$$G(f) = f + \alpha u G'(f) + (1/2)\alpha\sigma^2 G''(f). \tag{4}$$

The solution to eq. (4) depends upon assumptions about intervention policy.[6] For example, under a free-float the linear solution to (4) is $G(f) = f(t) + \alpha u$. In the standard target zone model, in which authorities (credibly) announce that they will intervene whenever the exchange rate reaches an upper limit $e_u(f_u)$ or a lower limit $e_\ell(f_\ell)$, imposing the smooth-pasting condition $G'(f_u) = G'(f_\ell) = 0$ yields the familiar S-shaped target-zone exchange rate solution.[7]

The presence of stochastic intra-marginal intervention alters the standard solution presented in eq. (4). 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

$$\pi(|f(t) - f_0|), \quad \pi' > 0, \tag{5}$$

where π is the probability that the central bank will intervene at that level of fundamentals, $f(t)$, and f_0 is the fundamental level associated with the target level of the exchange rate, $e_0(f_0)$.[8] 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.

With the probability of intra-marginal intervention as specified in (5), and

[6] All of the target-zone models assume that intervention affects fundamentals. However, much of the intervention by central banks is sterilized either directly or indirectly. Except for Dominguez and Frankel (1990), most of the empirical evidence has not found a link between sterilized intervention and either the exchange rate or its fundamentals. See the discussion in Edison (1990, 1992). However, Kaminsky and Lewis (1992) find some evidence that sterilized interventions by the Fed were linked to future changes in monetary policy during the late 1980s, suggesting that interventions do affect fundamentals as assumed in the target-zone literature.

[7] The closed-form solution in this case is presented in Froot and Obstfeld (1991b) and Svensson (1991a).

[8] This assumption of symmetry is imposed for purposes of exposition only and will be relaxed in the empirical analysis below.

setting f_0 equal to zero for ease of exposition, the solution to (2) is given by the second-order differential equation (6):[9]

$$G(f)=f+\alpha[(1-\pi(f))u-\pi'(f)\sigma^2]G'(f)+(1/2)\alpha\sigma^2(1-\pi(f))G''(f). \quad (6)$$

Eq. (6) appears the same as the standard solution (5) except for the term $(1-\pi(f))$ on the first and second derivatives of G and for the term $-\pi'(f)\sigma^2$. The term $(1-\pi(f))$ weights the drift term in fundamentals by the probability that no intervention will take place. The $\pi'(f)$ term captures the interaction between changes in fundamentals and the feed-back to changes in the probability.

We can compare the solution when there is stochastic intra-marginal intervention with the standard target-zone solution obtained when intervention only occurs at the boundaries. 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 are the same fundamentals where the probability of intervention reaches 1 in our model so that $\pi(|f_u-f_0|)=\pi(|f_\ell-f_0|)=1$. At this point, intervention induces a reflecting barrier on fundamentals. Fig. 1 depicts this relationship by comparing the line OZ, the standard target-zone solution, with 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 below OZ at the boundaries because the expected present value of fundamentals in (2) is lower when there is intra-marginal intervention as compared with 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.

Similarly, fig. 1 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. By the same reasoning that OA lies below OZ at f^A, intra-marginal intervention implies that the exchange rate function OB has a zero slope at f^B, a point to the right of f^A. Thus, in general, intra-marginal intervention allows the fundamentals to fluctuate within wider bands and still be consistent with a given exchange rate band.

Fig. 1 also 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 quickly. In the lower panel of fig. 1, we depict two different probability-of-

[9]See Lewis (1990) for a discussion of this solution. Unlike the free-float or standard target-zone cases, there is no closed-form solution to this equation.

