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Heterogeneous Market-Making in Foreign Exchange Markets: Evidence from Individual Bank Responses to Central Bank Interventions

Using high-frequency data this article provides evidence that, on average, central bank interventions lead to increased volatility and a widening of bid–ask spreads in the intra-day market for foreign exchange. The results also show that there is dispersion in the bid–ask spread revisions posted by individual banks in response to the central bank entering the market. The findings are consistent with predictions from standard models of market microstructure with heterogeneous agents and have implications for the market power of central banks as well as the payoff generated by trading large amounts of international reserves.

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An extensive body of research in open economy macroeconomics has examined the impact of central bank interventions on exchange rate dynamics. Traditional explanations rely on fundamentals and rational expectations models of exchange rate determination to examine the effects of central bank interventions (Dominguez and Frankel 1983a, 1983b, 1983c).[1] Sterilized interventions can affect exchange rates through two theoretical channels—the "portfolio balance" channel and the "signaling channel." According to the portfolio balance channel, sterilized interventions affect exchange rates by changing the currency denomination

1. See Edison (1993) and Sarno and Taylor (2001) for comprehensive surveys.

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of the supplies of different assets held by investors. Alternatively, sterilized interventions can signal future money supply or interest rate changes, thereby affecting the current value of the exchange rate. Empirically, however, both channels have received limited or ambiguous support in studies that use data at daily or weekly frequencies (Edison 1993, Dominguez and Frankel 1993a, 1993c, Humpage 1999).

A more recent strand of the literature investigates the market microstructure effects of central bank interventions (Peiers 1997, Naranjo and Nirmalendran 2000, Evans and Lyons 2003a, Dominguez 2003). Empirical market microstructure research notes that the failure of previous work to identify the impact of central bank interventions on exchange rates may stem from a lack of statistical power in studies that use data at more aggregated frequencies—a shortcoming that may be resolved by using higher frequency data (Evans and Lyons 2002, 2003b). In particular, a drawback with using aggregate data at daily or weekly frequencies is that the empirical estimations fail to unravel mechanisms by which market participants assimilate information about interventions. Intra-day or high-frequency data, on the other hand, allow the researcher to more precisely examine the mechanism through which the central bank intervention signals are transmitted to individual market participants and ultimately impact the aggregate exchange rate.

This article examines individual bank responses to the central bank interventions in foreign exchange markets. I use intra-day tick-by-tick data from the yen/dollar market to study inter-bank bid–ask quote revisions in response to news of central bank intervention to ask following questions. First, does intervention activity create asymmetric information or increased inventory carrying costs among traders, as evidenced by increased inter-bank bid–ask spreads?[2] Second, is there cross-sectional variation in the bid–ask spread changes quoted by individual banks when the central bank intervenes?

Microstructure models of central bank interventions predict that the degree of heterogeneity in trader beliefs about both spot rate fundamentals and the intervention signal affect the market's reaction to central bank intervention (Bhattacharya and Weller 1997, Vitale 1999). Specifically, central banks play a role akin to that of liquidity traders in standard microstructure models (Kyle 1985). Analogous to liquidity traders, central banks represent a source of demand that can be independent of the underlying fundamental value of the spot exchange rate. The potential independence of central bank trading from spot rate fundamentals makes the central bank's order flow a noisier signal of the target exchange rate.

Furthermore, recent evidence suggests that investor heterogeneity might play a key role in explaining exchange rate fluctuations. In particular, Evans and Lyons (2002) show that most short-run exchange rate volatility is related to order flow, which in turn is associated with heterogenous investors.[3] The theoretical premise in this article

2. See Campbell, Lo, and MacKinlay (1997) and Huang and Stoll (1997) for a survey of the literature on disentangling spread components.

3. See also Bacchetta and van Wincoop (Forthcoming), Froot and Ramadorai (2005), and Evans and Lyons (2003b).

is that individual trader signals about the fundamentals and the intervention signal combine to determine price responses in the inter-bank market for foreign exchange (Bhattacharya and Weller 1997, Vitale 1999). If an intervention announcement creates uncertainty among traders about future monetary policy or other fundamentals and hence the future spot rate, then volatility will increase and bid–ask spreads will widen in the spot market for foreign exchange. Conversely, volatility will fall and bid–ask spreads narrow if the central bank's signal reduces uncertainty about the short-run variability about the target exchange rate. Analyzing individual bank price responses to interventions may therefore allow for a better understanding of the aggregate market response to intervention episodes.

The data set used in the article contain 0.56 million yen/dollar spot rate quotes distinguished by 125 banks in the inter-bank market for foreign exchange. The empirical analysis combines tick-by-tick spot rate data with time-stamped Reuters reports to examine the impact of central bank order on the quote behavior of individual banks. Since the database includes market survey expectations from the Reuters FXNB page, the model distinguishes between anticipated and unanticipated intervention. Time-stamped news items verify the timing of intervention events and the direction of the interventions.

The sample period covers the period between October 1, 1992 and September 30, 1993. During this period, there were 71 announcement dates when news of Bank of Japan (BOJ) and the Federal Reserve intervention activity in the yen/dollar market was reported by Reuters. Since the distribution of the bid–ask spreads is discrete, an ordered probit model in an event study framework is used to correlate intervention news to movements in the spread. The results are disaggregated by individual bank traders to study the price responses of the top bank traders in the yen/dollar market following central bank interventions. The top 20 banks account for over 65% of total quote activity in the yen/dollar market.

My main findings are as follows. First, aggregate market uncertainty increases following central bank trading activity.[4] The estimations show that central bank interventions lead to a statistically significant increase in spot rate volatility and wider bid–ask spreads in the spot market for foreign exchange. The results, using high-frequency data, are therefore consistent with Naranjo and Nirmalendran (2000) who document an increase in aggregate bid–ask spreads using daily data. In addition, the estimations provide marginal effects from the ordered probit model to evaluate the economic significance of shifts in the bid–ask spread distribution conditional on news of central bank intervention. The estimates show that if the probability of an intervention by the Federal Reserve increases by one standard deviation, the probability of observing a bid–ask spread of less than 10 basis points falls by 8.14% while the probability of observing a bid–ask spread greater than or equal to 10 basis points rises by 7.8%. Marginal effect estimates for increases in the volatility of the spot rate

4. See Fatum and Hutchinson (1999) who show that interventions significantly increase the conditional variance of the federal funds futures rate, suggesting an increase in the degree of uncertainty about the course of future monetary policy.

also result in an increase in bid–ask spreads. Extending the estimation procedure to account for an irregular quote arrival pattern reveals that spreads widen during periods of infrequent trading activity.

Second, individual bank estimates from the top 10 banks with the most quotes following the arrival of news about central bank activity show dispersion in the bid–ask spreads posted by individual banks. The results provide evidence that the aggregate market reaction of wider bid–ask spreads reflects the increase in bid–ask spreads posted by a subset of individual banks when central banks intervene. Marginal effects estimates show that the probability of bid–ask spreads increasing to the third-highest category of 10 basis points or higher increases significantly for Banca Commericale Italiana, Chemical Bank, and the Industrial BOJ when the Federal Reserve intervenes and Dai-Ichi Kangyo Bank, Dresdner Bank, and Morgan Guaranty when the BOJ intervenes. Notably, Tokai Bank and the Industrial Bank of Japan post narrower spreads when the BOJ intervenes. The posted spreads for some banks in the top 10 remain unaltered in response to central bank interventions. The aggregate market response—increased spot rate volatility and wider bid–ask spreads—therefore represents a cumulative reaction made up of the disaggregated responses from individual banks.

Comparing responses across BOJ and Federal Reserve interventions also suggests that there is cross-sectional variation in individual bank responses depending on which central bank intervenes. The finding is consistent with the fact that the lineup of banks in the top 10 changes depending on the identity of the intervening central bank. The cross-sectional dispersion in bid–ask spread revisions may point to differences in the magnitude of inventory problems faced by individual banks when a central bank intervenes.

The results in this article contribute to the evidence in studies that examine market microstructure effects of macro-announcements in general and central bank interventions in particular. For example, Ederington and Lee (1993) and Anderson et al. (2003) note that the arrival of public information induces abrupt price changes, and that the average price move is typically attained within minutes. Yet, volatility and trading volume tend to remain elevated for several hours. If agents have identical information sets and interpret news similarly, the protracted response pattern is hard to explain and provides an argument in favor of models with heterogeneously informed agents. Analyzing individual bank responses to the arrival of public news, such as interventions provides a step in this direction.

For example, Peiers (1997) identifies price leadership patterns in foreign exchange trading, with Bundesbank interventions as an informational trigger. Granger-causality regressions for a cross-section of individual-bank quotes suggest transitory price leadership by Deutsche Bank between 60 and 25 minutes before Bundesbank intervention reports. The results provide evidence of information asymmetries across individual bank participants in the foreign exchange market surrounding the release of intervention news.

Furthermore, price adjustments will eventually reflect information-based order flows (Kyle 1985). In this article, I examine bid–ask spread revisions posted by individual banks in response to intervention reports. Bid–ask spreads represent order processing, inventory, and adverse selection costs in the foreign exchange market. When a central bank intervenes, increases in posted bid–ask spreads provide information about increased asymmetric information risk, as well as inventory risk. The cross-sectional dispersion in the quotes posted supply disaggregated information about how different market participants respond to central bank intervention signals.

In addition, using intra-daily data, Dominguez (2003) and Chang and Taylor (1998) show that aggregate market volatility is higher on intervention days in comparison to days where the central bank does not enter the foreign exchange market. The evidence in this article confirms the finding that intervention days are accompanied by greater market volatility. Related papers that use intra-day data to study central bank interventions include Goodhart and Hesse (1993) who show that interventions have no short-term or systematic effect on returns in the foreign exchange market. Payne and Vitale (2003) use exchange rate data sampled at 15-minute intervals to quantify the effects of intervention operations on the U.S. dollar/Swiss franc (USD/CHF) rate.

