

# **Bid-ask Spread and Order Size in the Foreign Exchange Market: An Empirical Investigation**

Liang Ding\*

*Department of Economics, Macalester College,  
1600 Grand Avenue, St. Paul, MN55105, U.S.A.*

**Short Title:** Bid-ask Spread and Order Size in the FX market

**Abstract:**

This article empirically examines the relationship between order sizes and spreads in the foreign exchange market based on a FX dealer's quotes. It is found that spreads are independent of order sizes in the inter-dealer market, but they are negatively correlated in the customer market.

*JEL classification:* F31; G14

*Keywords:* bid-ask spread; order size; foreign exchange market; inter-dealer market; customer market.

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\* Corresponding author: Liang Ding, Phone: 1-651-696-6822, Fax: 1- 651-696-6746.  
*Email address:* ding@macalester.edu.

**Non-technical summary:**

In the past two decades, an increasing body of literature has been devoted to the determination of bid-ask spreads in the foreign exchange market. Theoretically, economists have recognized four determinants of spreads: exchange rate volatility (market uncertainty), trading volume, number of dealers (market competition), and order sizes. Accordingly, many studies made empirical investigations about the relationships between the spreads and determinants mentioned above. Among these studies, however, an empirical examination of spread and order size, a determinant indicated constantly by theoretical models, can hardly be found.

This article empirically examines the relationship between order size and spread in the foreign exchange market. A new data set has been collected from an online foreign exchange dealer who reveals both customer and inter-dealer bid-ask quotes in response to each trading request. Then the data are tested by an econometric model to find out the relationship between order size and spread. It is found that spreads are independent of order sizes in the inter-dealer market, while they are negatively correlated in the customer market.

None of the current models can explain this finding alone, so new models need to be created to provide more convincing theoretical reasoning. One possible direction for future research would be the combination of all factors that have been discussed in literature. Following this track, spreads are independent of order sizes in the inter-dealer market probably because positive factors are offset by negative ones, while the negative correlation between order sizes and spreads in the customer market might be due to the dominance of negative factors.

# **Bid-ask Spread and Order Size in the Foreign Exchange Market: An Empirical Investigation**

**Keywords:** bid-ask spread; order size; foreign exchange market; inter-dealer market; customer market.

## **1. Introduction**

The relationship between order size and bid-ask spread in the foreign exchange (FX) market remains unsettled. On the theoretical level, existing models give mixed predictions about the impact of order size on spread.<sup>1</sup> Processing cost models contend that order size and spread should be negatively related, while inventory holding risk and information cost models both suggest that order size and spread should be positively related. On the empirical level, economists have found mixed results. Lyons (1995) showed that order size and spread were positively related for a particular inter-bank dealer during a week in 1992, while Yao (1998) and Bjønnes and Rime (2005) concluded that currency spread bears little or no relation to order size. The empirical evidence for the papers mentioned above is based on inter-dealer data only, while the relationship in the customer FX market has rarely been discussed.<sup>2</sup>

Several questions need to be addressed. What is the impact of order size on spread? Is the impact different in the inter-dealer and customer markets? Which theoretical model can explain the findings? If none of the current models is consistent with the empirical reality, how should future research be directed?

This paper inspects the impact of order size on spread in both the inter-dealer and customer FX markets using new data. The data were collected from an online foreign exchange dealer who displayed both customer and inter-dealer bid-ask quotes in response to each trading request. The

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<sup>1</sup> Section 2 provides a detailed discussion of this issue.

<sup>2</sup> Osler et al. (2006) did examine the impact of order size on spread in the customer FX market. However, this paper was started before their results were available publicly.

data were then tested by an econometric model to determine the relationship between order size and spread, revealing that spread is independent of order size in the inter-dealer market and negatively correlated in the customer market. Since none of the current models alone can explain these findings, an intuitive explanation will be offered.

The remainder of the paper is organized as follows: Section 2 summarizes the current literature about the relationship between order size and spread; Section 3 examines this relationship empirically and displays results; and Section 4 concludes.

## **2. Literature review**

Financial theory has identified three basic sources of bid-ask spreads: order processing costs, inventory holding risks, and information costs of market making.