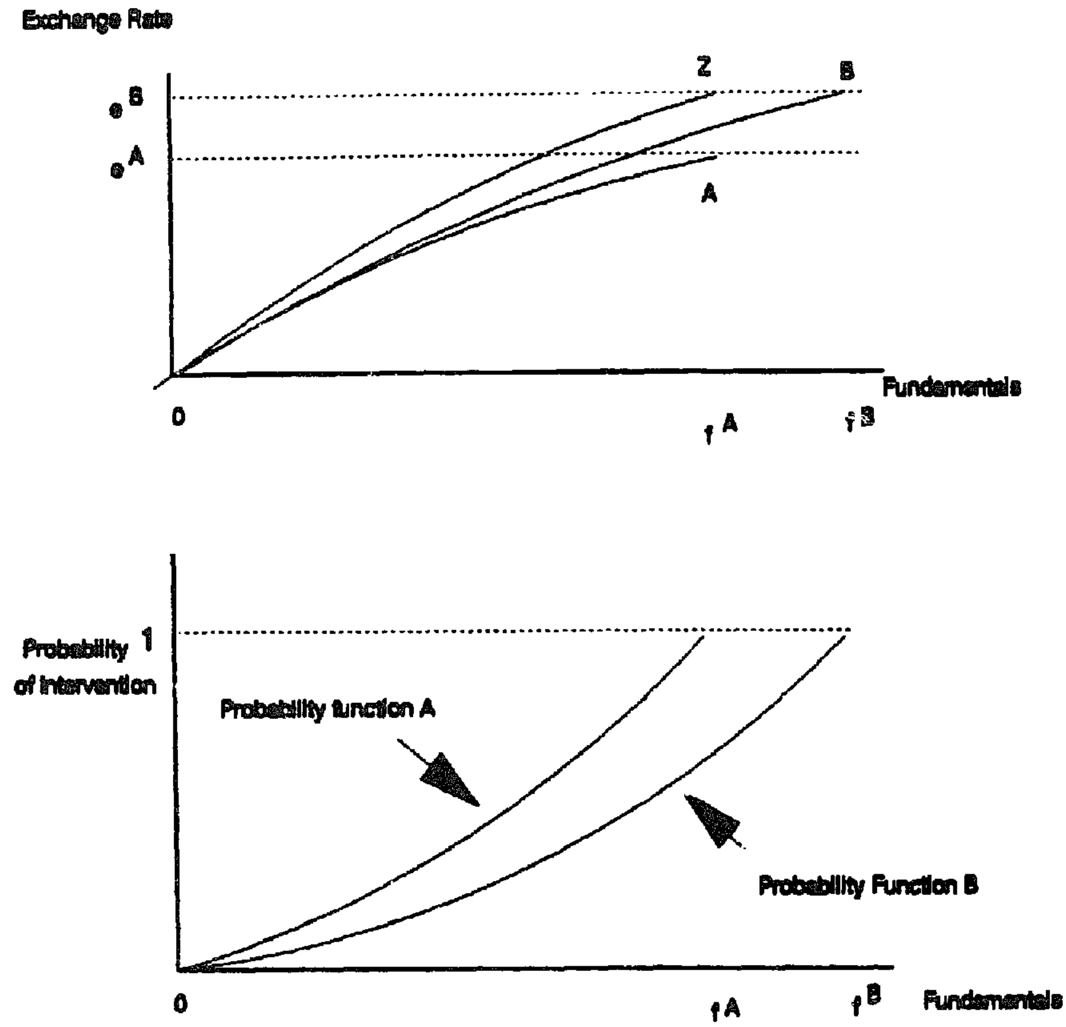

Fig. 1. Intra-marginal intervention target zone.

intervention functions, π^A and π^B. 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 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.

2.2. Learning about intervention

The solution in fig. 1 depends upon how the market believes monetary authorities will intervene, a belief which is captured by the probability-of-intervention function $\pi(f)$. In many situations, however, the market may not be sufficiently certain about the intervention policy 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 towards currency stabilization following the Louvre Meeting in February 1987.[10] Details of actual policy implementation were kept confidential at that time.

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 fig. 1 depending upon a given $\pi(f)$ function, the exchange rate at any moment 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 particular, if the market is uncertain about the exchange rate bands, the learning process yields a time series of S-shaped curves. As the market learns the true probability distribution over time, the solution converges to a single S-shaped curve.

To illustrate the learning process, consider the following situation.[11] 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 the likelihood of intervention given current fundamentals. This probability can be written[12]

$$I_t = f_t \beta + \varepsilon_t. \tag{7}$$

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

When the market does not know the intervention policy process, parameterized by β, then the market does not know the true probability distribution. In this case, market traders try to learn the behavior of this process over time. If people learn in a Bayesian fashion, they combine their

[10] 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 somewhat between realignment periods.

[11] 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 (1988).

