Government Intervention and Adverse Selection Costs in Foreign Exchange Markets

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An important group of traders in the foreign exchange market is governments who often adhere to a foreign exchange rate policy of occasional interventions with otherwise floating rates. In this article we provide a theoretical model and empirical evidence that government foreign exchange interventions create significant adverse selection problems for dealers. In particular, our model shows that the adverse selection component of the foreign exchange spread is positively related to the variance of unexpected intervention and that expected intervention has no impact on the spread. After controlling for inventory and order processing costs, we find that bid-ask spreads increase with U.S. dollar and German deutsche mark foreign exchange rate intervention during the period 1976–1994. Furthermore, when the intervention is decomposed into *expected* and *unexpected* components, we find a statistically and economically significant increase in spreads with the variance of unexpected intervention, while expected intervention has no significant impact on spreads.

Several researchers have developed information-based models that posit an important role for heterogeneously informed traders in determining bid-ask spreads. For example, in the information-based models of Copeland and Galai (1983), Glosten and Milgrom (1985), Easley and O'Hara (1987), and Benveniste, Marcus, and Wilhelm (1992), the spread compensates market makers for adverse selection losses arising from trading with better-informed agents. In equity markets, the adverse selection problem faced by market makers arises from some traders being better informed about firm-specific information. In the foreign exchange market, on the other hand, one might expect a reduced potential for market-maker losses to better-informed traders, because currency valuation depends primarily on macroeconomic (public) information.[1] However, central banks occasionally intervene in the foreign exchange market with the intent of altering the exchange rate. Dealers in

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[1] Ito, Lyons, and Melvin (1998) examine the effect of the introduction of trading over the lunch hour in Tokyo on the yen/$ return variance and find support for the existence of private information in the foreign exchange market.

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the foreign exchange market are therefore likely to increase spreads to protect themselves against potential losses when faced with greater information asymmetry around government interventions.[2] In this article we provide a theoretical model and empirical evidence that government foreign exchange interventions have a significant impact on the adverse selection component of the exchange rate spread.

The previous literature on the determinants of the foreign exchange spread has primarily focused on inventory costs and the impact of exchange rate volatility.[3] The effect of adverse selection on bid-ask spreads within the foreign exchange market, however, has received little attention, although many theoretical and empirical models of spread determination in equity markets include adverse selection as a key determinant of the spread. One notable exception is Bossaerts and Hillion (1991) who develop an asymmetric information model of the foreign exchange spread subject to occasional government interventions. They show that tests of the unbiasedness of the forward rate as a predictor of the future spot rate are inconsistent when rates are measured as averages of bid-ask spreads.[4]

In addition to Bossaerts and Hillion (1991), Bessembinder (1994) discusses the importance of adverse selection costs arising from government intervention, and Lyons (1995) finds support for both information and inventory effects. However, the primary focus of both Bessembinder's and Lyons' articles is on measuring inventory costs. Osterberg (1992) uses government intervention data from 1985 to 1991 to test whether or not the *anticipation* of intervention explains wider bid-ask spreads. He finds that spreads are narrower around periods of purported intervention. Finally, Peiers (1997) identifies asymmetric information flows and price leadership patterns in foreign exchange trading using Reuters screen headlines of central bank intervention as an informational trigger. With the exception of Osterberg (1992), none of the above studies use official government foreign exchange intervention data in their analysis.

In this study, we employ both U.S. and German official government foreign exchange intervention data to examine the impact of intervention on the

[2] Consistent with governments possessing information, several studies on the profitability of central bank intervention find that central banks make profits from their interventions [e.g., Edison (1993) and Leahy (1995)]. Edison (1993), moreover, finds that foreign exchange market participants believe that intervention is important, and they react to the news of intervention.

[3] For example, Bessembinder (1994) investigates the effect of dealer inventory on the spread, while Lyons (1995) uses proprietary inventory data of a single dealer over a 5-day period to assess inventory costs. Huang and Masulis (1999) use intraday data to analyze the effect of competition and inventory costs on spreads. Glassman (1987), Bollerslev and Melvin (1994), Bessembinder (1994), Wei (1994), and Jorion (1996) use proxies for exchange rate volatility such as the conditional variance from a GARCH (1,1) model or implied volatilities from foreign exchange options to associate dealer risk bearing with the foreign exchange spread.

[4] It is important to note that Bossaerts and Hillion's (1991) results only require that spreads be asymmetric—the source of the asymmetry is not critical. In fact, Bossaerts and Hillion (1991) do not use government foreign exchange intervention data in their analysis. They instead conjecture that bid-ask spreads are higher on Fridays because of pending government intervention decisions during weekends. Bessembinder (1994), however, attributes the larger Friday spreads to inventory costs.

adverse selection component of the DM/$ exchange rate spread. In particular, we examine the impact of the *total* amount of U.S. and German intervention as well as the impact of the *expected* and *unexpected* components of these interventions. The unexpected component of government intervention is likely to lead to an increase in adverse selection costs and, therefore, widen bid-ask spreads. On the other hand, the expected component of government intervention can be considered predetermined and should not generally have an effect on the spread. That is, dealers are likely to adjust the exchange rate level based on the expected intervention, while the spread should only widen if there is an increase in information asymmetry. In the following section, we provide a simple theoretical model that shows that foreign exchange bid-ask spreads are positively related to the variance of unexpected intervention and that expected intervention should not have an impact on the spread.

After controlling for inventory and order processing costs, we find that DM/$ spot and forward spreads increase with U.S. and German foreign exchange intervention during the period 1976–1994. Furthermore, when the intervention is decomposed into expected and unexpected components, we find a statistically significant increase in DM/$ spreads with the variance of unexpected government foreign exchange intervention, while the impact of expected intervention is not statistically significant. We also find that DM/$ spreads increase on days in which both the United States and Germany intervened. Our results also suggest that the higher transaction costs arising from government foreign exchange intervention are economically significant.

Our findings have several important implications. First, they provide support for adverse selection models of the bid-ask spread. Second, by analyzing the response of market makers to government intervention, our findings provide additional evidence on the information channels through which foreign exchange intervention affects the exchange rate.[5] Finally, our results regarding the relative effects of expected versus unexpected intervention and the impact of coordinated intervention may have important policy implications for the implementation of government intervention.

The remainder of this article is organized as follows. In Section 2, we present a simple model of the impact of government foreign exchange intervention on foreign exchange bid-ask spreads. In Section 3, we discuss proxies for each component of the foreign exchange spread. The model specification and estimation methods employed in this study are presented in Section 4. In Section 5, we present our main results; and in Section 6, we summarize our findings and offer some concluding remarks.

[5] The plausible channels through which intervention affects the exchange rate are not completely understood. In particular, the impact of foreign exchange intervention on the money supply is typically sterilized by offsetting open-market purchases or sales of government securities. Since the monetary base is not changed, standard monetary-type models predict that there should not be a change in the exchange rate due to sterilized intervention. This sterilization practice therefore creates a challenge for explaining how government foreign exchange intervention affects the exchange rate. The literature has focused primarily on two alternative explanations: an expectations/signaling channel and a portfolio balance channel [e.g., Dominguez and Frankel (1993a) and Lewis (1995)].