Processing cost models claim that spread is the compensation for dealers who offer immediacy while bearing some fixed costs of market making. Such costs may include subscriptions to electronic information, connection to the dealing system, and administrative expense. In the earliest literature on spread determination, Demsetz (1968) presented the first formal model for the stock market bid-ask spread. Finding that buy and sell orders generally do not reach the market at the same time, Demsetz assumed a separate class of market participants who provide immediacy by standing ready to buy and sell. To cover the cost of standing ready, these providers of immediacy must, on average, sell shares at a higher price than they buy shares. The difference between the selling (ask) and buying (bid) prices is the spread. Stoll (1978) and Hartmann (1998 and 1999) also built spread determination models from this perspective. Since order processing cost is relatively stable in the short run, the compensation for each unit of transaction tends to be smaller if the trading volume is larger. Thus, this line of models usually predicts that the spread should be negatively affected by the order size.

Inventory risk models generally argue that spread is the compensation for dealers who provide immediacy and assume risk by holding inventory at the same time. These models usually view dealers as risk aversion agents who provide liquidity and optimize their own securities portfolios. In these models, dealers choose bid-ask prices to maximize their expected utility. After analyzing a centralized security market with risk aversion dealers, Ho and Stoll (1981) showed that the spread is a positive function of single transaction size (order size), the dealer's degree of risk aversion, and the security return variance. Other similar models include Stoll (1978) and Biais (1993). Apparently, the risk of holding inventory is higher if the price of an asset is more volatile. To compensate for this risk, spread is shown to be positively correlated with market uncertainty. Given the same market uncertainty, the transaction with a larger order size is more likely to change the inventory level unexpectedly and raise the dealer's risk. Thus, this line of models suggests that the spread should be positively affected by the order size.

Information cost models – also known as asymmetric information or adverse selection models – maintain that spread is the compensation for dealers who might lose money when trading with better-informed agents. If some investors are better informed than others, the person who places a firm quote will lose to investors with superior information. To cover the possible loss caused by trading with better-informed agents, dealers quote higher selling prices and lower buying prices. Bagehot (1971) first noted that the losses to informed traders must be offset by profits from uninformed traders if dealers are to stay in business. Glosten and Milgrom (1985), Kyle (1985) and Admati and Pfleiderer (1988) can also be put into this category. The asymmetric information model suggests that as a trade grows larger with someone who is better informed, a dealer's potential loss also grows larger. Therefore, a dealer would widen the spread to deter such transactions. Thus, this line of models usually claims that order size and spread should have a positive relationship.

In summary, various models provide mixed predications of the relationship between spread and order size. Which candidate model is correct? How is order size related to spread in the real world? The empirical testing in the following section will provide some answers.

### **3. Empirical testing**

#### *3.1. Data collection and description*

The data used in this paper were collected from an online foreign exchange dealer.<sup>3</sup> This dealer displayed both customer and inter-bank bid-ask quotes for several major currencies on its quotes window in response to individual quote requests randomly generated by a computer program. The dealer's responses – its bid-ask quotes – become part of my dataset. I focused on the rate of the US dollar versus the Euro (USD/EUR), currently the most frequently traded currency pair in the world.<sup>4</sup>

To obtain quotes for large, medium and small orders, the program selected order size based on the normal distribution around \$5,000,000, \$500,000, and \$10,000 respectively. The sample generally contained similar numbers of large, medium and small sizes. I used each order size for five times at the interval of one minute. Every five-minutes, I switched to a different order size.<sup>5</sup>

The 970 observations in my sample were collected during the period of July 7 through July 15, 2004, with weekend days excluded due to low transaction volume. About three hours each day were spent collecting data (usually 9:00 a.m. to noon local time, thought to be the busiest trading time each weekday). The customer quotes collected are all for individuals and not for wholesale customers, such as financial institutions. Although not obtained through real transactions, the prices

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<sup>3</sup> The dataset, as well as details regarding data sources, are available upon request.

<sup>4</sup> Supporting evidence can be found in the BIS's triennial survey of foreign exchange and derivative market activity. According to the most recent survey conducted in April 2004, the USD/EUR currency pair accounts for 28% of total foreign exchange activity and is the most heavily traded currency pair in the world. The results of the survey can be accessed from the BIS's website (<http://www.bis.org/publ/rpfx04.pdf>).