[12] See Maddala (1983). This linear probability model has some undesirable features including probability estimates that may be negative. We therefore use this model only for ease of exposition. Actual estimates in section 3 employ a probability function in logistic form.

prior beliefs about the process together with observations of the intervention to obtain estimates of the probability function. That is, market traders at any time t have a prior conjecture about the distribution of β that includes a prior mean $\hat{\beta}_{t-1}$, and a prior precision estimate (the inverse of the variance of β) $\hat{H}_{t-1}$. As people observe new information about intervention, their estimates of these parameters and, therefore, the probability function, will vary as well. With each additional observation of f_t, the parameter estimates will evolve according to the Bayesian rule:[13]

$$\hat{\beta}_t=[\hat{H}_{t-1}+f_t'f_t]^{-1}[\hat{H}_{t-1}'\hat{\beta}_{t-1}+f_t'I_t]. \tag{8}$$

If policy is credible and consistent, the parameter estimates must converge to their true values as people learn the new process. In other words, $\hat{\pi}_t(f)=f_t\hat{\beta}_t$ will converge to $\pi(f)=f_t\beta_t$. On the other hand, if policy is not consistent, these estimates will not converge. In this case, $\hat{\pi}_t(f)$ and, therefore, the implied target zone may experience considerable shifts in its evolution. Below we examine the learning process for the case of the Louvre Accord period to evaluate the stability of the target zone perceived by traders.

3. An application: The Louvre Accord

Exchange rate policy among the United States, West Germany and Japan in the wake of the Louvre Meeting on 21–22 February 1987 was characterized by some of the key features of the learning model developed above. First, foreign exchange intervention policy during this period was based upon the stabilization of currencies within implicit exchange rate bands. In the model, this policy corresponds to the increasing probability of intervention as the exchange rate moves away from its target level. Second, policies agreed upon at the Louvre Meeting were widely perceived as representing a break from the past so that people did not know the true probability function. Third, actual details of intervention policies and exchange rate bandwidths were not explicitly announced.

In view of these characteristics, we apply our model of intra-marginal intervention with learning to daily data drawn from the period following the Louvre Accord. Our sample runs for 8 months since policy shifted focus after the worldwide stock market crash on 19 October 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

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

have not found strong empirically-reliable relationships between the exchange rate and variables commonly viewed as its important determinants. On the other hand, the current exchange rate contains all current information about fundamentals.[14] 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 eq. (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 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 price of foreign currency:

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

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 (7) provided a simple illustration, this model implies undesirable features as a probability function, as is well known.[15] Therefore we assume the probability-of-intervention function is a logistic distribution function.

The data required for our analysis includes daily exchange rate series and daily intervention data. The daily exchange rate data represent spot rates at 7.00 A.M. Eastern Standard Time.[16] 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*, the *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. The frequency of these reports of intervention data are presented in table 1. As shown in this table, reported intervention was undertaken most frequently by the Bank of Japan and least frequently by the Federal Reserve. All of the

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

[15]For example, see Dhrymes (1986, pp. 1568–1572) or Maddala (1983).

[16]The exchange rates are those reported in the London market. The data were kindly provided by Kathryn Dominguez.

Table 1
Frequency of intervention data, 22 February 1987 to 16 October 1987 (170 observations).

Intervention by	Number of days on which there were reports of Dollar purchases	Dollar sales
Federal Reserve	14	7
Bank of Japan	37	0
Bundesbank	16	9
Federal Reserve and Bundesbank	9	4
Federal Reserve and Bank of Japan	10	0
Federal Reserve or Bundesbank	21	12
Federal Reserve or Bank of Japan	41	7

reported interventions by the Bank of Japan and about two-thirds of the reported interventions by the Federal Reserve and the Bundesbank were dollar purchases. Intervention by either the Federal Reserve or the Bundesbank or both was reported on 33 days (21 days of purchases, 12 days of sales), representing almost a fifth of all days. Intervention by either the Federal Reserve or the Bank of Japan or both was reported on 48 days (41 days of purchases, 7 days of sales), representing 28 percent of the days. There were no reported days of intervention at cross purposes, that is intervention in one direction by one central bank and in the other direction by the other central bank.[17]

3.1. *The probability of intervention*

In this subsection we develop and estimate an intervention probability for the period from the February 1987 Louvre Meeting to that year's October stock market crash. The estimates presented 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 and to determine whether the zone was credible.