1. A Model of the Impact of Government Foreign Exchange Intervention on Bid-Ask Spreads[6]

Consider a competitive foreign exchange dealer market in which a market maker sets a bid price, B_t, and an ask price, A_t, conditional on an information set, H_t, available to the market maker at time t. Given the competitive nature of the market, the market maker sets the bid and ask price to earn zero expected profit. The traders in this foreign exchange market consist of governments who occasionally intervene through open market purchases and sales to influence foreign exchange rates and other traders who trade for non-information-related reasons (e.g., liquidity traders).

Let IV_{t+1} denote *signed* government intervention volume, and OBV_{t+1} and OSV_{t+1} denote buy and sell volumes of "other" traders over the period t to $t+1$. Also let P_t = \$/DM exchange rate at time t. Assume that the logarithm of the exchange rate, p_t [where $p_t = \ln(P_t)$], is a martingale—$E_t[p_{t+1} \mid H_t] = p_t$. Note that p_t also incorporates the information associated with the expected intervention at time $(t+1)$ conditional on the information set H_t. That is, p_t includes the effect of $E_t[IV_{t+1} \mid H_t]$.

Given the above assumptions, we can model the change in p_t as a function of the unexpected intervention at time $(t+1)$ and a random shock that is uncorrelated with the unexpected intervention:

$$p_{t+1} = p_t + b[IV_{t+1} - E_t[IV_{t+1} \mid H_t]] + e_{t+1}, \tag{1}$$

where $b > 0$ and $E_t[e_{t+1} \mid H_t] = 0$. For small relative changes, $p_{t+1} - p_t \approx (P_{t+1} - P_t)/P_t$. Therefore, we can reformulate Equation (1) as:

$$P_{t+1} = P_t + P_t b[IV_{t+1} - E_t[IV_{t+1} \mid H_t]] + P_t e_{t+1}. \tag{1$'$}$$

Denote $BV_{t+1}(>0)$ and $SV_{t+1}(>0)$ as the total buy and sell volumes (includes government intervention and other trader volume) respectively at time $t+1$. The zero profit condition is then given by

$$E_t[(A_t - P_{t+1})BV_{t+1} + (P_{t+1} - B_t)SV_{t+1} \mid H_t] = 0. \tag{2}$$

The buy and sell volumes [$BV_{t+1}(>0)$ and $SV_{t+1}(>0)$ from t to $t+1$] can be separated into government intervention volume, IV_{t+1}, and other trader volume (other buy volume, OBV_{t+1}, and other sell volume, OSV_{t+1}):

$$BV_{t+1} = IV_{t+1} + OBV_{t+1}, \text{ when } IV_{t+1} > 0, \tag{3}$$

$$SV_{t+1} = -IV_{t+1} + OSV_{t+1}, \text{ when } IV_{t+1} < 0. \tag{4}$$

Assume that OBV_{t+1} and OSV_{t+1} are uncorrelated with e_{t+1} (i.e., there is no other informed buying or selling). Furthermore, if we assume that the expected conditional buy and sell volumes are equal, $E_t[BV_{t+1} \mid H_t] =$

[6] We wish to thank Larry Glosten for providing the basic formulation of the model.

$E_t[SV_{t+1} \mid H_t] = v$, and substitute for P_{t+1} from Equation (1′) into Equation (2), we get[7]

$$v[A_t - B_t]/P_t = bE_t[(IV_{t+1} - E_t[IV_{t+1} \mid H_t])(BV_{t+1} - SV_{t+1}) \mid H_t]. \tag{5}$$

Using Equations (3) and (4), we can rewrite Equation (5) as[8]

$$\begin{aligned} v[A_t - B_t]/P_t = bE_t[(IV_{t+1} - E_t[IV_{t+1} \mid H_t])IV_{t+1} \mid H_t] \\ + bE_t[(IV_{t+1} - E_t[IV_{t+1} \mid H_t]) \\ \times (OBV_{t+1} - OSV_{t+1}) \mid H_t]. \end{aligned} \tag{6}$$

For simplicity, we assume that the other buy and sell trading volumes are uncorrelated with the unexpected government intervention, and hence the second term on the right-hand side of Equation (6) is equal to zero. Notice that the first term on the right-hand side can be expressed as the conditional variance of government intervention:

$$(A_t - B_t)/P_t = (b/v)[\mathrm{var}(IV_{t+1} \mid H_t)]. \tag{7}$$

The total intervention at $(t+1)$ consists of expected intervention conditional on the information set H_t and unexpected intervention u_{t+1}. Therefore the intervention at $t+1$ can be modeled as[9]

$$IV_{t+1} = E_t[IV_{t+1} \mid H_t] + u_{t+1}. \tag{8}$$

From Equation (8) we get

$$\mathrm{var}[IV_{t+1} \mid H_t] = \mathrm{var}[u_{t+1} \mid H_t]. \tag{9}$$

And from Equations (7) and (9) we get

$$(A_t - B_t)/P_t = \alpha \mathrm{var}[u_{t+1} \mid H_t], \tag{10}$$

where $\alpha = b/v$ is positive. Equation (10) shows that the proportional spread at time t is positively related to the conditional variance of unexpected government intervention and that expected intervention should not have an impact on the spread.

An interesting aspect of the model is that the government is informed because the market acts as if intervention affects future prices, and this leads

[7] The assumption that the expected conditional buy and sell volumes are equal simplifies the analysis and enables us to focus on information effects. Furthermore, Lyons (1998) finds that foreign exchange dealers intensively manage their inventories. Note that A_t and B_t can be taken out of the expectation to get $[A_t - B_t]v = E_t[P_{t+1}(BV_{t+1} - SV_{t+1}) \mid H_t]$. Also note that substituting for P_{t+1} from Equation (1′) and rearranging terms, we get $[A_t - B_t]v = E_t[(P_t + P_t e_{t+1})(BV_{t+1} - SV_{t+1}) \mid H_t] + P_t b E_t[(IV_{t+1} - E_t[IV_{t+1} \mid H_t])(BV_{t+1} - SV_{t+1}) \mid H_t]$. Notice that the first term on the right-hand side is zero, given the assumption that the expected conditional buy and sell volumes are equal and the assumption that OBV_{t+1} and OSV_{t+1} are uncorrelated with e_{t+1}.

[8] Note that $BV_{t+1} - SV_{t+1} = OBV_{t+1} - OSV_{t+1} + IV_{t+1}\{IV_{t+1} > 0\} + IV_{t+1}\{IV_{t+1} < 0\} = OBV_{t+1} - OSV_{t+1} + IV_{t+1}$.

[9] In Section 2.2.2, we provide details on the government foreign exchange intervention model.

to a spread. However, there is no presumption that central banks make profits all the time. They could be buying at an ask above the future price and selling at a bid below the future price. The main point, however, is the result that the proportional spread is positively related to the variance of unexpected intervention.

2. Proxies for the Components of Foreign Exchange Bid-Ask Spreads

As a supplier of immediacy, market makers face various costs and risks. These costs and risks arise from three sources: adverse selection, inventory holding, and order processing.[10] Two empirical approaches have been utilized to measure the components of the spread. In the first approach, transaction-level data are used to decompose the spread, while in the second approach, events such as earnings announcements are used to measure the impact of the event on the spread and components of the spread [e.g., Lee, Mucklow, and Ready (1993) and Maddala and Nimalendran (1995)].[11] In this study we use the second approach to examine the impact of government intervention on the adverse selection component of the spread.

