Private information, bid-ask spreads and return volatility in the foreign exchange market

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Abstract

Trading volume and order flow have both been closely associated with informed trader activity in the market microstructure literature. Using theory that explains regular intraday patterns in trading data, we transform these variables into proxies for private information and examine their relationships with bid-ask spreads and return volatility. We use a unique and unusually rich high-frequency intraday dataset from the world's largest financial market, namely, the electronic inter-dealer spot foreign exchange market. Our analysis takes account of institutional features peculiar to this order-driven market. Our empirical results strongly affirm our theoretical understanding of how these markets work. They also reveal how the structure of the inter-dealer spot FX market affects exchange rate volatility.

JEL Classification: F31; G12; G15; D4

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1. Introduction

Private information is a common theme across various theories in the context of the widely documented patterns that exist in intraday trading data. These patterns emerge in volume, volatility and bid-ask spread data from a wide variety of financial markets (see ap Gwilym and Sutcliffe (1999) for a survey). Our research harnesses this theme to explore how private information influences the formation of price changes and bid-ask spreads. We also introduce order flow as an additional variable under analysis. Evans and Lyons (2002) convincingly established a strong relationship between cumulative order flow and exchange rates. Our unique dataset enables us to explore the intraday relationship between order flow and volume, volatility, and bid-ask spread.

Intraday trading data exhibit letter-shaped patterns, as markets go through the daily ritual of opening up, settling into normal trading and closing down. Patterns in bid-ask spreads, trading volume and return volatility have been widely observed and recorded for all major financial markets. To the best of our knowledge, no previous study has analyzed the intraday pattern for order flow for any market.

Our data are sourced from the world's biggest financial market, the inter-dealer spot foreign exchange market. In spite of its size and importance, the spot FX market has previously been underrepresented in the literature on intraday empirical regularities, due to difficulties in obtaining data. The present analysis will partially correct this imbalance.

Evans and Lyons (2002) define order flow as "the net of buyer-initiated and seller-initiated orders" and state that "it is a measure of net buying pressure". They argue that order flow is driven by (private) information and they provide strong evidence to show that order flow is the proximate driver of price in the spot FX market. Specifically, they show that cumulative order flow is highly correlated with cumulative price change. From market microstructure theory, Easley and O'Hara (1992) suggest another variable as being closely linked to private information, namely, unanticipated fluctuations in trading volume levels. We explore both of these ideas.

There is an abundance of theory which models bilateral relationships between the variables that we observe in intraday data, e.g. linking volatility and volume, or volume and bid-ask spreads. As ap Gwilym and Sutcliffe (1999) observe, the most common theme across these bilateral relationship models is private information. We use a correlation matrix to test multiple contemporaneous hypotheses, and to examine how the relationships under investigation changed following the introduction of the euro. Finally, we reveal the importance of private information in explaining observed fluctuations in bid-ask spreads and return volatility.

We take account of structures and practices in the inter-dealer spot FX market that are different from the assumed market structure underlying most of the existing market microstructure theory. The market we study is electronic, order-driven and conspicuously lacks market makers at its core. Rather, any eligible agent who wishes to trade in this market has two choices. He can submit a market order or a limit order. A market order executes immediately by selecting a trader on the other side of the market who has previously advertised on the electronic system that he is willing to trade. A limit order is where a potential trader submits an advertisement that he is willing to trade. This limit order will sit alongside the bank of orders already in the system. Limit orders can be either ask-side or bid-side. The same is true for market orders. There is no pressure on any participant in this market to submit two-way limit orders and no evidence that any party actually submits two-way limit orders.

The remainder of the paper is organized as follows. Section 2 reviews the empirical literature documenting patterns in intraday trading variables and explores the theory relating these data variables to each other in order to deduce a comprehensive set of mutually consistent bilateral hypothesized relationships. Section 3 describes the data and methodologies we use. Section 4 presents the empirical results. Section 5 concludes.

2. Literature Review and Hypotheses

In this section, we review the literature on empirical regularities of intraday trading variables and on the market microstructure theory that relates these variables to each other. From the former, we will document the observed patterns with which we compare the patterns in our data. From the latter, we deduce bilateral hypotheses of how each variable relates to the others and to formalize these in a matrix of signs of expected correlation coefficients.

The vast majority of studies which look at the intraday patterns of bid-ask spreads[1], trading volume[2] and return volatility[3] in financial markets find that they are U-shaped. In some cases, the open is larger than the close, giving an L shape. Sometimes, the close is larger than the open, giving a J shape. In some instances, there is a spike of activity at lunchtime, giving a W shape. However, these are merely variations on the predominant U shape which shows large volume, high volatility and wide bid-ask spreads at the open and close, and more moderate levels of all three in between. The only persistent exception is the spot FX market, which, as the only truly global market, does not experience daily open and close events. This market produces

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[1] Evidence of U-shaped intraday bid-ask spreads in futures markets were reported by Ma et al (1992), Wang et al (1994), Abhyankar et al (1995), and Ding (1999). Equity intraday bid-ask spreads were found to be U-shaped by McInish and Wood (1992), Brock and Kleidon (1992), Lee et al (1993), Lehmann and Modest (1994), Chan, Chung and Johnson (1995), Werner and Kleidon (1996), Abhyankar et al (1997), Brockman and Chung (1998), Ahn et al (2001), Levin and Wright (1999) and Madhavan et al (1997).