Other studies that have examined bid–ask spreads in the foreign exchange market include Naranjo and Nirmalendran (2000) who use daily bid–ask spreads in the DM/dollar market to argue that uncertainty surrounding the unexpected component of central bank interventions may induce dealers to increase their spreads because of adverse selection considerations. The results in this article complement these findings using high-frequency data. Pasquariello (2005) provides a theoretical rationale for interventions to affect bid–ask spreads through their impact on dealers' inventories and shows that the aggregate market spreads for the USD/CHF increase during intervention event windows. This article takes the analysis one step further by examining bank-level quotes to disaggregate the responses of individual banks when a central bank intervention takes place. The disaggregated individual bank results bring a piece of evidence to bear on the existing literature by providing a look inside the "black box" of the aggregate market response to central bank intervention in the foreign exchange market.

The article proceeds as follows. Section 1 presents a brief theoretical motivation for asymmetric information frameworks where the central bank is the strategic "informed insider." Section 2 describes the data. Section 3 outlines the empirical methodology employed and discusses the results from the analysis. Section 4 presents additional tests and robustness checks. Section 5 concludes.

1. ASYMMETRIC INFORMATION, CENTRAL BANKS, AND INDIVIDUAL BANK TRADERS

Models with asymmetric information and heterogeneous agents from the market microstructure literature can be used to motivate the signaling explanation of central bank interventions. Microstructure models with a strategic informed insider (such as Bhattacharya and Weller 1997) assume that central banks are informed insiders since they have an informational advantage about spot rate fundamentals. In particular, these models assume that central banks have inside information about the course of future monetary policy. Further, central bank utility functions differ from standard profit maximizing agents since central banks can choose to make losses on their intervention operations by leaning against the wind. In doing so, central banks weigh the expected loss on currency transactions against their success in achieving targeting objectives or reducing exchange rate volatility. However, rational speculators (in our case individual banks) in the foreign exchange market also have private information with respect to central bank objectives. Therefore, a combination of asymmetric information and Bayesian learning can be used to model central bank interventions functioning as signals that communicate information about future monetary policy and the fundamentals process underlying the spot rate.

Specifically, microstructure models identify two conditions under which information may differ across participants in the foreign exchange market when the central bank intervenes (Kyle 1985, Bhattacharya and Speigel 1991). First, central banks and bank traders as a group can differ in their interpretation of the fundamentals. Second, individual traders' private signals about the fundamentals may differ across traders.[5] These two effects can lead to an increase in market uncertainty if the target spot rate implied by the intervention signal is not consistent with fundamentals.

A modified version of the timeline in Bhattacharya and Weller (1997) can be applied to the spot market for foreign exchange as follows:

Timeline of Intervention

$t = -2$ Speculators have a common prior about the fundamentals process. In addition, each speculator i has private information about the fundamentals process. Speculators also have a common prior associated with the prevailing exchange rate target level. The central bank has its own prior about the fundamentals. In order to explicitly model the central bank's superior information about the fundamentals, it is assumed that the central bank has control over monetary policy.

$t = -1$ Each speculator $i \in [0,1]$ observes a private signal about the fundamentals, and updates her prior about the fundamentals accordingly. In addition, the central bank chooses its desired target level.

$t = 0$ The central bank intervenes. Speculators update priors for a second time about the fundamentals and the central bank's target rate. If signal correlation across speculators about the fundamentals and the central bank's target is low, spot rate volatility increases with trading and bid–ask spreads widen.

$t = 1$ All uncertainty is resolved and the spot market clears.

5. Lyons (2001) discusses several channels through which private information could play an important role in the foreign exchange market. For example, since trading takes place in a decentralized setting where traders advertise their quotes on trading screens and strike deals over the phone, the information on order flow and transaction prices remains largely private.

The first-order condition for the optimal choice of this period's spot rate, P_0, in Bhattacharya and Weller (1997) is given by

$$P_0 = b_1 + b_2\tilde{\varepsilon}_p + b_3\tilde{\varepsilon}_T. \tag{1}$$

Here, $\tilde{\varepsilon}_p \cong N(0, \tau_p)$ is the speculators' common prior about the fundamentals, and $\tilde{\varepsilon}_T \cong N(0, \tau_T)$ is the speculators' common prior about the prevailing exchange rate target. Note that τ_p and τ_T are measures of precision, and the inverse of the precision, τ^{-1} is the variance.

The first-order condition for P_0 implies that the variance of the spot rate can be written as

$$\sigma^2_{P_0} = b_2^2\sigma^2_{\tilde{\varepsilon}_p} + b_3^2\sigma^2_{\tilde{\varepsilon}_T} + 2b_2b_3\sigma_{\tilde{\varepsilon}_p,\tilde{\varepsilon}_T}. \tag{2}$$

In equation (2), $\sigma_{\tilde{\varepsilon}_p}$ depends on τ_p, the prior precision of speculators about the fundamentals process, and $\sigma_{\tilde{\varepsilon}_T}$ depends on τ_T, the prior precision of speculators about the central bank's objective.

From equation (2), we can infer that the volatility of the spot exchange rate depends on both the speculators' priors about the volatility of the fundamentals and the variability of the target rate.[6] In this model, an increase in the dispersion across speculators in their prior beliefs about the fundamentals, as well as the central bank's target rate should increase spot rate volatility. Therefore, the variability of the spot rate can be directly related to individual bank traders' interpretations of the intervention signal. That is, if trader beliefs about the fundamentals are inconsistent with the intervention signal, spot rate volatility will increase after intervention episodes. Further, the link between the volatility of an asset and the spread on the asset suggests that increased volatility leads to adverse selection and greater inventory risk (Ho and Stoll 1983, Glosten and Milgrom 1985, Kyle 1985, Subrahmanyam 1991), and hence wider bid–ask spreads.

The model specification also has implications for the impact of expected rather than unexpected interventions on the bid–ask spread. Note that the volatility of the spot rate in equation (2) depends on the prior precision of the traders' signal about (i) the fundamentals and (ii) the central bank's target. Moreover, increases in spot rate volatility directly contribute to an increase in bid–ask spreads following interventions. Expected central bank intervention will lower the dispersion across traders' prior beliefs about the intervention signal and increase its prior precision, τ_T, and should not have an impact on bid–ask spreads (Naranjo and Nirmalendran 2000).

Also, the conditional variance of the spot rate is inversely proportional to the prior precision of traders' beliefs about the intervention signal. The lower the precision, the greater will be the dispersion across trader beliefs and the higher the volatility of the spot rate leading to wider bid–ask spreads following intervention. If interventions

6. The impact of the covariance term depends on the correlation coefficient between the distributions of the fundamentals and the target levels. If the fundamentals and the central bank's target are assumed to be independent, the covariance term drops out.

are unexpected, the model predicts that bid–ask spreads should be positively related to the conditional variance of the spot rate induced by intervention.

It is reasonable to assume that the mean of the current bid–ask spread is a function of the volatility in the previous period (Kyle 1985). The bid–ask spread in the current period depends on dealers' expectations of current volatility. However, if dealers do not know current volatility, they must form an estimate of it. This estimate of current volatility in turn can depend on past volatility if volatility is serially dependent. The relationship between past volatility and current bid–ask spreads implies that if past volatility increases, the expected value of the bid–ask spread will widen and the spread distribution will shift right. The relationship between intervention, volatility, and bid–ask spreads can be mapped to the data using an ordered probit model.

The reduced form equation that is estimated in the ordered probit analysis is

$$S_t^* = b_0 + b_1\hat{\sigma}_{m,t-1}^2 + b_2 Intervention_{t-1} + b_3 S_{t-1} + \varepsilon_{S,t}, \tag{3}$$

$$\sigma_{S_t^*} = \exp\left(\gamma_1\hat{\sigma}_{m,t-1}^2 + \gamma_2 Intervention_{t-1} + \gamma_3 S_{t-1}\right), \tag{4}$$

where S_t^* is the current bid–ask spread, $Intervention_{t-1}$ is the central bank intervention dummy, S_{t-1} is the lagged spread and $\hat{\sigma}_{m,t-1}^2$ is the past volatility measure. Note, from the above discussion that expected intervention should not impact volatility or spreads in spot market for foreign exchange.

2. THE DATA

2.1 High-Frequency Real-Time Yen/Dollar Spot Rate Quotations

The data set consists of all yen/dollar quotes appearing on the Reuters screen between October 1, 1992 and September 30, 1993. During this period, 567,718 quotes were posted on the screen by approximately 125 banks. Each observation lists the time of day when the quote was posted, the Reuters code for the name of the bank making the quote, the city where the bank is located, and the bid–ask prices. To illustrate the information available, consider the following five consecutive quotes for June 23, 1993:

Five Consecutive Yen/Dollar Spot Rate Quotes: An Example

No.	Time	Bank	City	Bid–ask Quotes
1.	7:50:04	Chemical Bank	London	110.28/110.38
2.	7:50:10	Dresdner Bank	Frankfurt	110.35/110.40
3.	7:50:22	Lloyds Bank	London	110.35/110.39
4.	7:50:38	Citibank	Tokyo	110.40/110.45
5.	7:51:04	Tokai Bank	Tokyo	110.38/110.45

TABLE 1

Summary Statistics: Intervention Announcements

	Bank of Japan	Federal Reserve	Joint Interventions
Panel A. Intervention announcements(Reuters AAMM News Screen)			
Total	150	32	49
Mean	2.3	6.4	9.8
Median	2	6	12
Minimum	1	3	4
Maximum	7	11	14
Total dates	65	6	6
Panel B. Official intervention amounts ($ million)			
Total	$23,423	$1,431	$4,474
Average (per day)	$478	$286	$895
Median	$439	$200	$1,082
Minimum	$47	$165	$321
Maximum	$1,837	$492	$1,241
Official dates	50	5	5

Note: This table summarizes intervention announcements by the Bank of Japan and the Federal Reserve between January 01, 1992 and September 30, 1993. Panel A presents the frequency of unilateral and joint announcements by the two central banks from the Reuters AAMM news screens. Panel B presents summary statistics for the official intervention amounts. The official intervention data are obtained from <http://www.mof.go.jp/english/e1c021.htm> and <http://www.treas.gov/offices/international-affairs/esf/ history/Intervention93-00. shtml>.