2.1 Foreign exchange rate data

The foreign exchange rate data used in this study consists of daily spot and 3-month forward, bid and ask German deutsche mark quotes against the U.S. dollar from January 1976 to December 1994. The foreign exchange data were obtained from Data Resources Incorporated (DRI). The quotes are from a representative bank reflecting the New York open from 1976 to 1986 and 11:30 A.M. New York from 1987 to 1994. This is the same data source used by Bossaerts and Hillion (1991). The quotes, as provided by DRI, have been converted to American terms (dollars per foreign currency). However, the convention in the foreign exchange market is to quote the deutsche mark, and most currencies, against the U.S. dollar in European terms (foreign currency per dollar). In our analysis, we report our results in European terms (DM/$). When stated in American terms ($/DM), we obtain the same reported conclusions.

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[10] Models that discuss the importance of adverse selection include Bagehot (1971), Copeland and Galai (1983), Glosten and Milgrom (1985), Kyle (1985), Easley and O'Hara (1987), Admati and Pfleiderer (1988), and Subrahmanyam (1991). Models that emphasize inventory holding costs in spreads include Demsetz (1968), Stoll (1978), Amihud and Mendelson (1980), and Ho and Stoll (1981, 1983), among others. An excellent review of both adverse selection and inventory cost models can be found in O'Hara (1995).

[11] The statistical models used with the studies that use transaction-level data fall into three general classes: serial covariance models, trade indicator models, and order flow models. For examples of serial covariance models, see Roll (1984), Choi, Salandro, and Shastri (1988), Stoll (1989), George, Kaul, and Nimalendran (1991), and Huang and Stoll (1997). Glosten and Milgrom (1988) and Madhavan, Richardson, and Roomans (1997) provide examples of trade indicator models; while examples of order flow models can be found in Hasbrouck (1991a,b), Hausman, Lo and MacKinlay (1992), and Foster and Viswanathan (1993). In addition to the statistical decomposition models, Huang and Stoll (1996) and Bessembinder and Kaufman (1997) also provide a technique for measuring the information content of trades.

In Table 1, we provide descriptive statistics on the DM/$ spreads. Panel A of Table 1 provides summary statistics on the spot and 3-month forward exchange rate spreads (both percentage spread and ask minus bid), while panel B shows the frequency distribution of the DM/$ spot and forward exchange rate spread. Panel A of Table 1 shows that both the spot and 3-month forward spreads display significant skewness and kurtosis and are autocorrelated. In addition, panel B of Table 1 shows that quoted spreads tend to cluster on a few values when stated in conventional terms. The spot spread takes the value of 10 pips for 55.2% of the quotes. Other common values observed are 5 (6.4%), 7 (8.7%), and 15 (7.1%).[12] Similar to the spot spreads, the forward spreads also cluster on several discrete values, but the clustering occurs at higher spread values. These findings are similar to those reported by Bessembinder (1994), Bollerslev and Melvin (1994), Lyons (1995), and others. This clustering of spreads occurs despite the absence of constraints imposed by minimum tick rules.

2.2 Government intervention and adverse selection

In Section 1, we provide a model that shows that the adverse selection component of the foreign exchange spread is positively related to the variance of unexpected intervention and that expected intervention should not have an impact on the spread. To test these hypotheses, we decompose the intervention into its expected and unexpected components and use the squared residuals from the unexpected component as a proxy for the variance of unexpected intervention. The expected amounts of intervention are defined as the fitted values from a policy reaction model, whereas the unexpected amounts are defined as the difference between the realized amounts of intervention and the fitted values. Since spread changes depend on unsigned quantities, we use the *absolute* values of the *expected* intervention in our analysis.[13] In the following section we describe the intervention data, and then in the subsequent section we layout the policy reaction model used to decompose the intervention into its expected and unexpected components.

2.2.1 Descriptive statistics on active U.S. and German DM/$ exchange rate intervention. Table 2 provides descriptive statistics on the amount of active U.S. and German daily foreign exchange rate intervention in the DM/$ market from January 1, 1976 to December 31, 1994 (4723 trading days).[14]

[12] When stated in nonconventional terms (inverted quotes), the spreads display large clustering at lower spread values.

[13] We also obtain similar results when we use the squared or signed expected amounts.

[14] The sample range corresponds to the availability of the German intervention data on a daily basis. There are 4723 observations in the overlapping sample of the *entire* dataset. Ninety weekday observations were eliminated because of missing exchange rate, futures volume, and/or inventory holding cost proxy data. These 90 observations were dispersed throughout the sample. Of the 90 observations, there were 12 U.S. intervention days, 21 German intervention days, and 6 days in which both the U.S. and Germany intervened.

Table 1
Descriptive Statistics on DM/$ Spot and 3-Month Forward Exchange Rate Spreads: January 1976–December 1994 (4723 Trading Days)

Panel A: Summary statistics on DM/$ spot and 3-month forward exchange rate spreads[a]

	Spot rate		3-Month forward rate	
Summary statistics	DM/$ % spread	DM/$ spread (ask-bid)	DM/$ % spread	DM/$ spread (ask-bid)
Mean	0.051	10.367	0.074	14.885
Median	0.050	10.000	0.073	13.993
Std. Dev.	0.023	4.957	0.027	5.834
Skewness	5.389	5.172	4.503	3.936
Kurtosis	82.473	60.402	57.885	36.824
ACF(1)	0.518	0.499	0.568	0.573

Panel B: Frequency distribution of DM/$ spot and 3-month forward exchange rate spreads: ask-bid[b]

Spot rate			3-Month forward rate		
DM/$ spread (ask-bid)	Frequency		DM/$ spread (ask-bid)	Frequency	
0 < SP < 5	156	(3.3%)	0 < SP < 9	203	(4.3%)
SP = 5	300	(6.4%)	SP = 9	356	(7.5%)
5 < SP < 7	164	(3.5%)	9 < SP < 12	375	(7.9%)
SP = 7	412	(8.7%)	12 <= SP <= 15	2498	(52.9%)
7 < SP < 10	191	(4.0%)	15 < SP < 20	552	(11.7%)
SP = 10	2607	(55.2%)	SP = 20	342	(7.2%)
10 < SP < 15	258	(5.5%)	20 < SP <= 25	247	(5.2%)
SP = 15	337	(7.1%)	25 < SP	150	(3.2%)
15 < SP < 20	13	(0.3%)	—		—
SP = 20	205	(4.3%)	—		—
20 < SP	80	(1.7%)	—		—

[a] The spread is measured as the quoted ask minus the quoted bid and is converted into pips (currency units $\times 10^4$). The DM/$ % spread is defined as [(ask − bid)/midpoint]*100.

[b] In the frequency column, each observation contains the number of occurrences and the percentage of occurrences in parentheses.

Official U.S. foreign exchange intervention data were obtained from the Board of Governors of the Federal Reserve System, and the German intervention data were obtained from the Bundesbank. The intervention data that we use covers active intervention operations (i.e., "In Market") made with the intent of impacting foreign exchange rates. Passive trades (i.e., "Directly With Customer") instigated for reasons unrelated to exchange rate management are not included. In "passive" trades, a customer, rather than the central bank, initiates the trades. The customers of central banks include a central bank's own government when the government has receipts of payments in a foreign currency as well as other central banks and foreign governments. On a given day, the U.S. foreign exchange intervention data contain the amount of active intervention in the DM/$ market stated in millions of dollars, while the German intervention data contain the amount of active intervention in the DM/$ market stated in millions of DM.