We define the intervention variables as follows:

$I_t = 0$, no intervention,

$I_t = 1$, intervention with dollar sales,

[17]Since the model is based upon traders' expectations [see eq. (2)], it is more appropriate to use data on reported intervention rather than data on actual intervention. For a study of the accuracy of newspaper reports of intervention by the Federal Reserve between 1985 and 1990 see Klein (1994). Actual intervention data are not publicly available for the Bundesbank nor for the Bank of Japan.

$I_t = -1$, intervention with dollar purchases.

The probability of intervention may then be characterized as[18]

$$\text{Prob}(I_t=0\,|\,s_{t-1}) = \frac{\exp(g_0+g_1 s_{t-1})}{1+\exp(c_0+c_1 s_{t-1})+\exp(g_0+g_1 s_{t-1})}, \tag{9a}$$

$$\text{Prob}(I_t=1\,|\,s_{t-1}) = \frac{1}{1+\exp(c_0+c_1 s_{t-1})+\exp(g_0+g_1 s_{t-1})}, \tag{9b}$$

$$\text{Prob}(I_t=-1\,|\,s_{t-1}) = \frac{\exp(c_0+c_1 s_{t-1})}{1+\exp(c_0+c_1 s_{t-1})+\exp(g_0+g_1 s_{t-1})}. \tag{9c}$$

As the exchange rate moves away from the target level, the probability of intervention increases. To see how this probability relates to the parameters, it is useful to rewrite eqs. (9) in terms of the logarithms of the odds ratios:

$$\log(\text{Prob}(I_t=-1)/\text{Prob}(I_t=1)\,|\,s_{t-1}) = c_0+c_1 s_{t-1}, \tag{10a}$$

$$\log(\text{Prob}(I_t=0)/\text{Prob}(I_t=1)\,|\,s_{t-1}) = g_0+g_1 s_{t-1}, \tag{10b}$$

$$\log(\text{Prob}(I_t=-1)/\text{Prob}(I_t=0)\,|\,s_{t-1}) = (c_0-g_0)+(c_1-g_1)s_{t-1}. \tag{10c}$$

In (10a), 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 (10b), 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 (10c), 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 $|c_1|>|g_1|$.[19]

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 intervention. The probability of no intervention at low values of the dollar exceeds the probability of dollar sales. Therefore, we expect to find $c_0>g_0$ and $c_0>(c_0-g_0)$.

Table 2 reports the results of estimating this model for the Deutschemark/dollar and the yen/dollar rates from just after the Louvre Meeting on 22 February 1987 to just before the 19 October 1987 stock market crash. The model was estimated for the Deutschemark/dollar rate using a series of

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

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

Table 2

Multinomial logistic intervention estimation, Louvre Meeting to stock market crash: 22 February 1987 to 18 October 1987.

Exchange rate	c_0	c_1	g_0	g_1	Correctly predicted (%)
Deutschemark/dollar intervention					
Combined	123[a]	−67[a]	81[a]	−42[a]	79
intervention	(29)	(16)	(22)	(12)	
Intervention by	156[a]	−84[a]	127[a]	−67[a]	86
Federal Reserve	(40)	(21)	(34)	(18)	
Intervention by	144[a]	−79[a]	79[a]	−41[a]	85
Bundesbank	(33)	(18)	(24)	(13)	
Yen/dollar					
Combined	76.7[a]	−0.51[a]	51.7[a]	−0.33[a]	72
intervention	(22)	(0.15)	(20.9)	(0.14)	
Intervention by	67[a]	−0.45[a]	55[a]	−0.35[a]	88
Federal Reserve	(23)	(0.15)	(21)	(0.14)	
Intervention by			27[a]	−0.19[a]	79
Bank of Japan			(7.6)	(0.05)	

[a]Significant at the 95 percent confidence level.

Notes: Numbers in parentheses are estimated standard errors. Combined 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.

market observations when either the Fed or the Bundesbank intervened (called 'Combined intervention' in the table) as well as separately for intervention by the Federal Reserve and for intervention by the Bundesbank. Similarly, the probability model for the yen/dollar rate was estimated with a series when either the Federal Reserve or the Bank of Japan intervened as well as separately for each central bank.