The time of day is Greenwich Mean Time; for the first observation it is 7:50:04. That is 7:50 a.m. and 4 seconds, while the second observation is just 6 seconds later at 7:50:10. The second column represents the bank making the quote and the third column maps the corresponding location of the quoting bank, since the major banks participating in the foreign exchange market have branches all over the world. The final column provides the bid–ask prices. In short, at 7:50:04 a.m., Chemical Bank in London was willing to buy yen at 110.38 per dollar, and sell yen at 110.28 per dollar. For the five observations listed above, the absolute spreads are 10, 5, 4, 5, and 7 basis points, respectively.[7]

Table 1 provides summary statistics for the intervention reports that appeared on the Reuters' screen. The table shows that news of BOJ interventions in the yen/dollar market appeared on 65 dates between January 10, 1992 and September 30, 1993, while reports of interventions by the Federal Reserve appeared on six dates during the same period (Panel A). In addition, the BOJ intervened in the market on all six dates when the Federal Reserve was seen in the market.[8] Panel B of Table 1 presents summary statistics for the official data released by the BOJ and the Federal Reserve about intervention activity in the yen/dollar market over the sample period. The data

7. Bollerslev and Melvin (1994) document a similar pattern for bid–ask spread quotations in the DM/dollar market.

8. A complete list of time-stamped news reports that appeared on the Reuters' screen is available on my personal website <http://sitemaker.umich.edu/anusha.chari>.

show that interventions by the BOJ are much larger in magnitude than Federal Reserve interventions.[9] The direction of intervention remained the same over the entire sample period—the U.S. dollar was bought and the yen was sold in every instance.

2.2 *Quote Activity and Bid–Ask Spreads for Individual Banks*

Bank and location information allow for a disaggregated analysis of major market-makers around intervention announcements. Table 2 (Panel A) lists the top 20 banks that posted the highest number of quotes in the yen/dollar market along with head-quarter locations. The table shows that there is substantial cross-sectional variation in the geographic locations of the most active players in the yen/dollar market. Banks posting quotes are located in Canada, Germany, Italy, Japan, Switzerland, the United Kingdom, and the United States.

Panel A of Table 2 also shows that the top 20 banks account for 65% of total quote activity in the yen/dollar market. Examining the frequency of quote activity around intervention announcements by the BOJ and the Federal Reserve reveals that the top 20 banks account for 60% and 71% of total quotes posted around intervention windows and dates. It is striking to note that the top 10 banks account for 48% and 55% of total quotes posted on BOJ and Federal Reserve intervention dates. Chemical Bank is seen as the leading market-maker on Federal Reserve intervention dates while Credit Suisse accounts for the highest number of quotes on BOJ intervention dates. Note also that the lineup of the banks with the highest quotes changes depending on whether the Federal Reserve or the BOJ intervenes. The top five banks around Federal Reserve interventions are Chemical Bank, Banca Commerciale Italiana, Citibank, Dresdner Bank, and Swiss Bank Corporation. The corresponding list for BOJ interventions is Credit Suisse, Morgan Guaranty, Amsterdam–Rotterdam Bank, Chemical Bank, and Dai-Ichi Kangyo Bank.

Panel B of Table 2 presents summary statistics for bid–ask spreads posted by the top 20 quoting banks in the yen/dollar market. Once again, there is substantial cross-sectional variation in the mean values and standard deviations in spread values across individual banks. The mean bid–ask spreads for 15 of the top 20 banks are wider on intervention dates compared to the full sample of quotes. A paired equality of means t-test shows that bid–ask spreads on intervention dates are higher and statistically significant at the 5% level.

Table 3 presents the distribution of quotes by location in the yen/dollar market. The largest volume of quotes comes from the United Kingdom followed by Japan, the United States, and Switzerland. The geographic location of quote activity also varies depending on whether the BOJ or the Federal Reserve intervenes. Japan followed by Singapore, Hong Kong, Switzerland, and the United Kingdom account for the greatest frequency of quote activity when the BOJ intervenes. The number of quotes posted

9. A breakdown of daily intervention amounts and the direction of the interventions are also available on my website.

TABLE 2

THERE IS CROSS-SECTIONAL VARIATION IN QUOTE ACTIVITY BY INDIVIDUAL BANKS IN THE YEN/DOLLAR MARKET

Panel A

	Headquarter location		Quote percentage					
Bank name	Country	City	Rank (total quotes)	Full sample	Bank of Japan intervention windows	Federal Reserve intervention windows	BOJ+FED	Non-intervention sample
Chemical Bank	United Kingdom	London	1	8.2	4.83	12.34	5.62	8.75
Credit Suisse	Switzerland	Zurich	2	7.53	9.9	3.32	9.21	5.46
Industrial Bank of Japan	Japan	Tokyo	3	4.27	3.8	2.94	3.71	5.19
Morgan Guaranty	United States	New York	4	4.12	6.34	3.66	6.06	4.1
Citibank	United States	New York	5	3.68	3.78	6.37	4.06	3.56
Dresdner Bank	Germany	Frankfurt	6	3.56	2.01	4.37	2.26	2.92
Swiss Bank Corporation	Switzerland	Basle	7	2.87	2.77	3.96	2.9	3.29
Bankers Trust Company	United States	New York	8	2.8	0.13	0	0.11	2.2
Chase Manhattan Bank	United States	New York	9	2.72	0.42	2.3	0.62	4.11
Dai-Ichi Kangyo Bank	Japan	Tokyo	10	2.6	4.04	2.88	3.92	2.35
Royal Bank of Canada	Canada	Montreal	11	2.59	1.71	3.11	1.86	3.99
Union Bank of Switzerland	Switzerland	Zurich	12	2.59	2.85	3.56	2.92	2.47
Sumitomo Bank	Japan	Tokyo	13	2.55	1.62	1.64	1.62	2.46
Royal Bank of Scotland	United Kingdom	Edinburgh	14	2.53	0.6	2.77	0.82	2.72
Amsterdam–Rotterdam Bank	Netherlands	Amsterdam	15	2.35	5.48	0.9	5	1.42
Fuji Bank	Japan	Tokyo	16	2.34	1.99	1.43	1.93	2.96
Bank of America	United States	Charlotte, NC	17	2.2	2.38	0.96	2.23	1.6
Banca Commerciale Italiana	Italy	Milan	18	2.19	0.68	10.65	1.73	0.97
Bank of New York	United States	New York	19	2.08	3.96	0.7	3.61	1.53
Canadian Imperial Bank of Commerce	Canada	Toronto	20	2.03	0.39	3.13	0.68	3.17
Tokai Bank	Japan	Tokyo	21	1.72	5.44	3.75	5.26	0.57
Total (quote %)				67.52	65.12	74.74	66.13	65.79
Total (quotes #)				0.56 million	46,936	5,390	14,567	12,072

NOTE: This table lists the top 20 banks posting the highest number of quotes in the yen/dollar market during October 1, 1992 to September 30, 1993 along with headquarter locations. The table provides the rank by the total number of quotes for each bank in the full sample. Quote percentage figures are presented for the full sample of quotes, Bank of Japan and Federal Reserve intervention windows that begin 120 minutes before the time-stamped intervention event and end 120 minutes after the event. Finally, the table presents the fraction of quotes by bank for a sample of 25 non-intervention dates.

TABLE 2

THERE IS CROSS-SECTIONAL VARIATION IN BID–ASK SPREADS POSTED BY INDIVIDUAL BANKS IN THE YEN/DOLLAR MARKET

Panel B

	Bid–ask spreads					
	Full sample of quotes					
Bank name	Mean	Standard deviation	Bank of Japan intervention windows Mean	Federal Reserve intervention windows Mean	BOJ+FED Mean	Non-intervention sample Mean
Chemical Bank	5.82	2.08	7.63	6.1	7.28	1.55
Credit Suisse	10	0.61	9.97	10	9.97	0.48
Industrial Bank of Japan	6.82	2.43	8.62	5.95	8.39	2.43
Morgan Guaranty	9.59	1.57	9.94	10.36	9.96	1.41
Citibank	9.06	1.98	7.65	9.76	8	1.4
Dresdner Bank	7.98	2.54	8.43	8.97	8.54	2.2
Swiss Bank Corporation	9.28	1.77	8.93	9.71	9.05	2.16
Bankers Trust Company	5.4	1.84	7.78	0	7.78	0.9
Chase Manhattan Bank	8.91	2.13	9.34	8.39	8.97	1.82
Dai-Ichi Kangyo Bank	6.7	2.59	7.06	5.78	6.96	2.38
Royal Bank of Canada	8.37	2.9	8.11	10.12	8.46	2.96
Union Bank of Switzerland	9.44	1.62	8.81	9.56	8.91	0.83
Sumitomo Bank	5.91	2.33	7.71	6.78	7.61	2.5
Royal Bank of Scotland	5.12	2.7	5.41	5.71	5.52	0.34
Amsterdam–Rotterdam Bank	7.87	2.59	7.96	7.23	7.94	2.37
Fuji Bank	5.45	1.47	6.63	5.99	6.58	1.38
Bank of America	7.81	2.73	6.56	9.65	6.7	2.48
Banca Commerciale Italiana	7.61	2.51	8.8	8.64	8.7	2.55
Bank of New York	5.23	2.25	5.4	5.73	5.41	1.9
Canadian Imperial Bank of Commerce	8.92	1.59	9.51	9.48	9.49	1.64

NOTE: This table presents summary statistics for the bid–ask spreads for the top 20 banks posting the highest number of quotes in the yen/dollar market during October 1, 1992 to September 30, 1993 along with headquarter locations. Mean values for bid–ask spreads are presented for the full sample of quotes, Bank of Japan and Federal Reserve intervention windows that begin 120 minutes before the time-stamped intervention event and end 120 minutes after the event. Finally, the table presents mean bid–ask spreads by bank for a sample of 25 non-intervention dates.