Out of a total of 4723 trading days, the United States intervened on 704 days with an average absolute dollar intervention amount of $97.73 million

Table 2

Descriptive Statistics on Daily U.S. and German DM/$ Exchange Rate Intervention: January 1976–December 1994 (4723 Trading Days)

Panel A: Intervention over whole sample

	U.S. intervention (mil $, absolute values)	German intervention (mil DM, absolute values)
Mean	97.73	149.30
Std Dev	123.25	232.68
Frequency	704	1166

Panel B: Intervention by day of the week

	U.S. intervention (mil $, absolute values)	German intervention (mil DM, absolute values)
Monday:		
Mean	89.15	151.06
Std Dev	108.32	196.35
Frequency	139	241
Tuesday:		
Mean	82.69	164.77
Std Dev	90.77	252.84
Frequency	142	240
Wednesday:		
Mean	113.75	147.55
Std Dev	155.52	267.02
Frequency	131	238
Thursday:		
Mean	103.59	137.39
Std Dev	123.44	203.39
Frequency	144	205
Friday:		
Mean	100.32	144.02
Std Dev	130.25	233.21
Frequency	148	242

The U.S. foreign exchange intervention data contain the aggregate amount of active intervention in the DM/$ market stated in millions of dollars, while the German intervention data contain the aggregate amount of intervention in the DM/$ market stated in millions of DM. The reported figures are for absolute values of government foreign exchange intervention.

and with a standard deviation of $123.25 million. Germany, on the other hand, intervened on 1166 days with an average absolute deutsche mark amount of DM149.30 million and with a standard deviation of DM232.68 million.[15] Both the United States and Germany intervened on the same day on 358 occasions, with an average amount of $126.08 million and DM200.58 million, respectively. Panel B of Table 2 shows that the average amount of intervention and the frequency of intervention are nearly equal for each day of the week.

[15] Although Germany intervened more frequently than the United States, the average absolute dollar amount of German intervention over the whole sample is less than the U.S. dollar amount. After converting the German intervention at the contemporaneous spot rate, the average absolute dollar amount of the German intervention is $69 million.

2.2.2 Expected and unexpected intervention: foreign exchange policy reaction model. Most studies that investigate foreign exchange central bank policy reactions include changes in the exchange rate and deviations from a target exchange rate level in the foreign exchange reaction model. Others include a measure of exchange rate volatility and other macroeconomic variables that may influence intervention decisions. However, the volatility measures are only used in studies that focus on absolute levels of intervention. Of the independent variables used in these models, the percentage change in the exchange rate and the difference between the current level of the exchange rate and a target level have generally been found to be the most important.[16]

In the policy reaction model that we estimate, we use the *signed* amount of intervention as the dependent variable. As independent variables, we use the percentage change in the DM/$ exchange rate, the deviation of the exchange rate from a target level and lagged government interventions. Our foreign exchange quotes are at the open of New York trading, while the intervention data is the total amount as of the close of trading. Consistent with our model in Section 1, the dealer sets the foreign exchange quote at the open conditional on the information available to him, including the expected level of intervention. To extract the expected and unexpected intervention components, we estimate the following intervention policy reaction model for both the United States and Germany:

$$\begin{aligned} INT_t = {} & \alpha_0 + \alpha_1(LS_t - LS^T) + \alpha_2 \Delta LS_t \\ & + \alpha_3 \Delta LS_{t-1} + \alpha_4 INT_{t-1} + \alpha_5 INT^*_{t-1} + e_t, \end{aligned} \tag{11}$$

where

INT_t = daily total amount of *signed* home country intervention as of the close of trading on day t,

INT^*_t = daily total amount of *signed* foreign country intervention as of the close of trading on day t,

LS_t = logarithm of the DM/$ exchange rate (midpoint of bid-ask) at the open of the New York market on day t,

LS^T = logarithm of the DM/$ purchasing power parity (PPP) target exchange rate calculated using relative German and U.S. wholesale price indices,[17] and

ΔLS_t = the 1-day percentage change in the spot exchange rate $(LS_t - LS_{t-1})$.

[16] Edison (1993) provides an excellent survey on the literature related to central bank policy reaction models.

[17] Since the collapse of the Bretton Woods system, the U.S. Federal Reserve has never officially announced a target exchange rate. However, a purchasing power parity (PPP) target has been used extensively in the literature. The PPP exchange rate is based on the "law of one price," and it is defined as the rate at which goods in one country sell for the same currency-adjusted price in the other country. For an extensive discussion on PPP, see Froot and Rogoff (1995). As an alternative to the PPP target, Dominguez and Frankel (1993b) consider

A significant negative coefficient on the deviation from the target rate variable indicates that the central banks are targeting the exchange rate level, while a significant negative coefficient on the percentage change in the spot exchange rate indicates that the central banks are pushing the exchange rate against a trend ("leaning against the wind"). The home country lagged intervention variable serves as a proxy for other unobservable factors that influence intervention decisions. The lagged foreign country intervention variable captures the extent to which home country intervention decisions are influenced by the actions of the foreign central bank interventions.

Table 3
Foreign Exchange Intervention Policy Reaction Function: January 1976–December 1994 (4723 Trading Days)

Variable	U.S.	Germany
Intercept: α_0	7.034***	7.438
	(3.39)	(1.62)
$LS_t - LS^T : \alpha_1$	−0.327***	−0.976***
	(−3.14)	(−4.24)
$\Delta LS_t : \alpha_2$	−7.332***	−13.874***
	(−6.32)	(−5.40)
$\Delta LS_{t-1} : \alpha_3$	−0.364	−14.076***
	(−0.31)	(−5.44)
$INT_{t-1} : \alpha_4$	0.416***	0.395***
	(30.50)	(29.24)
$INT^*_{t-1} : \alpha_5$	0.011*	0.241***
	(1.81)	(7.96)
Adj R^2	0.20	0.22

***, **, *: significance levels at 1%, 5%, and 10%, respectively.
t-statistics from heteroskedastic-consistent (Robust–White) standard errors are in parentheses.
We estimate the following foreign exchange intervention policy reaction model for both the U.S. and Germany:

$$INT_t = \alpha_0 + \alpha_1(LS_t - LS^T) + \alpha_2 \Delta LS_t + \alpha_3 \Delta LS_{t-1} + \alpha_4 INT_{t-1} + \alpha_5 INT^*_{t-1} + e_t,$$

where
INT_t = daily total amount of *signed* home country intervention as of the *close* of trading on day t,
INT^*_t = daily total amount of *signed* foreign country intervention as of the *close* of trading on day t,
LS_t = logarithm of the DM/\$ exchange rate (mid point of bid-ask) at the *open* of the New York market on day t,
LS^T = logarithm of the DM/\$ purchasing power parity (PPP) target exchange rate calculated using relative German and U.S. whole sale price indices, and
ΔLS_t = the 1-day percentage change in the spot exchange rate ($LS_t - LS_{t-1}$).

various unofficial post-1985 central bank targets. They report that their results using the alternative target measures are similar. In our analysis, we calculate the PPP rate using relative German and U.S. wholesale price indices and normalize it to begin at the same level as the spot rate. We also used consumer price indices and obtained similar results. The price indices were obtained from Datastream, and the source is *International Financial Statistics*.