As the estimates show, c_1 and g_1 are significantly negative in all equations. Also, as predicted by the probability model, $|c_1|>|g_1|$, $c_0>g_0$ and $c_0>(c_0-g_0)$ in all cases. Note that, while the Bank of Japan conducted no intervention to weaken the dollar during this period, the estimates of the probability of intervening to strengthen the dollar are significant and of the right sign. Note also that c_1 and g_1 in the Deutschemark equations are approximately 100 times larger than for the yen equations. This difference arises because these coefficients capture how the level of the exchange rate affects the probability while the units of the yen/dollar rate are almost 100 times large than the Deutschemark/dollar rate.[20] Finally, a high percent of the intervention events are correctly predicted by the model indicating that the equations characterize the data fairly well.

As the table shows, these basic results are robust to whether individual central banks or combined series are used. To the extent that intervention is

[20]In fact, the average exchange rates are ¥146/$ and DM 1.82/$ for this period.

related to fundamentals, this effect depends upon the combined impact from both central banks. For this reason, in what follows we use the results based upon the combined series.

3.2. The probability of intervention and G-3 intervention target zones

As shown in the model in section 2, market participants' view of the probability distribution for intervention determines the target zone. On the basis of the probability model discussed above, we can estimate the market participants' perceptions of the probability function and calculate the evolution 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 probability-of-no-intervention equation (9a) and solving for the exchange rate yields a target level of the exchange rate, s_0, as

$$s_0 = \frac{\log\left[\frac{g_1}{(c_1 - g_1)}\right] - c_0}{c_1}. \tag{11}$$

This exchange rate maximizes the probability of no intervention but is well defined only when $c_1 < g_1 < 0$, as found in table 1.

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. In the estimates that follow we illustrate the target zones by presenting the value of the exchange rates that represent a 50 percent chance of intervention. We also discuss some results for the 90 percent chance of intervention target zones.[21]

3.3. Learning about G-3 intervention target zones

The Louvre Accord represented the 'most serious attempt to implement

[21]In the figures the actual exchange rate is sometimes outside of the 50 percent likelihood of intervention range. This simply means that the estimated likelihood of intervention exceeds 50 percent at those times.

systematic currency stabilization'[22] among the major industrial nations since the advent of floating exchange rates.[23] The relative stability of currencies in the wake of the Louvre Accord has contributed to the perception that well-coordinated exchange rate management served to calm foreign exchange markets during that period. In this subsection we present estimates of the target zone during the period between the Louvre Accord and the October 1987 stock market crash. These target-zone estimates both vary over time and substantially widen from the beginning to the end of the sample. Thus these estimates stand in contrast to the perception of a consistent policy during this period. Instead, our estimates of the target zone suggest an erosion of the credibility of the commitment of central banks to well-defined exchange rate management policies.

Our estimates use the exchange rate solution represented in fig. 1 to evaluate the foreign exchange market's daily perception of the target zone for the Deutschemark/dollar and yen/dollar exchange rates following the Louvre Accord. We incorporate evolving estimates of the intervention probability function, $\hat{\pi}_t$, to calculate the market's changing view about the target zone. To estimate the learning process during the Louvre Accord period, the logistic probability model requires a non-linear estimation technique in place of eq. (7).[24] These estimates allow us to evaluate the behavior of the target zone in two ways. We are able to consider whether its behavior is consistent with informal accounts of the period. We can also examine the credibility of the target-zone policy implemented by the G-3 central bankers by evaluating the stability of the market's perceptions of the target zone.

Figs. 2 and 3 present the exchange rate and days of intervention as well as the estimated target level and target zone for the yen/dollar and Deutschemark/dollar rates, respectively. In these figures, the overlapping circles represent the 50 percent probability-of-intervention target-zone boundary. 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 percent and the upper boundary is the exchange rate where the probability of intervention to weaken the dollar is 50 percent. The solid line

[22]Funabashi (1989, p. 177).

[23]The communique issued after the Louvre Meeting on 22 February 1987 stated that finance ministers and central bank governors of the G-6 (i.e. the United States, West Germany, Japan, Great Britain, France, and Canada) 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.' 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' [quoted in Funabashi (1989, p. 177)].

[24]This technique is simply recursive estimation of the logistic model in eqs. (9a) and (9b).