<sup>5</sup> The data were collected in this manner because I wanted to see whether spread was affected significantly by other factors other than just the order size. I found that the spreads in my sample were stable within the five-minute period for the same order size.

received from the dealer were firm quotes – i.e. they were not proposed prices subject to later change.

Compared to the data used in prior literature, the most important feature of this paper's dataset is that it contains order sizes and matching spreads. Table 1 gives descriptive statistics of the variables contained in this dataset, showing the mean value of customer spreads as significantly wider than that of inter-dealer spreads. This pattern can be explained by market power theory, which suggests that the spread should be wider if the cost is higher to find the best deal in the market. It is generally thought that such cost is significantly less for dealers than customers due to the electronic inter-dealer trading system.

In an empirical research study, such as this project, the quality of the data critically affects the reliability of the conclusions. A major consideration here is the typicality of the dealer and its quotes. Given the nearly perfect capital mobility between industrialized countries and the dominance of the electronic trading system in today's FX market (which is continuously traded 24/7), non-spread transaction costs become ignorable. Thus, neither time nor geography should lead to significant differences among the quotes of various dealers. Meanwhile, with the rise of online trading, fierce competition among the dealers drives their quotes even closer to prevailing market rates. Moreover, I compared the midpoint of bid-ask quotes obtained from the dealer with market rates from other sources. The rates were similar and the directional changes exactly the same. Therefore, I believe that the quotes obtained from this particular dealer can represent the market. Finally, no special events occurred in the time period when the data were collected.

### 3.2. Estimation model and econometric methodologies

In this econometric model the dependent variable is spread, while the independent variables are order size and exchange rate volatility.<sup>6</sup> Since many studies have demonstrated that the volatility of spot exchange rates can be modeled as a GARCH process, this paper estimates the volatility through a MA (1)-GARCH (1,1) specification:

$$\begin{aligned} 10,000 \cdot \Delta M_t &= \mu + \theta \varepsilon_{M,t-1} + \varepsilon_{M,t} \\ \sigma_{M,t}^2 &= \varpi + \alpha \varepsilon_{M,t-1}^2 + \beta \sigma_{M,t-1}^2, \\ \varepsilon_{M,t} | I_{t-1} &\sim N(0, \sigma_{M,t}^2) \end{aligned}$$

where  $M$  stands for the spot exchange rate and  $\Delta M$  is the change of the rate.  $I$  represents the information set, and  $\mu, \theta, \varpi, \alpha, \beta$  are the parameters to be estimated. The time  $t$  subscript refers to the place in the order of the series of quotes, so that  $\hat{\sigma}_{M,t}^2$  provides an estimate of the exchange rate volatility. Since the magnitude of mid-quote fluctuations is very small within the 1-minute window, the exchange rate change  $\Delta M$  is multiplied by 10,000 to enlarge the effects of dependent variables so that estimated parameters will not be too small. In this estimation model, the observation of the exchange rate is measured as the logarithm of the mid-quote of bid-ask prices. Given that  $a_t$  and  $b_t$  denote the ask and bid prices respectively,  $M$  is computed by the following formula:

$$M_t = \log\left(\frac{a_t + b_t}{2}\right)$$

Please note that the data are not continuous in terms of time because they were not collected 24/7. To allow trading and weekend breaks in the estimation, I estimated the GARCH model for each day separately. After obtaining the exchange rate volatility, a simple linear model was applied to estimate the impact of order size on spread:

$$S_t = \gamma_0 + \gamma_1 \hat{\sigma}_t + \gamma_2 O_t + \varepsilon_t \quad \varepsilon_t \sim N(0, \sigma_\varepsilon^2), t=1,2,\dots,T. \quad (1)$$

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<sup>6</sup> Market competition is another major spread component mentioned in literature, but is omitted in this research because of the unlikelihood of changing significantly over the course of a one-week sample.

where  $S_t$  denotes spread,  $O_t$  denotes order size, and  $\hat{\sigma}_t$  represents the exchange rate volatility obtained from the GARCH estimation.  $\gamma_0, \gamma_1, \gamma_2$  are constant parameters, and  $\varepsilon_t$  is an error item following normal distribution with a zero mean. The variable  $O_t$  is taken as the logarithm of the original order sizes. The spreads are computed as the logarithm of the spread measured in pips<sup>8</sup> such that:

$$S_t = \log[(a_t - b_t) \cdot 10000] \quad (2)$$

The choice of estimation method is determined by the nature of the spread data. It is well known that high frequency financial data such as exchange rate spreads usually exhibit non-normality and high autocorrelation. Therefore, OLS or Maximum Likelihood Estimation might be inefficient to estimate the model. The statistical assumptions required by GMM for hypothesis testing are quite weak and neither autocorrelation of the data nor non-normality of the residuals jeopardizes its estimation.