Table 3 shows the estimates of the intervention reaction models for both the United States and Germany using daily intervention data. Similar to previous studies, we find statistically significant negative coefficients on the deviation from the target level (α_1), the change in the spot exchange rate (α_2), and the lagged change in the spot exchange rate (α_3). These results are consistent with the United States and Germany targeting exchange rate levels and leaning against the wind. We also find that the lagged home country intervention (α_4) is positive and significant for both countries. Of interest, the lagged German intervention in the U.S. specification (α_5) is positive, but only significant at the 10% level, whereas the lagged U.S. intervention in the German specification is positive and significant at the 1% level.

We also estimated several other policy reaction specifications to ensure that our results were robust. For example, we estimated pure time-series models of intervention and included additional intervention lags. We also included other explanatory variables, such as an interaction variable between the percentage change in the exchange rate and the deviation of the exchange rate from the target level, and annual indicator variables. In each case, our reported conclusions were robust.[18] An additional concern with our model specification is the potential simultaneity bias due to the possible joint determination of the exchange rate and intervention. However, given the timing of the exchange rate quotes (open) and the intervention data (close), simultaneity should not be a significant problem. Nevertheless, as an additional check, we used the instrumental variables (IV) estimation technique to control for potential simultaneity bias between changes in the exchange rate and intervention.[19] Finally, we also estimated the reaction model excluding the contemporaneous exchange rate change from the specification. Again, our conclusions were robust regardless of the estimation technique and model specification that we employed.

As a test that unexpected government interventions do in fact contain information, we regress the signed percentage change in the $/DM exchange rate on lagged values of the signed unexpected and expected interventions. We find that the coefficients on the expected components are not significantly different from zero, while the coefficients on the unexpected components are positive and significantly different from zero.[20] Consistent with Equation (1), a significant positive coefficient on the unexpected component indicates that

[18] These results can be obtained from the authors on request.

[19] Nelson and Starz (1990) show that in the case of multiple explanatory variables with several instruments the potential bias in OLS may be smaller than that of IV.

[20] We obtain the following results (coefficient estimates $\times 10^3$):

$$\begin{array}{llllll} p_t - p_{t-1} = & 0.018 + & 0.807\,(UEUS_{t-1}) & -\,0.260\,(EXUS_{t-1}) & +\,0.422\,(UEGER_{t-1}) & +\,0.187\,(EXGER_{t-1}) \\ (t\text{-statistics}) & (1.730) & (4.355) & (-0.575) & (2.214) & (0.022), \end{array}$$

where $p_t = \ln(\$/\mathrm{DM})_t$. Note that we used lagged values of the intervention components because the exchange rates are quoted in the morning while the intervention is as of the end of the day.

purchases of DMs lead to a strengthening of the DM and an increase in the $/DM exchange rate. These results provide evidence that unexpected government interventions contain information that can create adverse selection problems for dealers.[21]

2.3 Inventory holding cost proxies

In addition to an adverse selection component, several researchers have posited an important role for inventory costs in determining bid-ask spreads. Inventory holding costs arise from suboptimal portfolio positions held by dealers. In particular, market makers often hold inventory to provide immediacy to the market. Clearly, holding inventory imposes an opportunity cost and exposes market makers to the risk that the value of their inventories might change. Inventory costs, therefore, reflect the compensation for opportunity costs and exposure risk faced by a risk-averse dealer.

Bessembinder (1994) provides a detailed discussion of the inventory costs faced by dealers in currency markets. In his investigation, he examines whether inventory cost proxies can explain time-series variation in currency spreads. Bessembinder finds that currency spreads widen with proxies for inventory carrying costs, including forecasts of price risk and a measure of liquidity costs. In addition, he also finds that higher spreads before holidays and weekends can be attributed to inventory costs. Using transaction prices of a single dealer over a 5-day period, Lyons (1995) also finds significant inventory effects.

In our analysis, we employ three proxies similar to those used by Bessembinder to control for inventory effects: interest rate measures of liquidity costs (opportunity costs), forecasts of price risk, and a nontrading indicator variable. For the opportunity costs, we use the rate on 1-month Eurodollar deposits minus the rate on overnight Eurodollar deposits.[22] These data were obtained from Data Resources, Inc. To assess the effects on inventory carrying costs arising from uncertainty in the underlying asset value (price risk), we use the forecast of exchange rate volatility from a GARCH (1,1) model. In addition, we also include a nontrading indicator dummy equal to one on Fridays and one on the last trading day before holidays to examine the importance of the approach of nontrading intervals on currency bid-ask spreads [e.g., Bessembinder (1994)].

[21] Several other studies also suggest that government foreign exchange interventions have significant information content [e.g., Dominquez and Frankel (1993b), Edison (1993), Humpage (1994), Leahy (1995), Dominquez (1997), and Peiers (1997)].

[22] We also considered two additional opportunity cost measures similar to those employed by Bessembinder. The second opportunity cost measure captures the intertemporal component, and it is derived as the implied forward interest rate applicable to the second month after the observation date minus the 1-month rate on that date. The third opportunity cost measure is the first measure minus the second intertemporal measure. Results based on these two other opportunity cost measures support the same conclusions.

2.4 Order processing costs

In a competitive dealer market, order processing costs typically include exchange fees, clearing fees, and fixed costs. Since order processing costs are likely to be fixed for any particular transaction, they should decrease as the expected volume of transactions increases. Several researchers including Glassman (1987) and Bessembinder (1994) have examined the relation between trading volume and currency spreads. Copeland and Galai (1983), moreover, develop a model that suggests a negative relation between bid-ask spreads and trading volume in the long run, although it can be positive in the short run due to information effects. Easley and O'Hara (1992) also develop a model that implies that spreads decrease with forecastable trading volume.

Due to a lack of comprehensive trading volume data in the foreign exchange market, Glassman (1987) uses the volume of currency futures trading at the Chicago Mercantile Exchange (CME) as a proxy for the volume of spot currency trading. In her analysis of currency spreads, she obtains a positive coefficient estimate on the German mark trading volume proxy. Bessembinder, on the other hand, uses an ARIMA(10,1,0) model to decompose the futures trading volume proxy from the CME into forecastable and unexpected components. He finds the coefficient estimate on the expected component of the German mark to be negative and to be positive on the unexpected component. We also decompose the German mark CME futures trading volume proxy into expected and unexpected components using an ARIMA(0,1,2) model.[23]

3. Model Specification

Using the adverse selection, inventory risk, and order processing cost proxies defined in the previous sections, we obtain the following two model specifications described by Equations (12) and (13). The first specification includes the *total* amount of intervention in the estimation, while the second specification separates the amount of intervention into its *expected* and *unexpected* components. Consistent with the theoretical model in Section 1, we use the squared residuals from the policy reaction model as a proxy for the variance of unexpected intervention. For the expected amount of intervention, we use the absolute amount of the predicted values from the policy reaction model.[24] We obtain the parameter estimates for the two model specifications using both OLS and ordered probit estimation procedures.

[23] We experimented with various decomposition specifications. We found that an ARIMA(0,1,2) provided a more parsimonious representation than the ARIMA(10,1,0) specification. We also used models that constrain the predictions to be positive. Regardless of the model specification, the final reported results support the same conclusions.