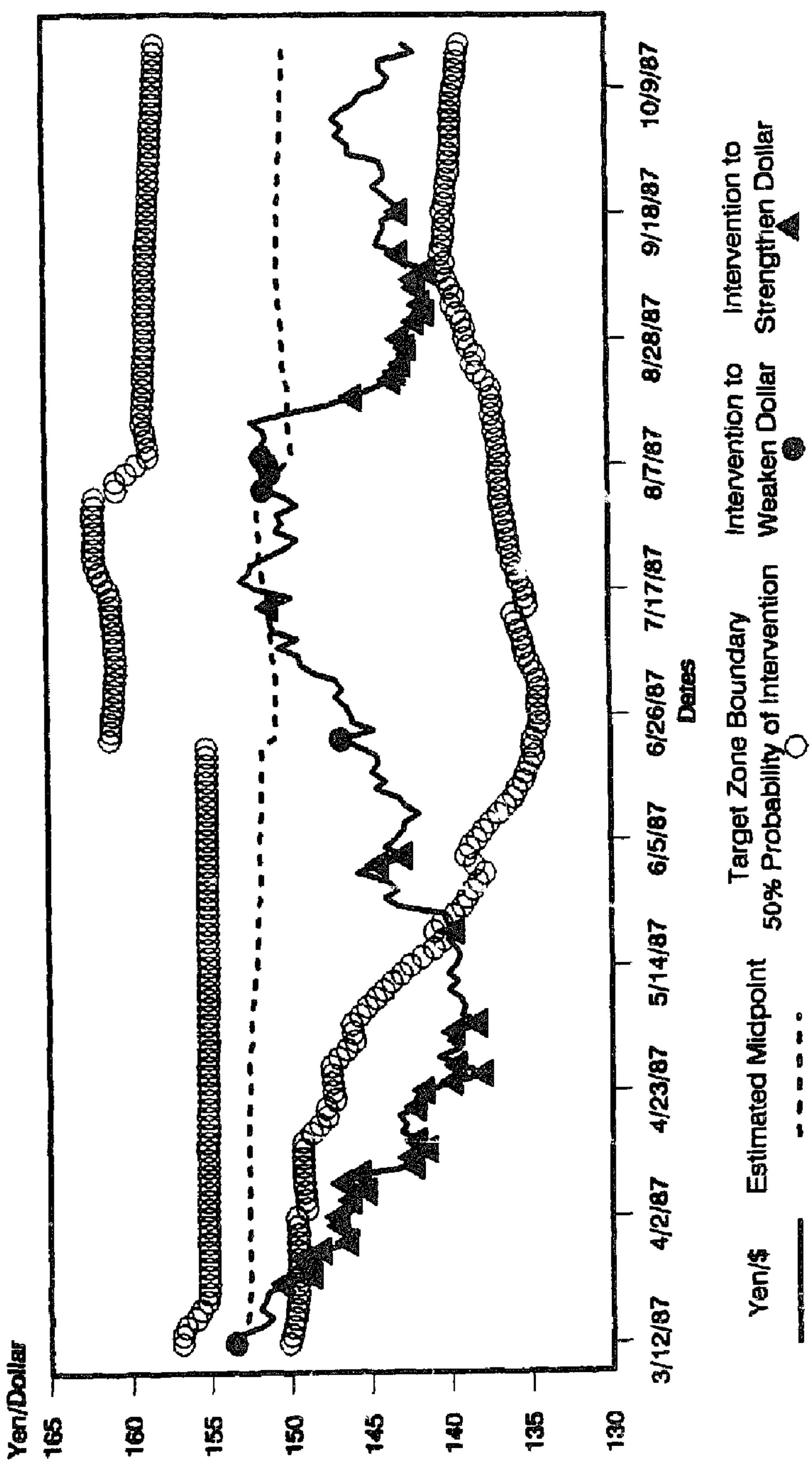

Fig. 2. Yen/dollar. Louvre Meeting to October stock market crash. Yen/$, target level, target zone, intervention.