$\gamma$  denotes the vector of parameters in the model, and  $M(\lambda)$  is the vector of moment conditions. Given a weighting matrix  $W$ , GMM chooses the parameters, which minimize the quadratic function  $J(\hat{\gamma})$  as below:

$$J(\hat{\gamma}) = M(\gamma)'WM(\gamma) \quad (3)$$

The weighting matrix  $W$  can be estimated by several approaches that can account for various forms of heteroskedasticity and/or serial correlation. In this paper, Newey-West (N-W), White and Gallant weighting matrixes are applied for the purpose of robustness. Meanwhile, instrument variables are chosen from the explanatory variables themselves. The first instrument matrix

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<sup>8</sup> Since order sizes are much larger than spreads in terms of magnitude, estimated parameters would be very small if the model was estimated by the original data. To balance the magnitude of variables on both sides of the equation, spreads measured in pips are used in the estimation.

employs the square of explanatory variables (GMM1), while the other is a one period lag of explanatory variables (GMM2).

A regular t-test and a likelihood ratio (LR) are used to test the significance of order size in the model. A Wald test is used to check the significance of coefficients jointly by testing the restriction formed as  $R\gamma = r$ , where  $R$  is the parameter vector of restriction conditions,  $\gamma$  is the coefficient vector, and  $r$  is a constant to be tested.  $R=[0,0,1]$  and  $r=0$  since our concern is whether the order size coefficient  $\gamma_2$  is positive, negative or zero.

Believing that the moment conditions and residual item ( $\varepsilon$ ) are orthogonal, the asymptotic distribution of the objective function, LR statistic, and Wald statistic all follow the Chi-square distribution – allowing an acceptance or rejection decision to be made according to critical values computed from the Chi-square distribution.

### *3.3. Estimation results*

Much of the following discussion will focus on  $\gamma_2$ , the order size coefficient, which should be either negative according to the processing cost model or positive according to both the inventory risk and asymmetric information models. The discussion will also extend to the estimate of  $\gamma_1$ , the exchange rate volatility coefficient, which should be positive according to theoretical models.

Table 2 reports the results of the volatility estimation for each day. None of the parameters is significantly different from zero except for the constant item in the innovation equation. This suggests that the volatility of spot exchange rates is fairly stable and does not possess the features of autocorrelation and heteroskedasticity – perhaps because the sample includes only the hours from 9:00 a.m. to noon for seven workdays. Volatility is sufficiently strongly autocorrelated that it probably did not vary much from day to day. Also, the time interval chosen may have had little intraday variation in volatility.

Panels A and B of Table 3 display the results of equation (1) for both customer and inter-dealer spreads. As shown in panel A, the t-test, Likelihood Ratio test and Wald test all suggest a significantly negative coefficient for order size at the 5% significance level with White standard errors. The negative coefficient for order size is also found at the 10% significance level with Newey-West and Gallant standard errors. This means that the spreads quoted by the dealer for individual customers are actually negatively related to the order sizes. In principle, this result is consistent with Osler et al. (2006), who also found that larger order sizes lead to narrower spreads for both commercial and financial customers.<sup>9</sup> Specifically, the estimate of  $\gamma_2$  suggests that if order size increase from \$1 million to \$2 million, the spread given by the dealer decreases about 1 pip for individual customers.<sup>10</sup>

In contrast, the dealer's inter-dealer quotes display a different scenario. No matter what instruments or density matrices are used, the parameters of order size ( $\gamma_2$ ) are very close to zero in all estimations. More importantly, the corresponding t-statistics of the coefficient (around -0.5) and both the Likelihood Ratio and Wald statistics (less than 0.3) are far below the critical value at a 5% significance level. This suggests that order size does not significantly impact this dealer's inter-dealer spreads in our sample.