[24] Although the model in Section 1 indicates that the expected amount of intervention should not have an impact on the spread, we include expected intervention in our specification because it is possible that government intervention may create inventory problems for dealers, which they may have to work out at some cost. If this is the case, then it is possible that expected intervention might have an impact on spreads. Furthermore, Osterberg (1992) argues that the anticipation of intervention may have an impact on spreads.

Model 1:

$$SP_t = \alpha_0 + \sum_{i=1}^{3} \alpha_i DWK_{i,t} + \alpha_4 FRIHOL_t + \alpha_5 SP_{t-1} + \alpha_6 1/S_{t-1}$$
$$+ \alpha_7 FVOLAT_t + \alpha_8 LIQPREM_t + \alpha_9 VOLUME_t$$
$$+ \alpha_{10}|INTUS_t| + \alpha_{11}|INTGER_t| + \alpha_{12} COORINT_t$$
$$+ \sum_{k=76}^{93} \alpha_k AD_k + e_t, \tag{12}$$

Model 2:

$$SP_t = \alpha_0 + \sum_{i=1}^{3} \alpha_i DWK_{i,t} + \alpha_4 FRIHOL_t + \alpha_5 SP_{t-1} + \alpha_6 1/S_{t-1}$$
$$+ \alpha_7 FVOLAT_t + \alpha_8 LIQPREM_t + \alpha_9 |EXVOL_t|$$
$$+ \alpha_{10}|UEVOL_t| + \alpha_{11}|EXUS_t| + \alpha_{12}(UEUS_t)^2$$
$$+ \alpha_{13}|EXGER_t| + \alpha_{14}(UEGER_t)^2 + \alpha_{15} COORINT_t$$
$$+ \sum_{k=76}^{93} \alpha_k AD_k + e_t \tag{13}$$

where

SP_t = DM/$ exchange rate spread (ask-bid or % spread) at the open of the New York market on day t,

DWK_i = day of the week indicator variables ($i = 1$ to $3 \Rightarrow$ Monday, Tuesday, Thursday),

$FRIHOL$ = a Friday/holiday indicator variable,

SP_{t-1} = 1-day lagged DM/$ exchange rate spread,

$1/S_{t-1}$ = inverse of the 1-day lagged DM/$ exchange rate,

$FVOLAT_t$ = conditional variance of the DM/$ exchange rate from a GARCH-M (1,1) specification,

$LIQPREM_t$ = estimated cost of holding liquid inventories calculated as the rate on 1-month Eurodollar deposits minus the rate on overnight Eurodollar deposits,

$VOLUME_t$ = DM/$ exchange rate futures trading volume from the Chicago Mercantile Exchange,

$|EXVOL_t|$ = absolute value of the *expected* DM/$ exchange rate trading volume using the fitted values from an ARIMA(0,1,2) specification on CME futures,

$|UEVOL_t|$ = absolute value of the *unexpected* DM/$ exchange rate trading volume using the residuals from an ARIMA(0,1,2) specification on CME futures,

$|INTUS_t|$ = absolute value of the daily total amount of U.S. foreign exchange intervention against the DM as of the close,

$|EXUS_t|$ = absolute value of the daily *expected* amount of U.S. foreign exchange intervention against the DM using the fitted values from the U.S. foreign exchange intervention policy reaction model,

$(UEUS_t)^2$ = squared daily *unexpected* amount of U.S. foreign exchange intervention against the DM using the squared residuals from the U.S. foreign exchange intervention policy reaction model,

$|INTGER_t|$ = absolute value of the daily total amount of German foreign exchange intervention against the $ as of the close,

$|EXGER_t|$ = absolute value of the daily *expected* amount of German foreign exchange intervention against the $ using the fitted values from the German foreign exchange intervention policy reaction model,

$(UEGER_t)^2$ = squared daily *unexpected* amount of German foreign exchange intervention against the $ using the squared residuals from the German foreign exchange intervention policy reaction model,

$COORINT_t$ = an indicator variable for days in which *both* the U.S. and Germany intervened, and

AD_k = annual indicator variables (1976–1993).

Similar to Bollerslev and Melvin (1994), we include the lagged spread in both model specifications to account for the effect of temporal dependence in the spread. Since studies on spreads in equity markets document a significant relation between the spread and the inverse of the price level, we also include the inverse of the lagged level of the exchange rate to account for a possible relation between the level of the spread and the exchange rate. We also include an indicator variable equal to one on days in which both the United States and Germany intervened (358 days) to examine whether these days differ systematically from other interventions. Finally, we include annual indicator variables from 1976 to 1993 [e.g., Bessembinder (1994)].

4. Results

4.1 The impact of government intervention on foreign exchange spreads

The main focus of this article is to assess the impact of government intervention on foreign exchange spreads after controlling for inventory and liquidity effects.[25] The two models that we estimate are described in Section 3, Equations (12) and (13). The first model specification, Model 1 (Equation 12), includes the absolute value of the total amount of intervention, while the second specification, Model 2 (Equation 13), separates the amount of U.S. and German intervention into its expected and unexpected components using the policy reaction model described in Section 2.2.2. The left panel of Table 4 contains the results using the proportional spot rate spread as the dependent variable, while the right panel contains results using the proportional 3-month forward rate spread as the dependent variable.

Using the proportional spot rate spread as the dependent variable and Model 1, Table 4 shows that the absolute level of German intervention (*INTGER*) has a statistically significant positive impact on spreads at the 1% level, while U.S. intervention (*INTUS*) is not statistically significant. The impact of joint U.S. and German intervention (*COORINT*) is also positive but not statistically significant. When we use the 3-month forward rate proportional spread as the dependent variable, we find that the intervention impact on spreads is positive and significant at the 5% level for Germany and at the 10% level for the United States. For the forward rates, the impact of joint U.S. and German intervention is again positive but not statistically significant.

[25] We control for inventory carrying costs using proxies, and therefore inventory cost variation may not be perfectly controlled. Hence there is a possibility that intervention may also affect spreads through channels other than adverse selection.

In Table 4 we also report estimates based on Model 2 in which we separate the intervention into expected and unexpected components. Consistent with the theoretical model from Section 1, we find that the coefficients on the variance of the unexpected component of U.S. and German interventions are both positive and statistically significant at the 5% and 1% level, respectively, whereas expected U.S. and German interventions are not statistically significant. The 3-month forward rate proportional spread results reported for

Table 4
OLS Estimates of the Effects of Government Foreign Exchange Intervention on DM/$ % Spreads: January 1976–December 1994 (4723 Trading Days)