TABLE 3

THERE IS CROSS-SECTIONAL VARIATION IN QUOTE ACTIVITY BY COUNTRY IN THE YEN/DOLLAR MARKET

Country	Rank (total quotes)	Full sample	Bank of Japan intervention windows	Federal Reserve intervention windows	BOJ+FED	Non-intervention sample
United Kingdom	1	25.21	7.85	30.52	10.37	23.89
Japan	2	15.34	31.24	4.83	28.48	15.37
United States	3	12.6	2.39	34.91	5.19	11.38
Switzerland	4	11.52	12.08	10.04	12.06	12.3
Singapore	5	10.81	24.67	4.6	22.62	11.23
Australia	6	8.79	5.26	0.41	5	8.42
Hong Kong	7	6.67	13.06	2.17	11.99	7.59
Canada	8	4.74	1.21	8.23	1.8	5.44
Germany	9	2.33	1.15	3.43	1.42	2.12
Belgium	10	0.71	0.47	0.19	0.43	0.78
Norway	11	0.68	0.32	0.46	0.35	0.67
Bahrain	12	0.35	0.2	0.02	0.2	0.47
Ireland	13	0.19	0.06	0.15	0.06	0.26
France	14	0.02	0	0	0	0.05
Netherlands	15	0.02	0.02	0	0.02	0
Saudi Arabia	16	0.02	0.01	0.04	0.01	0.02
Austria	17	0.01	0	0	0	0
United Arab Emirates	18	0.01	0	0	0	0.01

NOTE: This table lists the number of quotes posted by country in the yen/dollar market during October 1, 1992 to September 30, 1993. The table provides the rank by the total number of quotes for each country in the full sample. Quote percentage figures are presented for the full sample of quotes, Bank of Japan and Federal Reserve intervention windows that begin 120 minutes before the time-stamped intervention event and end 120 minutes after the event. Finally, the table presents the fraction of quotes by country for a sample of 25 non-intervention dates.

is the highest in the United States when the Federal Reserve intervenes followed by the United Kingdom, Switzerland, Canada, and Japan. A possible explanation for the geographic variation in quote activity around intervention announcements may be that trading hours vary by location so that a higher number of quotes are posted in Japan and Europe when the BOJ intervenes, while North America and Europe account for a bulk of the quote activity when the Federal Reserve enters the market. With the exception of Japan, the mean value of bid–ask spreads is higher for the top five quote locations (countries) when the Federal Reserve intervenes. Similarly, when the BOJ intervenes, mean values of spreads increase in the top five locations except Hong Kong.

2.3 Event Windows

News about central bank interventions was collected from the Reuters AAMM headline news screen. An electronic search was conducted for all reports of BOJ and Federal Reserve Bank (FED) interventions over the 1-year sample period. Each Reuters report consists of a date and time stamp to the nearest second the announcement was made, allowing precise matching with the spot exchange rate data.

Subsamples of the spot rate data around intervention reports are constructed using the following logic. Goodhart and Hesse (1993) claim that the time lag between an intervention and the report on the Reuters news screen is approximately 15–30 minutes. Conversations with traders suggest a lag of, at most, 10–15 minutes (Peiers 1997). The estimations trace intervention activity up to 60 minutes before the time stamp associated with the Reuters announcement. The data subsamples begin at 120 minutes prior to the announcements to distinguish between intervention and non-intervention data dynamics.

Since financial markets react quickly to new information,[10] most foreign exchange intervention effects should die out 120 minutes following an intervention report. Thus, the subsample time windows extend from −120 to +120 minutes surrounding the time-stamped Reuters announcements. Note that a variety of window sizes were tested to arrive at this estimate, which represents a length of time long enough for traders to observe and respond to a news announcement and short enough so other news does not contaminate the results. Based on these criteria, 65 BOJ and six Federal Reserve intervention announcement dates, reported by Reuters over the January 1, 1992 to September 30, 1993 time period, are selected as relevant event dates for this article. The data also suggest that multiple intervention announcements within a given day are not uncommon. Intervention windows in these cases begin 2 hours prior to the first intervention and end 2 hours after the last reported intervention of the day.

Note that although the entire data set contains 0.56 million quote observations, the intervention episodes studied in this article are highly clustered and irregular. Neely (2005) argues that the difficulties of applying traditional structural econometric techniques—simultaneity, identification, and the clustered distribution of central bank interventions—have all contributed to the use of event studies as an econometric method of choice to study the impact of central bank interventions. The event study methodology used in the article allows us to consider a cluster of interventions as one event and use a semi-non-parametric method, such as the ordered probit to evaluate the impact of intervention events on quote behavior. However, a caveat to bear in mind is that the accuracy of the timing of intervention events is vital for drawing reliable inferences from an event study. Furthermore, the event study methodology cannot evaluate the dynamic impact of interventions if it takes a few days for the market to fully adjust to an intervention episode. Nonetheless, high-frequency data are valuable for understanding the immediate impact of interventions. In this paper, we are interested in understanding whether central bank interventions create or resolve uncertainty in their immediate aftermath by examining bid–ask spreads posted by individual banks.

2.4 Frequency Distribution of the Spread

The article finds that the distribution of bid–ask spreads in the spot market for foreign exchange market is not continuous. Indeed, the values of 3, 4, 5, 7, 10, and 11 basis points account for 98.53% of the data, suggesting that the bid–ask quote pairs exhibit only a few discrete values. This characteristic of the quotes is evident from

10. Edison (1993) claims that intervention effects on the exchange rate are short lived.

TABLE 4

THE FREQUENCY DISTRIBUTION OF ABSOLUTE BID–ASK SPREADS IN THE YEN/DOLLAR MARKET

Absolute spread	Full sample	Bank of Japan intervention windows	Federal Reserve intervention windows	BOJ + FED	Non-intervention sample
0 <= x <= 5	3.64	3.88	0.8	3.56	4.36
x = 5	40.88	30.75	36.56	31.08	39.58
5 < x < 10	6.46	4.74	5.42	4.74	6.44
x = 10	48.16	59.58	56.16	59.49	48.83
10 < x < 15	0.49	0.39	0.02	0.35	0.51
15 < x < 20	0.19	0.34	0.63	0.43	0.19
20 < x < 30	0.15	0.26	0.35	0.29	0.09
30 < x < 40	0.02	0.05	0.06	0.05	0
x >= 40	0.01	0.01	0	0.01	0.01

Summary statistics for absolute Bid–ask spreads

Absolute bid ask spread (b.p.)	Full sample	Bank of Japan intervention windows	Federal Reserve intervention windows	BOJ + FED	Non-intervention sample
Mean	7.56	8.13	8.04	8.14	7.57
Median	7	10	10	10	8
Standard deviation	2.685	2.661	2.62	2.667	2.668
N	567,698	46,936	5,386	52,595	18,181

NOTE: This table presents the frequency distribution of absolute bid–ask spreads in the yen/dollar Market. “x” represents the absolute value of the bid–ask spread. The table presents the frequency distribution for the full sample, Bank of Japan, and Federal Reserve intervention windows and for a sample of non-intervention windows. Summary statistics are presented in the bottom panel of the table.

the frequency distribution presented in Table 4, which lists the frequency distribution for the complete set of quotes.[11]

Table 4 also presents preliminary evidence of a shift in the distribution of bid–ask spreads during intervention periods. Note from the first column of Table 4 that the probability of observing an absolute value for the bid–ask spread equal to or above 10 basis points is 49% for the full sample of quotes. Similarly, from the last column of Table 4, the probability of observing a bid–ask spread value equal to or above 10 basis points is also about 49% for a sample of non-intervention days. However, during BOJ and Federal Reserve intervention windows, the probability of observing a spread value equal to 10 basis points or more rises by a full 10 percentage points to 60%. A first look at the data suggests that the bid–ask spread distribution shifts to the right or bid–ask spreads widen during central bank intervention windows. The empirical analysis will test this hypothesis formally.

In the data set, the spreads in the yen/dollar market display a bi-modal distribution with peaks at 5 and 10 basis points. In the entire data set, 273,409 observations accounting for 48.2% of the data and 232,082 observations accounting for 40.9%

11. The raw spreads are converted into basis points by multiplying them by 10,000.

of the observations take values of 10 and 5, respectively. This is almost exactly the same proportion for the individual bank quotes. The lack of continuity suggests that continuous state space processes will not represent the spread data accurately. Addressing the issue of discreteness in U.S. stock market data, Hausman, Lo, and Mackinlay (1992) suggest an ordered probit model in their analysis of continuously recorded transaction price changes.[12]

2.5 GARCH(1,1) Volatility Estimation

Serial dependence in price change can cause a dispersion of beliefs across individual traders (Shalen 1993). When new information arrives in financial markets, different prior beliefs about the news can create incentives to trade—leading to price changes. As traders observe price changes, they may revise their prior beliefs that can lead to continued trading and further price changes. If it takes time for the market to resolve heterogeneous beliefs across traders about new information that reaches the foreign exchange market, the search for the equilibrium price can lead to volatility clustering around the arrival of news of an intervention.

Investigating the link between the bid–ask spread and exchange rate uncertainty associated with news about a central bank intervention therefore requires an estimate for time-varying spot rate volatility that can take into account persistence in volatility around the release of new information. An extensive literature demonstrates that the generalized autoregressive conditional heteroskedasticity (GARCH) procedure may be used to describe the asset price volatility process including exchange rates.[13] The GARCH(1,1) model is routinely found to provide accurate approximations to daily asset return volatility dynamics (Bollerslev and Melvin 1994, Anderson, Bollerslev, Diebold, and Vega 2003). This article employs a standard two-stage estimation procedure in which the conditional variance for the spot exchange rate is first estimated as a GARCH process. The estimated volatility series is then used as a proxy for exchange rate volatility in the second-stage ordered probit model to analyze variations in the spread behavior around intervention announcement windows.

The problem of simultaneity has been raised frequently in the context of measuring the effectiveness of interventions. Since interventions may not be exogenous to current market conditions, an empirical analysis may yield inconsistent and biased estimates. However, Goodhart and Hesse (1993) suggest that there is at least a 2-day lag between the time that spot rates become excessively volatile or deviate from target levels and the time that central banks intervene. This observation is especially true of studies that use high-frequency data. The intra-day frequency of the data offers the advantage that simultaneity can be avoided under two assumptions: (i) the timing

12. Hausman, Lo, and MacKinlay (1992) do not include contemporaneous trading volume in their model of tick-by-tick stock price movement for simultaneity reasons. In the case of the foreign exchange market, only indicative quotes for foreign exchange are available in the public domain, while volume data, although collected by the Reuters 2000–2 matching system, is limited in coverage.