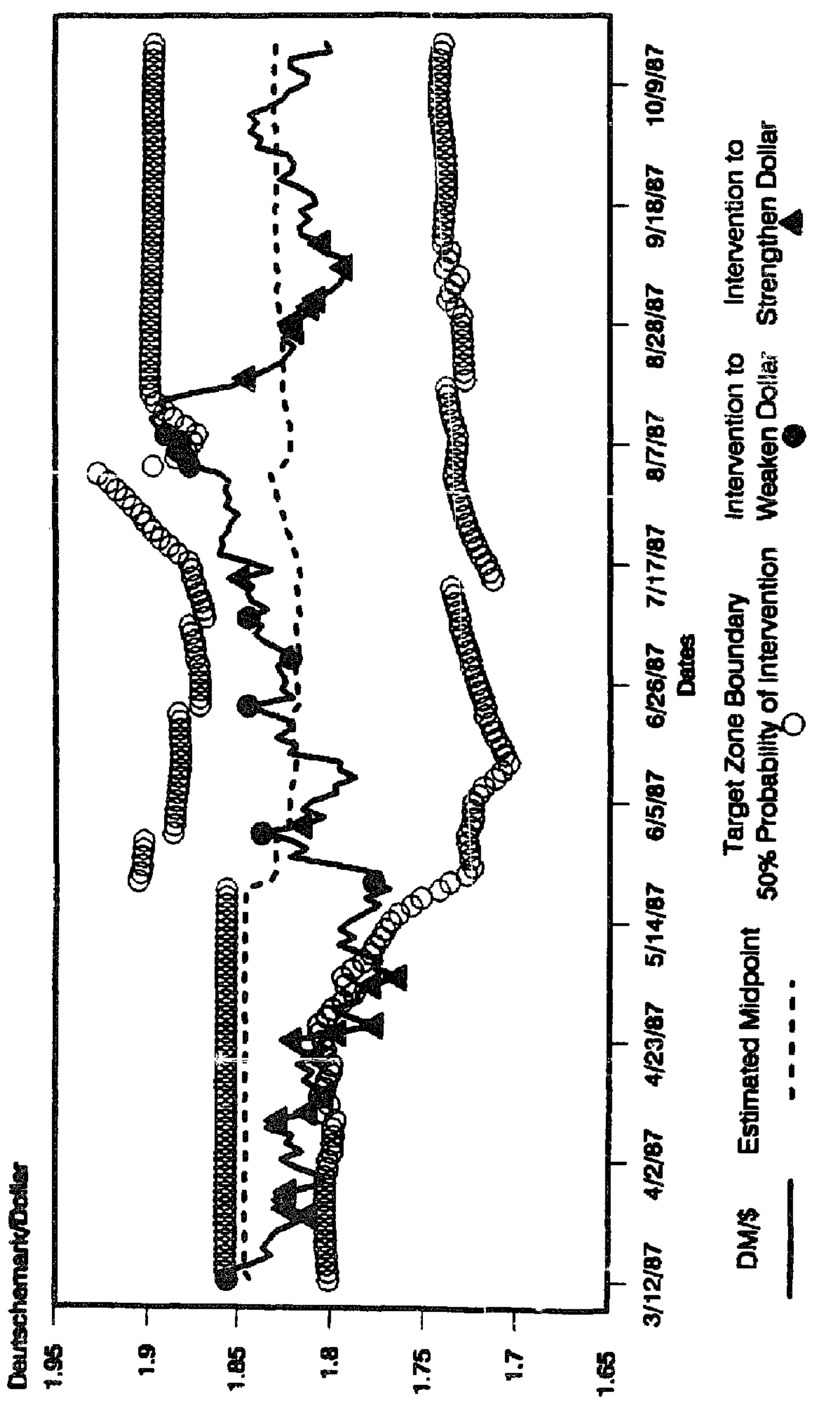

Fig. 3. Deutschemark/dollar. Louvre Meeting to October stock market crash. DM/$, target level, target zone, intervention.

in the figures depicts the actual exchange rate. The dashed line is the estimated target level of 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.[25]

Our initial estimated target level for the yen was 153.1 yen/dollar, with 50 percent probability-of-intervention boundaries at 150.1 to 156.8 yen/dollar (a 4.5 percent target zone width). The initial estimate of the target level for the Deutschemark was 1.847 Deutschemarks/dollar with a 50 percent probability-of-intervention target zone of 1.801 to 1.856 Deutschemarks/dollar (a range of 3.1 percent). Relatively tight estimates of the target zones at the beginning of the sample reflects central bank actions in support of the Louvre Accord. These estimates are consistent with the confidential joint proposal worked out at the Louvre Meeting. This proposal 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.[26]

The first challenge to the stability of currencies under the Louvre Accord occurred in late March and early April with the weakening of the dollar. The estimated target zones remained relatively tight during this time, however, since central banks attempted to support the dollar. 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 (1989, p. 191)] between the Louvre Meeting and the end of April.