	Spread measure: % spread			
	Spot rate		3-month forward rate	
Variable	Model 1	Model 2	Model 1	Model 2
Intercept	0.003	0.003	0.003	0.003
	(0.035)	(0.482)	(0.033)	(0.337)
DWK_1 (Mon.)	−0.003***	−0.003***	−0.003***	−0.003***
	(−3.185)	(−3.195)	(−3.119)	(−3.164)
DWK_2 (Tues.)	−0.001	−0.001	−0.001	−0.001
	(−0.883)	(−0.800)	(−0.983)	(−0.919)
DWK_3 (Thurs.)	0.001	0.001	0.001	0.002
	(1.543)	(1.621)	(1.483)	(1.573)
FRIHOL	0.006***	0.006***	0.006***	0.006***
	(7.634)	(7.517)	(7.022)	(6.917)
SP_{t-1}	0.377***	0.377***	0.410***	0.411***
	(27.410)	(27.424)	(30.376)	(30.421)
$1/S_{t-1}$	0.049***	0.046***	0.063***	0.061***
	(4.348)	(4.121)	(4.985)	(4.858)
$FVOLAT^a$	0.008***	0.009***	0.009***	0.010***
	(7.635)	(8.103)	(7.446)	(7.964)
$LIQPREM^a$	0.620	0.642	−0.003	−0.004
	(1.073)	(1.113)	(−0.053)	(−0.063)
$VOLUME^a$	0.001**	—	0.001**	—
	(2.181)		(2.098)	
$\|EXVOL\|$	—	0.001	—	0.001
		(0.781)		(1.179)
$\|UEVOL\|$	—	0.001	—	0.001
		(1.139)		(1.173)
$\|INTUS\|$	0.059	—	0.109*	—
	(1.038)		(1.736)	
$\|EXUS\|^a$	—	−0.091	—	−0.179
		(−0.676)		(−1.199)
$(UEUS)^{2\,b}$	—	0.025**	—	0.033***
		(2.233)		(2.675)
$\|INTGER\|$	0.079***	—	0.060**	—
	(3.481)		(2.374)	
$\|EXGER\|^a$	—	−0.051	—	−0.064
		(−0.907)		(−1.035)
$(UEGER)^{2\,b}$	—	0.009***	—	0.008***
		(5.741)		(5.104)
COORINT	0.001	0.003**	0.002	0.004***
	(1.052)	(2.426)	(1.508)	(3.067)
Adj R^2	0.35	0.36	0.40	0.41

***, **, *: significance levels at 1%, 5%, and 10%, respectively.
t-statistics from heteroskedastic-consistent (Robust–White) standard errors are in parentheses.
^{a} Coefficient estimate $\times 10^4$.
^{b} Coefficient estimate $\times 10^6$.

Table 4 *Continued*

We estimate the following models using OLS estimation procedures.

Model 1:

$$\begin{aligned} SP_t = \; & \alpha_0 + \sum_{i=1}^{3} \alpha_i DWK_{i,t} + \alpha_4 FRIHOL_t + \alpha_5 SP_{t-1} + \alpha_6 1/S_{t-1} + \alpha_7 FVOLAT_t \\ & + \alpha_8 LIQPREM_t + \alpha_9 VOLUME_t + \alpha_{10}|INTUS_t| + \alpha_{11}|INTGER_t| \\ & + \alpha_{12} COORINT_t + \sum_{k=76}^{93} \alpha_k AD_k + e_t. \end{aligned}$$

Model 2:

$$\begin{aligned} SP_t = \; & \alpha_0 + \sum_{i=1}^{3} \alpha_i DWK_{i,t} + \alpha_4 FRIHOL_t + \alpha_5 SP_{t-1} + \alpha_6 1/S_{t-1} + \alpha_7 FVOLAT_t \\ & + \alpha_8 LIQPREM_t + \alpha_9 EXVOL_t + \alpha_{10}|UEVOL_t| + \alpha_{11}|EXUS_t| + \alpha_{12}(UEUS_t)^2 \\ & + \alpha_{13}|EXGER_t| + \alpha_{14}(UEGER_t)^2 + \alpha_{15} COORINT_t + \sum_{k=76}^{93} \alpha_k AD_k + e_t. \end{aligned}$$

where

$SP_t =$ DM/$ exchange rate spread (ask-bid or percent spread) at the open of the New York market on day t,
$DWK_i =$ day of the week indicator variables ($i = 1$ to $3 \Rightarrow$ Monday, Tuesday, Thursday),
$FRIHOL =$ a Friday/holiday indicator variable,
$SP_{t-1} =$ 1-day lagged DM/$ exchange rate spread,
$1/S_{t-1} =$ inverse of the 1-day lagged DM/$ exchange rate,
$FVOLAT_t =$ conditional variance of the DM/$ exchange rate from a GARCH-M (1,1) specification,
$LIQPREM_t =$ estimated cost of holding liquid inventories calculated as the rate on 1-month Eurodollar deposits minus the rate on overnight Eurodollar deposits,
$VOLUME_t =$ DM/$ exchange rate futures trading volume from the Chicago Mercantile Exchange,
$|EXVOL_t| =$ absolute value of the *expected* DM/$ exchange rate trading volume using the fitted values from an ARIMA(0,1,2) specification on CME futures,
$|UEVOL_t| =$ absolute value of the *unexpected* DM/$ exchange rate trading volume using the residuals from an ARIMA(0,1,2) specification on CME futures,
$|INTUS_t| =$ absolute value of the daily total amount of U.S. foreign exchange intervention against the DM as of the close,
$|EXUS_t| =$ absolute value of the daily *expected* amount of U.S. foreign exchange intervention against the DM using the fitted values from the U.S. foreign exchange intervention policy reaction model,
$(UEUS_t)^2 =$ squared daily *unexpected* amount of U.S. foreign exchange intervention against the DM using the squared residuals from the U.S. foreign exchange intervention policy reaction model
$|INTGER_t| =$ absolute value of the daily total amount of German foreign exchange intervention against the dollar as of the close,
$|EXGER_t| =$ absolute value of the daily *expected* amount of German foreign exchange intervention against the dollar using the fitted values from the German foreign exchange intervention policy reaction model,
$(UEGER_t)^2 =$ squared daily *unexpected* amount of German foreign exchange intervention against the $ using the squared residuals from the German foreign exchange intervention policy reaction model, and
$COORINT_t =$ an indicator variable for days in which *both* the United States and Germany intervened,
$AD_k =$ annual indicator variables (1976–1993).

Model 2 in Table 4 are also similar to the spot rate proportional spread results. In particular, the variance of the unexpected components of intervention for both the United States and Germany along with the coordinated intervention dummy are all positive and significant at the 1% level, while the expected interventions are not statistically significant. Both the spot rate and 3-month forward rate results indicate that a significant source of adverse selection faced by dealers in the foreign exchange market is due to unexpected government intervention. Furthermore, our finding that expected interventions have no significant impact on the spread indicates that dealers do not face significant inventory problems during expected interventions.

To control for the effects of inventory and opportunity costs on DM/$ spreads, we include three proxies suggested by Bessembinder (1994) in our model specification: a forecast of price risk from a GARCH (1,1) model (*FVOLAT*), a nontrading indicator (*FRIHOL*) and an interest rate-based liquidity cost measure (*LIQPREM*). Similar to Glassman (1987), Bessembinder (1994), and Jorion (1996), we also include DM/$ futures trading volume from the CME (*VOLUME*), and we decompose the volume into its expected and unexpected components as well. In Table 4 we find that the parameter estimates on the forecast volatility, *FVOLAT*, are positive and significant in explaining both the spot and forward rate percentage spreads. Furthermore, we find that DM/$ spot and forward rate proportional spreads increase before weekends and holidays (FRIHOL) and are statistically significant in both models. These results are similar to those reported by Bessembinder (1994), Bollerslev and Melvin (1994), and Bossaerts and Hillion (1991). Also similar to Bessembinder (1994), we find the liquidity premium proxy to have a positive, but only marginally significant impact on DM/$ spot rate proportional spreads.