13. For a survey of GARCH modeling in financial environments, see Bollerslev, Chou, and Kroner (1992).

of intervention is measured precisely enough, and (ii) the decision interval of the monetary authority is less than the data frequency used (Neely 2005). Under these assumptions, there is no contemporaneous impact of exchange rates on intervention and no simultaneity: changes after the intervention are the result of the intervention and not vice versa. For example, this article examines spot rate behavior during a 2- to 3-hour window around the time the intervention is reported.

To explore the effectiveness of interventions, the paper uses the first difference of the logarithm of the mid-price (DLMID) of the spot rate for estimation purposes. The log of the mid-price (LMID) is calculated as follows:

$$\text{LMID} = \log\left(\frac{\text{BID} + \text{ASK}}{2}\right). \tag{5}$$

Furthermore, an MA (1)-GARCH (1,1) specification found to fit the data takes the form:

$$\begin{aligned} \text{DLMID}_t &= \mu + \theta\varepsilon_{m,t-1\_} + \varepsilon_{m,t} \\ \sigma^2_{m,t} &= \omega + \alpha\varepsilon^2_{m,t-1} + \beta\sigma^2_{m,t-1} \\ \varepsilon_{m,t\_}|I_{t-1} &\sim N\left(0, \sigma^2_t\right), \end{aligned} \tag{6}$$

where I_{t-1} denotes the $t-1$ information set, DLMID is the first difference of the log of the mid-price, and μ, θ, ω, α, β are the estimated parameters. For a more complete description of the quasi-maximum likelihood estimation procedure employed, see Bollerslev et al. (1992). The time t subscript refers to the place in the order of the series of quotes, and provides an estimate of the price volatility between quotes.

Panel A of Table 5 reports the maximum likelihood estimates from the GARCH model outlined above for all quotes contained in the sub-sample windows (-120 to $+120$ minutes) surrounding Federal Reserve intervention announcements. In order to avoid discontinuities between different subsamples, the estimation is conducted separately for each subsample date. Examining the estimates in the table reveals that the results are extremely robust across the different subsamples (different rows). Specifically, the GARCH effect is positive and highly significant at the 1% level, and the coefficient estimates are quite similar across all subsamples in size, sign, and significance. Standard diagnostic tests show that this relatively straightforward procedure effectively traces the time-varying dependencies in the conditional mean of the continuously recorded spot exchange rate (Bollerslev, Chou, and Kroner 1992). The same exercise was conducted for BOJ intervention announcements and yields a similar pattern of coefficient estimates. In the interest of brevity, results for all 65 sample dates are not reported here.[14] Instead, Panel B reports GARCH parameter estimates for BOJ interventions on the six dates when the Federal Reserve was reported

14. Details are available from the author.

TABLE 5

TIME VARYING VOLATILITY ESTIMATES: GARCH (1,1)-MA(1) MODEL

Panel A: Federal Reserve interventions

Date	μ	θ	ω	α	β	N
19930427	0.13	−0.45	6.24	0.21	0.54	955
19930527	−0.07	−0.29	1.22	0.07	0.87	1,024
19930528	0.02	−0.55	2.75	0.07	0.61	716
19930528	0.02	−0.46	5.14	0.13	0.63	696
19930601	0.06	−0.46	10.98	0.09	0.00	521
19930608	−0.08	−0.50	2.29	0.12	0.65	557
19930819	0.47	−0.29	3.53	0.17	0.76	927

Panel B: Bank of Japan interventions

Date	μ	θ	ω	α	β	N
19930427_01	−0.06	−0.57	2.72	0.17	0.47	630
19930527_01	−0.06	−0.57	0.59	0.12	0.83	1,246
19930527_02	−0.05	−0.29	1.23	0.06	0.86	389
19930527_03	0.10	−0.29	10.93	0.23	0.30	192
19930528_01	0.00	−0.55	3.88	0.09	0.45	1,158
19930528_02	0.10	−0.53	3.10	0.13	0.56	290
19930528_03	0.02	−0.48	2.99	0.12	0.64	1,426
19930528_04	−0.01	−0.46	4.16	0.17	0.64	546
19930601_01	−0.15	−0.61	2.93	0.20	0.53	366
19930601_02	0.04	−0.52	3.72	0.12	0.52	234
19930608_01	−0.05	−0.65	0.46	0.07	0.89	1,297
19930608_02	0.01	−0.51	1.87	0.13	0.72	321
19930819_01	0.06	−0.53	3.21	0.20	0.56	1,542
19930819_02	0.57	−0.34	2.62	0.18	0.78	343

Panel C: Summary statistics (averages)

Windows	μ	θ	ω	α	β	N
Non-intervention	0.00	−0.55	3.09	0.17	0.48	509
Bank of Japan	0.00	−0.53	3.26	0.14	0.54	758
Federal Reserve	0.08	−0.43	4.59	0.12	0.58	771

NOTE: This table reports the maximum likelihood estimates from the GARCH model (MA(1)-GARCH(1,1)) for all quotes contained in the subsample windows (−120 to +120 minutes) surrounding intervention announcements. Panel A reports estimates for individual Federal Reserve interventions reported on Reuters. Panel B reports estimates for individual Bank of Japan interventions that took place on the same days as the Fed interventions. Panel C reports summary statistics for Federal Reserve, Bank of Japan interventions, and a sample of non-intervention windows. The model takes the form:

$$\mathrm{DLMID}_t = \mu + \theta\varepsilon_{m,t-1\_} + \varepsilon_{m,t}$$
$$\sigma^2_{m,t} = \omega + \alpha\varepsilon^2_{m,t-1} + \beta\sigma^2_{m,t-1}$$
$$\varepsilon_{m,t\_}|I_{t-1} \sim N(0, \sigma^2_t).$$

to be intervening in the yen/dollar market on Reuters' screens. It becomes clear from Panel B that the BOJ also intervened on all six dates.

Panel C presents summary statistics (averages) for the GARCH parameters for separate sub-samples of Federal Reserve and BOJ intervention dates. In addition, average GARCH estimates for a sample of non-intervention dates are included. A t-test of means shows that the GARCH estimates across BOJ and Federal Reserve intervention dates are not significantly different. However, intervention dates display elevated levels of GARCH volatility in comparison to non-intervention dates.

3. ORDERED PROBIT ANALYSIS

The following testable implications emerge from the theoretical predictions in Section 1. First, greater uncertainty surrounding central bank interventions should lead to increased equilibrium spot rate volatility. Second, interpretations of the fundamentals and the intervention signal may differ across individual banks in the foreign exchange market. These differences in interpretation could result in greater spot rate volatility and bid–ask spreads following a central bank intervention. Several theories suggest that bid–ask spreads exist because of order processing costs, inventory costs, adverse selection, and specialist market power.[15] The empirical investigation in this section tests the hypothesis that agents widen bid–ask spreads to manage asymmetric information and inventory control risks when faced with increased spot rate volatility following intervention activity.

A stochastic model for prices is essential for examining spreads for several reasons. First, the costs and benefits of specific microstructure features, such as margin requirements, the degree of competition faced by dealers, the frequency with which orders are cleared, and intra-day volatility depend closely on price dynamics. Second, the timing of transactions prices tends to be irregular and random. Therefore, modeling such prices with discrete time processes may omit the information contained in waiting times between trades. Third, what is of economic interest is the conditional distribution of price changes—conditioned on the arrival of news, the time between trades, and the sequence of past price changes. For these reasons, ordered probit is the most appropriate specification to take account of both price discreteness and irregular trade times (Hausman, Lo, and MacKinlay 1992).

3.1 The Ordered Probit Model

Similar to Bollerslev and Melvin (1994), the following ordered probit methodology is employed in subsequent estimations.[16] As noted earlier, the observed spread, S_t, assumes only a fixed number of discrete values, $a_1, a_2, \ldots, a_N$. The unobservable continuous random variable, S_t^*, is given by:

$$S_t^* = \beta_0 + \beta' \mathrm{X}_t + \varepsilon_{S,t}. \tag{7}$$

The vector X_t represents the set of independent variables from our model that are hypothesized to have an effect on the conditional mean of S_t^*, and $\varepsilon_{S,t}$ has a conditional, normal distribution with a mean of zero and variance, $\sigma_{S,t}^2$:

$$\varepsilon_{S,t} \mid I_{t-1} \sim N\left(0, \sigma_{S,t}^2\right). \tag{8}$$

15. See Huang and Stoll (1997) and Glosten and Harris (1988) for examples.

16. See Maddala (1983) for a more thorough review of the ordered probit model.

Furthermore in this model, the logarithm of $\sigma^2_{S,t}$ is a linear function of the same explanatory variables that enter the conditional mean of S^*_t, to allow for conditional heteroskedasticity in the spread. This parameterization yields the following form for the multiplicative heteroskedasticity correction:

$$\sigma^2_{S,t} = \left[\exp(\delta' \mathrm{X}_t)\right]^2. \tag{9}$$

The ordered probit model relates the observed spreads to S^*_t via $S_t = a_N$, where all a_Ns form an ordered partition of the real line into N disjoint intervals.[17] The probabilities that enter the log-likelihood function for the maximum likelihood estimation are represented by $\mathrm{Prob}[y_i = j] = \mathrm{Prob}[y^*_i]$, which is in the jth range.

This means that:

$$\begin{aligned}
\mathrm{Prob}[y^*_i] &= \beta' X_i + \varepsilon_i \\
\varepsilon_i &\sim N[0, 1] \\
Y_i &= 0 \text{ if } Y^*_i \leq \mu_0 \\
&1 \text{ if } \mu_0 < Y^*_i \leq \mu_1 \\
&2 \text{ if } \mu_1 < Y^*_i \leq \mu_2 \\
&\quad \ldots \\
&\quad \ldots \\
&J \text{ if } Y^*_i > \mu_{J-1}.
\end{aligned} \tag{10}$$

In this model, the probability that the spread takes on the value a_N is equal to the probability that S^*_t falls into the appropriate partition, a_N. For the purpose of tractability, the empirical analysis limits the classification of the spread into four categories. From the discussion in Subsection 2.4, the six most common spreads account for 98.5% of the total number of quotes. In this categorization, the group a_1 contains spreads less than or equal to the five basis points, a_2 contains spreads greater than five but less than 10, a_3 represents the value of 10 basis points, and a_4 contains spreads greater than 10 basis points.[18] The corresponding intervals for the unobservable latent variable S^*_t are given by

$$\begin{aligned}
a_1 &=]-\infty, \mu_0] \\
a_2 &=]\mu_0, \mu_1] \\
a_3 &=]\mu_1, \mu_2] \\
a_4 &=]\mu_2, +\infty].
\end{aligned} \tag{11}$$

17. Since the μs are free parameters, the unit distance between the set of observed values of y merely provide a ranking. See Greene (1993) for a complete exposition.