In regard to the impact of exchange rate volatility shown in Panel A of Table 3, all tests in the estimation fail to show that coefficient  $\gamma_1$  is statistically different from zero in the customer market. For inter-dealer spreads, the results are similar. As shown by Panel B of Table 3, both GMM1 and GMM2 obtain positive results, but the values of t-statistics are around 1.4 and not large enough to suggest that exchange rate volatility affects spreads significantly. The most likely reason is that the

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<sup>9</sup> Their dataset does not contain quotes for individual customers. Also, their regression divides all order sizes into three groups (small, medium and large) and uses a dummy variable to estimate the impact of order size on spread, so only a general comparison can be made.

<sup>10</sup> The coefficient of order size is estimated when spreads and order sizes are measured in a logarithmic format. This needs to be taken into account when estimating the direct impact of order size on spread.

volatility in my sample wasn't volatile at all, considering that only the constant item was significant in the GARCH estimation. Thus, including volatility in the model is similar to feeding the model with a constant number and some white noise.

### *3.4. Discussion*

Looking back at the existing models surveyed in Section 2, it seems that only the processing cost model can explain the negative relationship between order size and customer spread. In addition, as suggested by Osler et. al. (2006), the negative pattern can also be supported by another important spread determinant in the FX market – strategic dealing. Building on abundant evidence that order flow carries information (e.g., Evans and Lyons 2002), the paper argues that rational FX dealers might strategically vary spreads to gain information that they can then exploit in future trades. Thus, FX dealers effectively subsidize spreads to attract those larger transactions most likely to carry useful information.

On the other hand, inventory risk and adverse selection might not be as significant as predicted by theories in this dealer's spread determination. Inventory risk is associated with the dealer's unexpected inventory change. When this dealer receives such a change, it can adjust its inventory and share the risk with other dealers through inter-dealer trading quickly and easily. With regard to asymmetric information, Bjonnes and Rime (2005) suggest that instead of order size, it is only the direction of an order that carries information, and this paper presents evidence consistent with this alternative hypothesis. Therefore, spreads could be unrelated to order size even under adverse selection either.

Overall, the dominance of processing costs and strategic trading over inventory risk and adverse selection explains the negative pattern in the customer market. Similarly, order size has little impact on the dealer's inter-dealer spread probably because all these impacts offset in the inter-dealer market. Since the order sizes used to extract both the inter-dealer and customer quotes are identical

at the same time, the transaction costs should not be the cause of reason that causes the differences in the inter-dealer spread. Since spread and order size might not be significant spread components in our sample, the difference between the two markets must be caused by strategic trading. To be logically consistent, the effect of strategic trading should indeed be greater in the customer market than in the inter-dealer market.

This claim seems consistent with both intuition and reality. In the FX market, dealers first obtain information from customer order flow. This information then spreads in the market through inter-dealer trading. So, dealers have more incentive to reduce spread to attract large orders in the customer market than in the inter-dealer market. Therefore, the strategic trading effect is likely stronger in the customer market.

#### **4. Conclusions**

This article empirically examines the relationship between order size and spread in the foreign exchange market. Based on quotes from an individual FX dealer, spread appears to be independent of order size in the inter-dealer market, while the two are negatively correlated in the customer market. None of the current models can explain this finding alone, so new models are needed to provide more convincing theoretical reasoning.

As discussed in the previous section, one possible direction for future research would be the combination of all factors found to affect spread. Following this line of thinking, spread would be independent of order size in the inter-dealer market probably because positive and negative factors offset, while the negative pattern in the customer market could be due to the dominance of negative factors over positive ones.

Although this paper focuses on the relationship between order size and spread in the foreign exchange market, it also reveals additional areas to be explored. First, this study focused on one individual dealer and one currency pair. Whether the conclusions apply to other dealers and other

currencies deserves more research. Second, the dataset used in this paper is not large. More data need to be tested to verify whether this article's finding is robust. Finally, revealing empirical facts is not difficult once data are available. However, proposing a theory that explains such a result is more important. Although this paper proposes one possible solution, more research needs to be completed to build a satisfying theoretical model.