To control for the effect of trading volume on spreads, we use the total volume in Model 1 and expected and unexpected volume in Model 2. In Table 4, the total volume has a positive and significant impact on both the spot rate and 3-month forward rate proportional spreads. These results are consistent with those reported by Glassman (1987). When we decompose the volume into expected and unexpected components using an ARIMA(0,1,2) model, we find that both variables have a positive effect on the spread, but neither is statistically significant.

As a robustness check, we also estimated Models 1 and 2 for both the spot and 3-month forward rates using the absolute spread (ask-bid) as the dependent variable. The results are similar to those reported in Table 4 using proportional spreads. Due to the clustering of quoted spreads (as shown by the frequency distribution in Table 1), Bollerslev and Melvin (1994) argue that using stochastic processes with continuous state spaces is not efficient. Therefore, as an additional robustness check, we also employed the ordered probit methodology to examine the determinants of the quoted spreads. Although not reported, we obtain very similar results using ordered probit estimation procedures.[26]

4.2 Government foreign exchange intervention and transaction costs

We report the estimated transaction costs arising from government foreign exchange intervention in Table 5. The costs are estimated using the coefficient

[26] These results are available from the authors on request.

Table 5
The Impact of Intervention on Transactions Costs in the DM/$ Spot Exchange Rate Market

Intervention	Change in proportional spread[a]	Annual cost[b] (mil. $)
Expected intervention	−0.00026	−81
Unexpected intervention	0.00021	64
Coordinated intervention[c]	0.00023	72
Total intervention	0.00018	55

[a] The change in the proportional spreads (ΔSP) due government intervention is measured by:

$$\Delta(SP) = \hat{\alpha}_{11} \cdot \mathrm{E}(|EXUS|) + \hat{\alpha}_{12} \cdot \mathrm{E}(UEUS^2) + \hat{\alpha}_{13} \cdot \mathrm{E}(|EXGER|) + \hat{\alpha}_{14} \cdot \mathrm{E}(UEGER^2) + \hat{\alpha}_{15} \cdot \mathrm{E}(COORINT),$$

where

E(·) is the respective average value, and | · | is the absolute value,

$SP =$ [(ask − bid)/midpoint] $\times 10^2$,
$|EXUS_t| =$ absolute value of the daily *expected* amount of U.S. foreign exchange intervention against the DM using the fitted values from the U.S. foreign exchange intervention policy reaction model,
$(UEUS_t)^2 =$ squared daily *unexpected* amount of U.S. foreign exchange intervention against the DM using the squared residuals from the U.S. foreign exchange intervention policy reaction model,
$|EXGER_t| =$ absolute value of the daily *expected* amount of German foreign exchange intervention against the dollar using the fitted values from the German foreign exchange intervention policy reaction model, and
$(UEGER_t)^2 =$ squared daily *unexpected* amount of German foreign exchange intervention against the dollar using the squared residuals from the German foreign exchange intervention policy reaction model,
$COORINT_t =$ an indicator variable for days in which *both* the United States and Germany intervened.

[b] The annualized dollar costs arising from foreign exchange intervention are measured by multiplying the change in proportional spread by one-half of the daily turnover figure ($127 billion), and the number of trading days per year (250 days).
[c] We define coordinated intervention as days in which *both* the United States and Germany intervened.

estimates on the intervention variables from Table 4, the average values of the intervention variables, and a daily DM/$ exchange rate turnover of $254 billion as reported by the Bank for International Settlements (1996).[27] Since the turnover figures reported by the Bank for International Settlements make no distinction between sale and purchase transactions, we divide the reported turnover figure by two to obtain a round-trip transaction cost.

More specifically, using Model 2 (Equation 13), the change in the proportional spread (ΔSP) due to government foreign exchange intervention is given by:

$$\Delta(SP) = \hat{\alpha}_{11} \cdot \mathrm{E}(|EXUS|) + \hat{\alpha}_{12} \cdot \mathrm{E}(UEUS^2) + \hat{\alpha}_{13} \cdot \mathrm{E}(|EXGER|) + \hat{\alpha}_{14} \cdot \mathrm{E}(UEGER^2) + \hat{\alpha}_{15} \cdot \mathrm{E}(COORINT), \quad (14)$$

where E(·) is the average value, and | · | is the absolute value. The annualized dollar costs arising from foreign exchange intervention are measured by multiplying the change in proportional spread (ΔSP) by one-half of the

[27] The triennial survey by the Bank for International Settlements (1996) reports that global turnover in traditional foreign exchange market segments reached an estimated daily average of nearly $1.2 trillion. DM/$ dollar exchange rate trading accounted for the largest market share at an average daily amount of $254 billion. These foreign exchange turnover figures are net of local and cross-border interdealer double-counting.

daily turnover figure ($127 billion) and the number of trading days per year (250 days).

As shown in Table 5, the transaction costs arising from U.S. and German government foreign exchange intervention are $55 million on an annualized basis. For unexpected U.S. and German government foreign exchange intervention, the costs are $64 million, while expected intervention leads to a reduction in costs. When the intervention is coordinated, the costs rise by $72 million. It is important to note, however, that the impact of expected intervention is not significantly different from zero, and therefore the total transaction costs as a result of intervention are likely to be understated. Furthermore, the squared residuals are a noisy proxy for the "true" variance of unexpected intervention, and therefore these estimates are potentially biased toward zero. To address the potential impact of this bias on our transaction cost estimates, we also estimate an upper bound for the transaction costs using the inverse of the coefficient estimates from reverse regressions.[28] In this case, the transaction costs from unexpected government intervention are as high $27.5 billion on an annualized basis.

5. Conclusion

Governments often adhere to a foreign exchange rate policy of occasional interventions to influence exchange rates. These government interventions increase the level of information asymmetry among foreign exchange market participants, and therefore provide an ideal setting to test adverse selection models. In this study we employ a dataset of both German and U.S. government foreign exchange intervention to examine the effects of intervention on the adverse selection component of the DM/$ exchange rate spread.

After controlling for inventory and order processing costs, we find that DM/$ spreads increase with U.S. and German foreign exchange intervention. More importantly, when we decompose the intervention into its *expected* and *unexpected* components, we find a statistically significant increase in DM/$ spreads with the variance of unexpected government foreign exchange intervention, while expected intervention has no significant impact on spreads. These results are consistent with our theoretical model of the effects of government intervention on bid-ask spreads. Finally, we also find that the higher transaction costs arising from government intervention are economically significant.

Our results have several important implications. First, they provide support for adverse selection models of the bid-ask spread. Second, by analyzing

[28] We carry out the reverse regression by first regressing the spread on all the observable variables, excluding the unexpected intervention. Then, we regress the unexpected intervention on the residuals from the first regression. The inverse of the slope coefficient is used as an upper-bound estimate. For a discussion of errors-in-variables problems in financial models, see Maddala and Nimalendran (1996).

the response of market makers to government intervention, this study provides additional evidence on the information channels through which foreign exchange intervention affects the exchange rate. In particular, our results are consistent with expectations/signaling explanations of how foreign exchange intervention affects the exchange rate. Finally, our results regarding the relative costs of expected versus unexpected intervention and coordinated versus uncoordinated intervention may have policy implications for the implementation of government intervention. For instance, by increasing the transparency of government intervention policies and strategies, this would result in a decline in the variance of unanticipated intervention and a reduction in spread transaction costs. Overall, our results suggest that the market microstructure approach provides fruitful insights into foreign exchange rate analysis.

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