Fig. 2 depicts this intensive intervention to support the dollar against the yen at the beginning of our sample. Intervention to strengthen the dollar against the yen occurred on 23 of the first 32 observations in fig. 2. During this time the exchange rate was consistently below the estimated midpoint of the target zone. By the end of these first 32 observations, on 5 May 1987 the estimated target zone was 146.2–155.1 yen/dollar, a range of 6.1 percent.[27]

As shown in fig. 3, the target zone for the Deutschemark/dollar exchange rate behaved in a similar fashion at the beginning of our sample. Interven-

[25]The prior distribution at the time of the Louvre Accord was assumed to be diffuse. 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.

[26]This information comes from Funabashi (1989) who interviewed officials who participated in exchange rate policy during this period.

[27]Recall that the 'target zones' depicted in figs. 2 and 3 represent the values of exchange rates where the estimated likelihood of intervention is 50 percent. When the actual exchange rate is outside these estimated bands it simply means that our estimates suggest that market participants thought intervention more likely than not.

tion 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. As with the estimated yen/dollar target zone, relatively tight estimates of the Deutschemark/dollar target zone during this time reflect central bank actions in support of the Louvre Accord.

Despite the efforts of central banks, the dollar remained weak during March and April. In late April the dollar plunged to a 40-year low of 137.9 yen. The central parity of the yen/dollar target zone was rebased to 146 yen/dollar 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 fig. 2 estimates when intervention to weaken the dollar halted for two weeks after 5 May and the lower boundary of the target zone fell to 140.4 yen/dollar. A dollar-weakening intervention on 23 June, when the target level exceeded the actual exchange rate, raised the upper boundary from 155.1 to 161.2 yen/dollar. The 50 percent probability-of-intervention target zone at this time was 134.8–161.2 yen/dollar, a 19.6 percent spread (the 90 percent probability-of-intervention target zone at this time was 106.6–178.9 yen/dollar, a 67.8 percent range).

A similar widening of the dollar/Deutschemark target zone is found at roughly the same time. Fig. 3 shows that on 21 May, in the face of the dollar weakening against the Deutschemark, there was intervention to further weaken the dollar. The dollar/Deutschemark target zone went from 1.741 to 1.856 Deutschemarks/dollar (a 6.6 percent range) on the day before this intervention to 1.736–1.906 Deutschemarks/dollar (a 9.8 percent range) on 21 May (the 90 percent probability-of-intervention range increased from 1.64 to 1.86 Deutschemarks/dollar, a range of 13.4 percent, to 1.62 Deutschemarks/dollar to 1.97 Deutschemarks/dollar, a range of 21.6 percent).

The yen/dollar target zone in fig. 2 remained stable between late June and early August. At that time, 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 percent range). A 5 percent decline in the exchange rate in less than a week in mid-August, and a subsequent 2.5 percent 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 19 August to 11 September intervention occurred on all but five of the trading days. This intervention activity maintained the 50 percent probability-of-intervention exchange rate target zone close to the approximately 13 percent range of 140–158 yen/dollar over the final part of our sample.

The Deutschemark/dollar target zone in fig. 3 began to narrow in response to intervention in June. Twice in that month the upper boundary of the

Deutschemark/dollar 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 percent range of 1.74–1.87 Deutschemarks/dollar. A purchase of dollars when the exchange rate exceeded the target level on 15 July 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 Deutschemarks/dollar (an 11.6 percent 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 percent probability-of-intervention target zone stayed close to the 9.8 percent range of 1.73–1.90 Deutschemarks/dollar (during this time the 90 percent probability-of-intervention target zone was close to 1.62–1.95 Deutschemarks/dollar; a 20.4 percent range).

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 according to the account of this period in Funabashi (1989). This narrative is consistent with our estimates. We find that target-zone estimates are much wider at the end of the sample than at its outset. The credibility of the initial Louvre Accord policy had essentially eroded.

4. Concluding remarks

In this paper we consider how the market's evolving beliefs about interventions to target exchange rates within bands directly affects the relationship between the exchange rate and fundamentals. When there is stochastic intra-marginal 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 evolves 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 not been successful in finding non-linearities in the exchange rate.[28]

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 generally viewed as one of successful international coordination on

[28]For example, see Meese and Rose (1990) and Flood et al. (1990).

exchange rate policy. Our results suggest, however, that the market's perceptions of the target zone shifted significantly during this period.

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