## REFERENCES

- Admati AR, Pfleiderer P. 1988. Selling and trading on information in financial markets. *American Economic Review* 78: 96–103.
- Bagehot W. 1971. The only game in town. *Financial Analysts Journal* 22: 12–14.
- Biais B. 1993. Price formation and equilibrium liquidity in fragmented and centralized markets. *Journal of Finance* 484: 157-185.
- Bjønnes GH, Rime D. 2005. Dealer behavior and trading systems in foreign exchange markets. *Journal of Financial Economics* 75: 571-605.
- Bollerslev T, Melvin M. 1994. Bid-ask spreads and volatility in the foreign exchange market: an empirical analysis. *Journal of International Economics* 36: 355-372.
- Cheung YW, Chinn MD, Marsh IW. 2004. How do UK-based foreign exchange dealers think their market operates? *International Journal of Finance and Economics* 9: 289-306.
- Demsetz H. 1968. The cost of transacting. *Quarterly Journal of Economics* 82: 33-53.
- Demos AA, Goodhart C. 1996. The interaction between the frequency of market quotations, spread and volatility in the foreign exchange markets. *Applied Economics* 28: 377-86.
- Evans M, Lyons R. 2002. Order flow and exchange-rate dynamics. *Journal of Political Economy* 110: 170-180.
- Glosten LR, Milgrom PR. 1985. Bid, ask, and transaction prices in a specialist market with heterogeneously informed traders. *Journal of Financial Economics* 14: 71-100.
- Hartmann P. 1998. Do Reuters spreads reflect currencies' differences in global trading activity? *Journal of International Money and Finance* 17: 757-784.
- Hartmann P. 1999. Trading volumes and transaction costs in the foreign exchange market. *Journal of Banking and Finance* 23: 801-824.
- Ho T, Stoll H. 1981. Optimal dealer pricing under transactions and return uncertainty. *Journal of Financial Economics* 9: 47-73.
- Huang DR, Masulis RW. 1999. FX spread and dealer competition across the 24-Hour trading day. *The Review of Financial Studies* 12: 61-93.
- Kyle A. 1985. Continuous auctions and insider trading. *Econometrica* 53: 1315–1336.
- Lyons RK. 1995. Tests of microstructural hypotheses in the foreign exchange market. *Journal of*

*Financial Economics* 39: 321-351.

Osler CL, Mende A, Menkhoff L. 2006. Price Discovery in Currency Markets. Mimeo.

Payne R. 2003. Informed trade in spot foreign exchange markets: an empirical investigation.  
*Journal of International Economics* 61: 307-329.

Stoll HR. 1978. The supply of dealer services in securities markets. *Journal of Finance* 33: 1133-51.

Yao JM. 1998. Market making in the interbank foreign exchange market. Working paper S-98-3,  
Stern School of Business, New York University.

Table 1: Descriptive Statistics of the Data

This table gives descriptive statistics of the data. All quotes are exchange rate for USD/EUR

Variable	Number of observations	Mean	Std. Dev.	Min	Max
Customer spreads	970	.013811	.0040681	.0043	.0201
Inter-dealer spreads	970	.0016051	.0002341	.0011	.0022
Order sizes	970	908506.4	2133810	203	9501000

Table 2: Exchange Rate Volatility Estimation

This table gives the estimate of exchange rate volatility for each day in the sample (weekends 7/10 and 7/11 are excluded). The volatility is estimated by a GARCH specification as below:

$$10,000 \cdot \Delta M_t = \mu + \theta \varepsilon_{M,t-1} + \varepsilon_{M,t}$$

$$\sigma_{M,t}^2 = \varpi + \alpha \varepsilon_{M,t-1}^2 + \beta \sigma_{M,t-1}^2,$$

$$\varepsilon_{M,t} | I_{t-1} \sim N(0, \sigma_{M,t}^2)$$

where  $M$  stands for the spot exchange rate and  $\Delta M$  is the change of spot exchange rate.  $I$  represents the information set, and  $\mu, \theta, \varpi, \alpha, \beta$  are the parameters to be estimated. The time  $t$  subscript refers to the place in the order of the series of quotes, so that  $\hat{\sigma}_{M,t}^2$  provides an estimate of the exchange rate volatility. Since the magnitude of mid-quote fluctuations is very small within the 1-minute window, the exchange rate change  $\Delta M$  is multiplied by 10,000 to enlarge the effects of dependent variables so that estimated parameters will not be too small. In this estimation model, the observation of the exchange rate is measured as the logarithm of the mid-quote of bid-ask prices. Given that  $a_t$  and  $b_t$  denote the ask and bid prices respectively,  $M$  is computed by the following formula:

$$M_t = \log\left(\frac{a_t + b_t}{2}\right)$$

Standard errors are reported in parentheses, and \* denotes significance at the 5% level.