18. Bollerslev and Melvin (1994) adopt a similar parameterization.

The partition parameters, μ_I, are estimated jointly with the other parameters of the model. Note that, the ordered probit model described by the above equations allows for the estimation of the probability of a particular spread being observed as a function of the independent variables X_t. To test whether the spread is affected by central bank intervention news, controlling for spot rate volatility, the model includes an intervention dummy, $INTERVENTION_t$ and the GARCH estimates of the conditional variance of the logarithm of the spot price, $\hat{\sigma}^2_{S,t}$. Given the partition boundaries determined by the data, the article examines whether a higher conditional mean $B'X_t$ for the spread is caused by an intervention announcement, while controlling for the conditional variance of the spot rate. If so, interventions are accompanied by greater adverse selection and asymmetric information and inventory risk, as displayed by a higher conditional mean for the underlying bid–ask spreads.

$$\begin{aligned} S^*_t &= \beta_0 + \beta_1 * \hat{\sigma}^2_{S,t-1} + \beta_2 * INTERVENTION_{t-1} + \beta_3 * S_{t-1} + \varepsilon_{S,t} \\ \sigma_{S,t} &= \exp\left(\gamma_1 * \hat{\sigma}^2_{S,t-1} + \gamma_2 * INTERVENTION_{t-1} + \gamma_3 * S_{t-1}\right). \end{aligned} \tag{12}$$

In the above equations, the intervention dummy, $INTERVENTION_t$ takes a value of negative one for the time prior to an intervention announcement within each subsample, a value of zero for the time closest to the time when the announcement appears on the Reuters news screen and a value of plus one for subsample data points following the news arrival. S_{t-1} takes into account the impact of a one-period lagged spread on the subsequent spread. In addition to the parameters specified in the ordered probit specification above, the model also includes threshold parameter estimates, μ_1 and μ_2. Following standard practice, the value of μ_0 is normalized to zero.

3.2 Aggregate Estimates for Intervention Windows

Maximum likelihood estimates of the ordered probit model for the pooled subsamples surrounding Federal Reserve and BOJ intervention announcements are presented in Table 6. The coefficient on the intervention dummy variable, β_2, in the benchmark specification suggests that intervention announcements can widen the bid–ask spread, implying that traders perceive greater uncertainty and inventory risk when the central bank enters the market (columns 1–2). The results lend support to the testable hypotheses that emerge from the theoretical predictions in Section 1. The estimate for β_3, the lagged spread variable, indicates strong intra-day persistence in the spread process; if the current quoted spread is large, the following spread also tends to be large. The γ_1 and γ_2 coefficients highlight the importance of heteroskedasticity in the spread equation. Both the conditional variance of the exchange rate and the lagged spread have a positive influence on $\sigma^2_{S,t}$. In addition, the boundaries for partitioning the data, μ_1 and μ_2, are estimated with a high degree of precision, as seen by the low standard errors.

Since the actual magnitudes of the ordered probit coefficients in Table 6 are not easily interpreted, marginal effects are estimated to examine the economic significance of the results. To capture shifts in the probability distribution of the spread about different

TABLE 6

ORDERED PROBIT ESTIMATES-BANK OF JAPAN AND FEDERAL RESERVE INTERVENTIONS

	Benchmark specification			Irregular trade time correction		
	(1a) Federal Reserve	(1b) Bank of Japan	(1c) Joint Intervention	(2a) Federal Reserve	(2b) Bank of Japan	(2c) Joint
Index function for probability						
Constant	1.929***	1.238***	1.957***	1.928***	1.241***	1.539***
	(0.177)	(0.032)	(0.467)	(0.177)	(0.033)	(0.058)
Volatility	0.023***	0.025***	0.012	0.023***	0.025***	0.013***
	(0.003)	(0.001)	(0.007)	(0.003)	(0.0012)	(0.0008)
Intervention	0.066**	0.039***	0.179***	0.065**	0.039***	0.1004***
	(0.029)	(0.008)	(0.056)	(0.029)	(0.008)	(0.009)
Lagged spread	0.054***	0.037***	0.032*	0.054***	0.037***	0.0467***
	(0.010)	(0.003)	(0.018)	(0.010)	(0.003)	(0.004)
Δtimesec				0.078***	0.057***	0.065***
				(0.011)	(0.014)	(0.010)
Variance function						
Volatility	0.673***	0.004***	0.009*	0.007***	0.004***	0.003***
	(0.001)	(0.0005)	(0.005)	(0.001)	(0.005)	(0.0005)
Intervention	0.011	0.054***	0.292*	0.011	0.053***	0.055***
	(0.029)	(0.008)	(0.150)	(0.029)	(0.008)	(0.0102)
Lagged spread	0.004	0.004*	−0.004	0.004	0.004*	−0.004
	(0.008)	(0.002)	(0.021)	(0.007)	(0.002)	(0.002)
Δtimesec				0.0001	0.0002	−0.388E−06
				(0.001)	(0.0003)	(0.78E−04)
Threshold paramters for index						
μ_1	2.294***	1.439***	1.938***	2.447***	1.441***	1.723***
	(0.078)	(0.032)	(0.579)	(0.209)	(0.032)	(0.0568)
μ_2	5.021***	4.134***	5.33***	5.858***	4.138***	4.377***
	(0.107)	(0.095)	(1.923)	(0.571)	(0.095)	(0.147)
Number of observations	5,390	46,936	14,567	5,390	46,936	14,567

NOTE: This table presents maximum likelihood estimates of the ordered probit model for the pooled subsamples surrounding Federal Reserve and Bank of Japan intervention announcements. The model takes the form:

$$S_t^* = b_0 + b_1\hat{\sigma}^2_{m,t-1} + b_2 Intervention_{t-1} + b_3 S_{t-1} + \varepsilon_{S,t}$$

$$\sigma_{S_t^*} = \exp(\gamma_1\hat{\sigma}^2_{m,t-1} + \gamma_2 Intervention_{t-1} + \gamma_3 S_{t-1}),$$

where the current bid–ask spread is the dependent variable. *Intervention* is the central bank intervention dummy, S_{t-1} is the lagged spread and σ_{t-1} is a lagged volatility measure, estimated using the GARCH(1,1)-MA(1) procedure, to account for irregular quote arrival, Δ*timesec* is the number of seconds that have elapsed since the previous quote. The intervention windows begin 120 minutes prior to an intervention announcement on the Reuters news screen and end 120 minutes after the announcment. *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively.

means, each explanatory variable is increased by one standard deviation, holding all other variables constant. This exercise indicates whether the bid–ask spread displays economically meaningful shifts following news of a central bank intervention. If the incidence or probability of an intervention by the Federal Reserve increases by one standard deviation, the probability of observing bid–ask spreads in categories a_1 or a_2 (9 basis points or lower) falls by 0.34% and 7.8%, respectively. Furthermore, intervention announcements increase the probability of the spread shifting to categories a_3 or a_4 (10 basis points or higher) by 7.81% and 0.35%, respectively. Increases in spot rate volatility result in a similar pattern in the probability distribution of the spread;

that is, the spread distribution shifts to the right if volatility in the spot market becomes elevated. Marginal effects estimates for interventions by the BOJ also suggest that the probability of observing a bid–ask spread of 10 basis points or higher increases significantly, implying that the aggregate bid–ask spread distribution shifts to the right when the BOJ intervenes.

Finally, the estimation procedure is extended to account for an irregular quote arrival pattern, with the inclusion of ΔT_{t-1}, where T is the number of seconds elapsed since a preceding quote. As the results in Table 6 indicate the coefficient estimate for β_4, the time between quotes, is positive suggesting that spreads widen during periods of infrequent trading activity. The unpublished appendix documents the total value of reserves expended by the Federal Reserve and the BOJ for the interventions in the sample period.[19] The data show that intervention episodes represent non-trivial trading losses for central banks.

3.3 Individual Bank Estimates for Intervention Windows

The market response of widened bid–ask spreads represents an aggregate estimate of individual bank responses to the central bank entering the market. The results for all the quotes posted during intervention time windows support the hypothesis that interventions increase asymmetric information risk and inventory-carrying risk. This section turns to individual bank responses to central bank intervention. In other words, is there cross-sectional variation in bid–ask spread revisions across individual banks when the central bank intervenes? To analyze individual bank behavior, the ordered probit model is estimated for the top 10 banks in the yen/dollar market in Table 7.[20]

Note from Table 2 (Panel A) that the set of individual banks that post the highest number of quotes during intervention windows is different from the entire set of quotations. Also, the lineup of individual banks with the highest quote frequency changes depending on which central bank intervenes. Chemical Bank, Morgan Guaranty, and Tokai Bank remain in the set of top 10 banks posting quotes for both sets of interventions. Other banks in the top 10 include Credit Suisse, Amsterdam–Rotterdam Bank, the Industrial BOJ, and Dai-Ichi Kangyo Bank for interventions by the BOJ, while Banca Commerciale Italiana, Citibank, and Dresdner Bank account for high numbers of quotes posted during Federal Reserve interventions. The identity of the most active players changes depending on which central bank intervenes. While Japanese banks are more active during BOJ interventions, it does not appear that U.S. banks become more active during Federal Reserve interventions. The ordered-probit estimations were conducted for all 10 banks for both sets of interventions to see if bid–ask spread revisions are different for the individual banks depending on which central bank intervenes. Such evidence would suggest individual banks differ in the nature of inventory

19. The data are available on my website.

20. For a small subset of banks for whom the ordered probit estimation fails, a binomial probit model is estimated instead. The binomial probit procedure does not provide estimates of the partition parameters, μ_1 and μ_2.

TABLE 7

ORDERED PROBIT ESTIMATES-INDIVIDUAL BANK ESTIMATES

Panel A

	(1) Amsterdam–Rotterdam Bank BOJ	(2) Banca Commerciale Italiana BOJ	(3) Chemical Bank BOJ	(4) Citibank BOJ	(5) Credit Suisse BOJ	(6) Dai-Ichi Kangyo Bank BOJ	(7) Dresdner Bank BOJ	(8) Industrial Bank of Japan BOJ	(9) Morgan Guaranty BOJ	(10) Tokai Bank BOJ
Index function for probability										
Constant	1.436***	1.412***	0.611***	0.791***	−0.565***	1.641***	1.114***	0.106	1.018***	0.848***
	(0.111)	(0.53)	(0.165)	(0.171)	(0.141)	(0.132)	(0.215)	(0.190)	(0.260)	(0.0838)
Volatility	0.0386***	0.289***	0.005***	0.0135***	−0.003	0.0129***	0.0142***	−0.009***	0.011***	0.005
	(0.0022)	(0.0068)	(0.0018)	(0.0017)	(0.004)	(0.0031)	(0.0029)	(0.003)	(0.0035)	(0.0033)
Intervention	0.0004	0.0754	−0.118	−0.0049	−0.086	0.0756***	0.0598***	−0.106***	0.159***	−0.172***
	(0.025)	(0.104)	(0.034)	(0.034)	(0.079)	(0.298)	(0.0486)	(0.037)	(0.051)	(0.035)
Lagged spread	0.072***	0.143***	0.365***	0.312***	0.282	0.1291***	0.161***	0.398***	0.223***	0.0029***
	(0.009)	(0.0312)	(0.0088)	(0.103)	(0.014)	(0.0115)	(0.018)	(0.0148)	(0.018)	(0.0011)
Threshold paramters for index										
μ_1	2.135***	2.50***	3.643***	3.319***	4.562***	2.825***	2.129***	2.949***	0.998***	
	(0.0756)	(0.391)	(0.145)	(0.145)	(0.904)	(0.1016)	(0.1346)	(0.110)	(0.132)	
μ_2	4.919***	5.567***	6.976***	6.427***		5.098***	5.481***		5.917***	
	(0.1195)	(0.541)	(0.189)	(0.171)		(0.133)	(0.263)		(0.196)	
Number of observations	2,475	307	2,183	1,709	3,247	1,823	907	1,871	2,862	2,457

NOTE: This table presents maximum likelihood estimates of the ordered probit model for individual banks around Bank of Japan intervention announcement events. The model takes the form:

$$S_t^* = b_0 + b_1\hat{\sigma}_{m,t-1}^2 + b_2 Intervention_{t-1} + b_3 S_{t-1} + \varepsilon_{S,t}$$

$$\sigma_{S_t^*} = \exp(\gamma_1\hat{\sigma}_{m,t-1}^2 + \gamma_2 Intervention_{t-1} + \gamma_3 S_{t-1}),$$

where the current bid–ask spread is the dependent variable. *Intervention* is the central bank intervention dummy, S_{t-1} is the lagged spread, and σ_{t-1} is a lagged volatility measure, estimated using the GARCH(1,1)-MA(1) procedure, to account for irregular quote arrival, $\Delta timesec$ is the number of seconds that have elapsed since the previous quote. *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively.

TABLE 7

ORDERED PROBIT ESTIMATES-INDIVIDUAL BANK ESTIMATES

Panel B

	(1) Amsterdam–Rotterdam Bank FED	(2) Banca Commerciale Italiana FED	(3) Chemical Bank FED	(4) Citibank FED	(5) Dai-Ichi Kangyo Bank FED	(6) Dresdner Bank FED	(7) Industrial Bank of Japan FED	(8) Morgan Guaranty FED	(9) Tokai Bank FED
Index function for probability									
Constant	−0.297	2.205***	−1.565***	−5.509	1.898***	−1.115***	2.438***	1.436***	−7.128
	(1.085)	(0.436)	(0.230)	(3.760)	(0.373)	(0.532)	(0.344)	(0.1105)	(5.233)
Volatility	−0.020	0.0298***	0.032***	0.207	0.0093	0.016	−0.0033***	0.0387***	0.019
	(0.116)	(0.0039)	(0.0043)	(0.189)	(0.0058)	(0.011)	(0.0084)	(0.0022)	(0.019)
Intervention	−0.526**	0.259***	0.398***	0.3229	0.0163	0.1123	0.067***	0.004	0.062
	(0.244)	(0.063)	(0.081)	(1.162)	(0.275)	(0.1116)	(0.125)	(0.025)	(1.727)
Lagged spread	−0.131	0.132***	0.0824***	0.629***	0.0005	0.209***	0.0009	0.072***	0.922
	(0.092)	(0.025)	(0.0245)	(0.122)	(0.038)	(0.0441)	(0.0098)	(0.009)	(0.107)
Threshold paramters for index									
μ_1		2.99***			3.222***		3.112***	2.135***	
		(0.365)			(0.291)		(0.304)	(0.076)	
μ_2		6.334***			4.707***			4.919***	
		(0.438)			(0.650)			(0.1195)	
Number of observations	48	566	656	339	153	233	152	196	200

NOTE: This table presents maximum likelihood estimates of the ordered probit model for individual banks around Federal Reserve intervention announcement events are presented. The model takes the form:

$$S_t^* = b_0 + b_1\hat{\sigma}^2_{m,t-1} + b_2 Intervention_{t-1} + b_3 S_{t-1} + \varepsilon_{S,t}$$

$$\sigma_{S_t^*} = \exp(\gamma_1\hat{\sigma}^2_{m,t-1} + \gamma_2 Intervention_{t-1} + \gamma_3 S_{t-1}),$$

where the current bid–ask spread is the dependent variable. *Intervention* is the central bank intervention dummy, S_{t-1} is the lagged spread and σ_{t-1} is a lagged volatility measure estimated using the GARCH(1,1)-MA(1) procedure, to account for irregular quote arrival, $\Delta timesec$ is the number of seconds that have elapsed since the previous quote. *, **, and *** denotes statistical significance at the 10%, 5%, and 1% levels, respectively.

TABLE 7

ORDERED PROBIT ESTIMATES-INDIVIDUAL BANK ESTIMATES

Panel C

	(1) Amsterdam–Rotterdam Bank Joint	(2) Banca Commerciale Italiana Joint	(3) Chemical Bank Joint	(4) Citibank Joint	(5) Dai-Ichi Kangyo Bank Joint	(6) Dresdner Bank Joint	(7) Industrial Bank of Japan Joint	(8) Morgan Guaranty Joint	(9) Tokai Bank Joint
Index function for probability									
Constant	1.44***	1.733***	0.913***	0.674***	1.558***	1.058***	0.106	0.990***	−7.245
	(0.109)	(0.319)	(0.154)	(0.167)	(0.125)	(0.203)	(0.190)	(0.249)	(0.502)
Volatility	0.039***	0.0298***	0.0069***	0.012***	0.007***	0.014***	−0.009***	0.013***	0.008
	(0.002)	(0.0034)	(0.0014)	(0.0016)	(0.003)	(0.003)	(0.003)	(0.004)	(0.005)
Intervention	−0.003	0.148***	−0.0436***	0.017	0.050*	0.024	−0.106***	0.171***	−0.518***
	(0.025)	(0.047)	(.0298)	(0.032)	(0.029)	(0.041)	(0.037)	(0.050)	(0.099)
Lagged spread	0.070***	0.145***	0.347***	0.348***	0.137***	0.172***	0.398***	0.229***	0.868
	(0.009)	(0.0192)	(0.0067)	(0.0096)	(0.011)	(0.017)	(0.015)	(0.017)	(0.041)
Threshold paramters for index									
μ_1	2.148***	2.77***	3.829***	3.321***	2.834***	2.174***	2.949***	0.992***	
	(0.075)	(0.264)	(0.141)	(0.143)	(0.095)	(0.131)	(0.110)	(0.131)	
μ_2	4.929***	6.012***	6.892***	6.789***	5.046***	5.542***		5.90***	
	(0.119)	(0.331)	(0.169)	(0.165)	(0.126)	(0.232)		(0.188)	
Number of observations	2,523	872	2,838	2,047	1,976	1,139	1,872	3,057	2,656

NOTE: This table presents maximum likelihood estimates of the ordered probit model for individual banks around Federal Reserve and Bank of Japan intervention announcement events are presented. The model takes the form:

$$S_t^* = b_0 + b_1\hat{\sigma}^2_{m,t-1} + b_2 Intervention_{t-1} + b_3 S_{t-1} + \varepsilon_{S,t}$$

$$\sigma_{S_t^*} = \exp(\gamma_1\hat{\sigma}^2_{m,t-1} + \gamma_2 Intervention_{t-1} + \gamma_3 S_{t-1}),$$

where the current bid–ask spread is the dependent variable. *Intervention* is the central bank intervention dummy, S_{t-1} is the lagged spread and σ_{t-1} is a lagged volatility measure estimated using the GARCH(1,1)-MA(1) procedure, to account for irregular quote arrival, Δ*timesec* is the number of seconds that have elapsed since the previous quote. The intervention windows begin 30 minutes prior to an intervention announcement on the Reuter's news screen and end 60 minutes after the announcment. *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively.

risks and/or asymmetric information risk they face conditional on which central bank intervenes.

Table 7 (Panel A) shows the individual bank responses to interventions by the BOJ. It becomes immediately apparent that there is dispersion in the bid–ask spread revisions across individual banks. While Dai-Ichi Kangyo Bank, Dresdner Bank, and Morgan Guaranty display significantly wider spreads as evidenced by the positive coefficient on the intervention dummy, intervention does not appear to have a significant impact on bid–ask spreads posted by Amsterdam–Rotterdam Bank, Banca Commerciale Italiana, Chemical Bank, Citibank, and Credit Suisse. Interestingly, both Tokai Bank and the Industrial BOJ post significantly narrower bid–ask spreads when the BOJ intervenes. In fact, the range of spreads posted by the two banks is between 3 and 11 basis points during intervention windows; other banks post spreads as high as 50 basis points during the same windows.