date	$\mu$	$\theta$	$\varpi$	$\alpha$	$\beta$
7/7/04	-0.1474 (0.1521)	-0.3343* (0.1058)	1.1245 (221.8100)	0.0113 (0.0371)	0.8161 (36.2590)
7/8/04	-0.1173 (0.1328)	-0.4567* (0.1237)	1.0257 (2.5600)	0.0252 (0.0521)	0.7321 (6.2700)
7/9/04	-0.0825 (0.0620)	-0.6712* (0.1548)	0.8146 (1.7851)	0.0178 (0.1007)	0.9321 (3.2487)
7/12/04	-0.0697 (0.0432)	-0.7336* (0.0594)	1.0750 (10.2490)	0.0139 (0.1108)	0.8877 (2.8724)
7/13/04	-0.0125 (0.0732)	-0.5669* (0.0930)	0.6541 (1.1844)	0.0668 (0.0985)	0.7471 (0.4101)
7/14/04	-0.0498 (0.1048)	-0.5515* (0.0871)	0.0033 (1.5680)	0.0212 (0.0405)	1.0001 (1.3251)
7/15/04	0.1452 (0.4155)	-0.3761* (0.1890)	15.2480 (13.6450)	0.1146 (0.1353)	0.0002 (0.8961)

Table 3: Test Results of Spreads and Order Sizes

This table gives the estimates for the regression model:

$$S_t = \gamma_0 + \gamma_1 \hat{\sigma}_t + \gamma_2 O_t + \varepsilon_t$$

Here,  $\hat{\sigma}_t$  represents the exchange rate volatility obtained from the GARCH estimation.  $O_t$  is the order size associated with each spread, and  $S_t$  is either the customer or inter-dealer spread calculated based on the following formula:

$$S_t = \log[(a_t - b_t) \cdot 10000]$$

where  $a_t$  and  $b_t$  denote original ask and bid quotes given by the dealer.  $\varepsilon_t$  is a standard error item.  $\gamma_0, \gamma_1, \gamma_2$  are corresponding coefficients of explanatory variables including a constant item. The regression model is estimated by GMM. Three different density matrix estimation methods are applied: White, Newey-West (N-W) and Gallant. There are two instrument variables: the square of explanatory variables (GMM1) and a one period lag of explanatory variables (GMM2). The t-statistics of estimates are reported in parentheses. LR stands for likelihood ratio, and w is for the Wald test statistic.

Panel A: Customer Spreads

Coefficient:	GMM1					GMM2				
	constant item	exchange rate volatility	order size	LR	w	constant item	exchange rate volatility	order size	LR	w
White	4.9360 (59.96)	0.0098 (0.50)	-0.0081 (-2.47)	5.98	6.08	4.9544 (16.21)	0.0082 (0.10)	-0.0092 (-2.72)	7.12	7.40
N-W	4.9360 (41.44)	0.0098 (0.42)	-0.0081 (-1.80)	3.12	3.24	4.9544 (12.85)	0.0082 (0.08)	-0.0092 (-1.90)	3.34	3.61
Gallant	4.9360 (41.92)	0.0098 (0.42)	-0.0081 (-1.83)	3.21	3.35	4.9544 (12.75)	0.0082 (0.08)	-0.0092 (-1.95)	3.56	3.80

Panel B: Inter-Dealer Spreads

Coefficient:	GMM1					GMM2				
	constant item	exchange rate volatility	order size	LR	w	constant item	exchange rate volatility	order size	LR	w
White	2.7490 (102.8)	0.0066 (1.33)	-0.0007 (-0.48)	0.19	0.24	2.9163 (65.85)	-0.0383 (-1.07)	-0.0010 (-0.60)	0.29	0.36
N-W	2.7490 (101.4)	0.0066 (1.44)	-0.0008 (-0.51)	0.21	0.27	2.9163 (61.61)	-0.0383 (-1.69)	-0.0010 (-0.63)	0.30	0.39
Gallant	2.7490 (100.3)	0.0066 (1.45)	-0.0008 (-0.50)	0.20	0.25	2.9163 (60.04)	-0.0383 (-1.61)	-0.0010 (-0.61)	0.29	0.37