Table 7 (Panel B) presents the corresponding results for Federal Reserve Interventions. While Banca Commericale Italiana, Chemical Bank, and the Industrial BOJ post significantly wider bid–ask spreads when the Federal Reserve intervenes, Amsterdam–Rotterdam Bank posts significantly lower spreads. Federal Reserve interventions do not appear to have a statistically significant impact on bid–ask spreads posted by the remaining banks in the lineup of top 10 banks. Results for Credit Suisse are not reported since bid–ask spreads remained unaltered at 10 basis points throughout the intervention windows.

Repeating the procedure using the multiplicative heteroskedasticity correction yields insignificant coefficients for γ_1, γ_2, and γ_3. This indicates that time-varying heteroskedasticity appears to be absent for individual banks. By contrast, the likelihood ratio statistics for the joint significance of the explanatory variables in the mean part of the model are highly significant.

A comparison across the two panels reveals that bid–ask spread revisions can differ for the same bank depending on which central bank intervenes. While Tokai Bank and the Industrial BOJ post narrower spreads when the BOJ intervenes, the Industrial BOJ posts higher spreads when the Federal Reserve intervenes. BOJ interventions do not have a significant impact on spreads posted by Banca Commerciale Italiana or Chemical Bank; these two banks post significantly higher spreads when the Federal Reserve intervenes. Similarly, while Federal Reserve interventions have no significant impact on bid–ask spreads posted by Dai-Ichi Kangyo Bank, Dresdner Bank, or Morgan Guaranty, all three banks post significantly higher spreads when the BOJ intervenes.

The aggregate market response of wider bid–ask spreads, therefore, hides interesting patterns in individual bank responses suggesting that there are (i) differences in inventory risks faced by individual banks and (ii) differences in how the central bank intervention signal is absorbed by different banks. The differences in bid–ask spread revisions are consistent with volatility remaining elevated following the release of public news if it takes time for heterogeneous beliefs about the intervention to be resolved by different market participants.

4. ADDITIONAL TESTS AND ROBUSTNESS CHECKS

4.1 Joint Intervention Dates and Multiple Announcements

In order to test whether concerted interventions by both the BOJ and the Federal Reserve had a differential impact on bid–ask spreads, I conducted the estimations for a subsample of intervention dates when both central banks intervened in the yen/dollar market. It turns out that the BOJ intervened on all dates when the Federal Reserve was in the market. The estimations show that the impact of joint interventions on bid–ask spreads is statistically significant and of greater economic magnitude (Table 8, Columns 1–2, 4–6). Marginal effects reveal that the probability of the bid–ask spread being in the categories of 10 basis points or higher increases by 8%–11%, suggesting that joint interventions lead to significantly higher aggregate bid–ask spreads in the FX market. Using data at lower frequencies, Neely (2005) and Sarno and Taylor (2001) show that coordinated intervention is more likely to succeed than unilateral interventions. It appears from the joint intervention date results that coordinated interventions lead to wider aggregate bid–ask spreads in their immediate aftermath.

In a similar spirit, I estimated the ordered probit model separately for days when multiple intervention announcements appeared on the Reuters news screen. The results suggest that while bid–ask spreads are wider on days when there are more frequent news announcements in comparison to days when there are fewer announcements, the impact is not significantly different from days when there is a single intervention announcement (Table 8, columns 7–8). A potential explanation for this result is that a single news report of central bank intervention appears for only a small fraction of intervention dates in the sample.

4.2 Inaccurate News Announcements

When we compare the list of dates with the announcements that appeared on the Reuters screen, it becomes apparent that there are some dates when incorrect news about the central bank being in the market appeared.[21, 22] Note that inaccurate announcements usually occur only once during any given trading date, suggesting that single announcements of central bank intervention may not be believed by the market. In contrast, multiple announcements may provide confirmatory evidence that the central bank is indeed intervening in the market. The estimations were repeated separately for the subset of dates on which reports of central bank interventions appeared on the Reuters screen, but did not correspond to the official intervention dates. The data show that on June 1, 1993, a single inaccurate news report of an intervention by the Federal Reserve appeared on the Reuters screen. The coefficient on the intervention dummy for this date is statistically insignificant, suggesting that

21. Appendix 1b, which is made available on my website, presents official intervention date information released by the Federal Reserve and the BOJ.

22. For more on the accuracy of newswire reports for Central Bank interventions, see Fischer (Forthcoming).

TABLE 8

ORDERED PROBIT ESTIMATES–JOINT INTERVENTION DATES

	Joint Federal Reserve-Bank of Japan Intervention announcements						Multiple Annoucements		Incorrect annoucements	
	(1) April 27, 1993	(2) May 27, 1993	(3) May 28, 1993	(4) June 8, 1993	(5) August 19, 1993	(6) All joint dates	(7) BOJ	(8) Federal Reserve	(9) BOJ	(10) Federal Reserve
Index function for probability										
Constant	1.956***	1.398***	1.299***	0.839***	1.934***	1.957***	1.259***	1.987***	1.022***	1.614
	(0.467)	(0.138)	(0.103)	(0.095)	(0.164)	(0.467)	(0.048)	(0.196)	(0.052)	1.396
Volatility	0.0123	0.023***	0.006***	0.026***	0.008***	0.012	0.018***	0.021***	0.026***	0.027
	(0.008)	(0.004)	(0.002)	(0.005)	(0.001)	(0.007)	(0.002)	(0.003)	(0.002)	(0.041)
Intervention	0.179***	0.109***	−0.012	0.107***	0.183***	0.179***	0.058***	0.061***		−0.068
	(0.057)	(0.020)	(0.015)	(0.168)	(0.028)	(0.056)	(0.009)	(0.031)	*****	(0.094)
Lagged spread	0.032*	0.009	0.029***	0.013**	0.052***	0.032*	0.031***	0.049***	0.044***	0.017
	(0.184)	(0.008)	(0.006)	(0.005)	(0.009)	(0.0184)	(0.004)	(0.0105)	(0.006)	(0.029)
Variance function										
Volatility	0.009*	−0.004	−0.013***	−0.035***	0.003***	0.009*	−0.006***	0.006***	−0.003**	−0.032
	(0.005)	(0.003)	(0.002)	(0.007)	(0.001)	(0.005)	(0.002)	(0.001)	(0.001)	(0.079)
Intervention	0.292*	0.157***	0.038*	0.117***	0.015	0.292*	0.053***	0.012		−0.118
	(0.150)	(0.035)	(0.0225)	(0.024)	(0.022)	(0.150)	(0.009)	(0.033)	*****	(0.070)
Lagged spread	−0.004	0.005	−0.003	−0.003	−0.004	−0.004	−0.003***	−0.004	−0.004	0.029
	(0.021)	(0.009)	(0.007)	(0.008)	(0.006)	(0.021)	(0.002)	(0.008)	(0.005)	(0.027)
Threshold paramters for index										
μ_1	1.937***	1.325***	1.54***	1.056***	1.683***	1.938***	1.437***	2.409***	1.433***	2.485
	(0.579)	(0.143)	(0.124)	(0.114)	(0.113)	(0.579)	(0.044)	(0.226)	(0.054)	(2.263)
μ_2	5.331***	3.809***	3.871***	2.400***	4.323***	5.33***	3.656***	5.755***	3.865***	
	(1.923)	(0.388)	(0.342)	(0.268)	(0.282)	(1.923)	(0.113)	(0.616)	(0.151)	
Number of observations	1,909	2,848	4,827	2,173	2,810	14,567	12,400	3,320	6,558	521

NOTE: This table presents maximum likelihood estimates of the ordered probit model for joint Federal Reserve and Bank of Japan intervention dates. The model takes the form:

$$S_t^* = b_0 + b_1\hat{\sigma}^2_{m,t-1} + b_2 Intervention_{t-1} + b_3 S_{t-1} + \varepsilon_{S,t}$$

$$\sigma_{S_t^*} = \exp(\gamma_1\hat{\sigma}^2_{m,t-1} + \gamma_2 Intervention_{t-1} + \gamma_3 S_{t-1}),$$

where the current bid–ask spread is the dependent variable. *Intervention* is the central bank intervention dummy, S_{t-1} is the lagged spread and σ_{t-1} is a lagged volatility measure estimated using the GARCH(1,1)-MA(1) procedure, to account for irregular quote arrival, Δ*timesec* is the number of seconds that have elapsed since the previous quote. *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively.

the market did not react to the news report (Table 8, column 10). A pooled ordered probit estimation of inaccurate announcement dates for the BOJ failed to converge, suggesting once again that the market did not react to false reports of central bank intervention. When the model was re-estimated without the intervention dummy, the relationship between volatility and bid–ask spreads continues to hold (Table 8, column 9).

5. CONCLUSION

An appealing feature of the market microstructure approach is that it tackles the strategic interaction between central banks and speculative traders in response to intervention operations. This paper provides empirical support for the hypothesis that bid–ask spreads and spot rate volatility following central bank interventions depend on the volatility of both the fundamentals and the exchange rate target by speculators in the foreign exchange market. The empirical analysis focuses on movements in quoted bid–ask spreads as a function of spot rate volatility and the arrival of intervention news. If an intervention announcement creates further uncertainty about future monetary policy or the fundamentals, and hence about the future spot rate, market microstructure theory suggests that the bid–ask spread should widen. Alternatively, if the central bank credibly transmits a signal to the market designed to reduce uncertainty about the short-run variability about the target exchange rate, then the bid–ask spread should narrow.

The analysis combines high-frequency (tick-by-tick) data of quotes posted on the Reuters FXFX screen by different banks in the inter-bank market for foreign exchange with time-stamped news announcements of central bank interventions on the Reuters news screen. Testing 65 subsamples of data surrounding interventions by the BOJ and five by the Federal Reserve over the period between October 1992 and September 1993 reveals that, on average, intervention announcements are followed by greater spot rate volatility and wider quoted bid–ask spreads, suggesting an increase in aggregate market uncertainty and inventory carrying costs following central bank intervention. High-frequency data also permit an investigation of the mechanism by which the central bank intervention signal is transmitted to individual market participants and ultimately impacts the aggregate exchange rate. The results presented in this article illustrate that there is heterogeneity in individual bank responses to intervention episodes and suggest that individual banks may interpret the intervention signal differently or face different inventory problems. Thus, individual market-maker responses aggregate to determine the foreign exchange market's response when the central bank enters the market.

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