[2] Ekman (1992) and DeJong and Donders (1998) find a U-shaped intraday pattern in the number of trades in futures markets. A U-shaped intraday volume pattern is found in futures markets by Gannon (1994), Abhyankar et al (1995), ap Gwilym et al (1996), Franses et al (1997), Buckle et al (1998), Piccinato et al (1998) and Tse (1999). A U-shaped intraday pattern in equity trading volumes is reported by Jain and Joh (1988), McInish and Wood (1990), Stephan and Whaley (1990), Gerety and Mulherin (1992), Foster and Viswanathan (1993), Lee et al (1993), Niemeyer and Sandas (1993), Lehmann and Modest (1994), Atkins and Basu (1995), Chan, Chung and Johnson (1995), Werner and Kleidon (1996), and Madhavan et al (1997). U-shaped intraday volume is reported by Chan, Christie and Schultz (1995) for Nasdaq stocks.

[3] U-shaped return volatility is reported in futures markets by Kawaller et al (1990), Froot et al (1990), Cheung and Ng (1990), Chan et al (1991), Ekman (1992), Ito and Lin (1992), Becker et al (1993), Gannon (1994), Lee and Linn (1994), Wang et al (1994), Chang et al (1995), Daigler (1997), Franses et al (1997), Kofman and Martens (1997), Buckle et al (1998), and Tse (1999). U-shaped intraday return volatility in equity markets is reported by McInish and Wood (1990), Gerety and Mulherin (1992), Lehmann and Modest (1994), Chan, Christie and Schultz (1995), Werner and Kleidon (1996) and Abhyankar et al (1997). Andersen and Bollerslev (1997) found a W-shaped return volatility pattern for S&P 500 futures, while Hiraki et al (1995) found a reverse L shape for the Nikkei futures.

intraday patterns for volume and volatility in the shape of the letter M and intraday bid-ask spreads in a W-shaped pattern.[4]

Danielsson and Payne (2001) find an M-shaped volume pattern and a W-shaped bid-ask spread pattern for USD/DEM spot exchange rate on Reuters global inter-dealer FX trading platform. Baillie and Bollerslev (1990) found that volatility for the major currency pairs peaks twice during the day, when London and New York open, yielding an M-shaped plot. Low and Muthuswamy (1996) find similar peaks in price change volatility for three major currency pairs when London and New York open and close. Hseih and Kleidon (1996) and Docking et al (1999) find the same pattern for the USD/DEM. To date, the literature on intraday empirical regularities neglects intraday order flow. Our analysis reveals the intraday pattern for order flow for the five most important spot foreign exchange rates.

Ap Gwilym and Sutcliffe (1999) divide the explanations for these observed patterns in intraday trading data into two categories. One approach, typified by Brock and Kleidon (1992), attributes these patterns to differing trader behavior around the market open and the market close. The other approach, typified by Admati and Pfleiderer (1988), attributes the patterns to the strategic behavior of informed traders. Since there is no daily open and close in the global foreign exchange market, it is the latter approach that is the focus of our attention in the present analysis.

Admati and Pfleiderer (1988) argue that informed traders trade when there are a lot of uninformed traders in the market, in order to minimize their transactions costs, i.e. bid-ask spreads. The bid-ask spread will be lower when there are many uninformed traders because market makers' inventory management costs are lower in such circumstances. If informed traders can hide among the uninformed traders, they can avail of these lower bid-ask spreads. This perspective fits well with an analysis of the global foreign exchange market which has trading volume naturally concentrated in London and New York business hours. However, it is not clear that we can use this

[4] There are a few exceptions in this literature to the overall U-shape and spot FX M-shape story. For example, Franses et al (1997) find a flat distribution of bid-ask spreads across the day for the LIFFE Bund future. Another example is Chan, Christie and Schultz's (1995) finding that Nasdaq bid-ask spreads are flat throughout the day and tail off significantly at the close. In addition, Abhyankar et al (1997) find an M-shaped volume pattern for UK stocks.

argument to treat volume as a direct proxy for private information because we also have more uninformed trading activity at high volume times. Any relationship that we might discover between high volume and bid-ask spreads or return volatility may just as easily be caused by the high uninformed trading volume as by trading volume generated by informed traders. Easley and O'Hara (1992) provided an important insight into the link between trading volume and private information when they suggested that private information signals cause trading volume to deviate from its normal level. Empiricists, such as Bessembinder (1994), Jorion (1996), Hartmann (1998) and Danielsson and Payne (2001) have used this idea to split trading volume into expected and unexpected components. Unexpected trading volume is associated with private information. Expected trading volume is not. We employ this idea in our analysis. Expected and unexpected volume should be orthogonal to each other.

H1: Expected Correlation (Expected Volume, Unexpected Volume) = 0

Our other proxy for private information is order flow. Evans and Lyons (2002) provide compelling empirical evidence of a strong relationship between cumulative order flow and exchange rates. They attribute this to unobservable shifts in expectations which affect not only future returns but also risk appetites and discount rates. From market microstructure theory, Kyle (1985), upon which Admati and Pfleiderer (1988) base their model, uses order flow as the conduit by which private information affects the bid-ask spread. However, Garman (1976) links order flow to inventory effects. These could just as easily arise from uninformed trading as from informed trading. Garman's (1976) model considers supply and demand volumes as being determined separately from independent distributions. This gives rise to temporal imbalances between supply and demand, i.e. (uninformed) order flow. In the context of our analysis, the supply and demand distributions will vary as trading volume varies throughout the day. Therefore, the potential for imbalance between independently determined supply and demand volumes should vary over the trading day in a systematic way linked to trading volume. As such, it seems prudent to divide order flow into expected and unexpected components in the same way as we divide volume. As with volume, the unexpected component would be associated with private information but the unexpected component would not. Expected and unexpected volume should be orthogonal to each other. The proxies for private information should be positively correlated. Similarly, the proxies for uninformed trading activity should also be positively correlated with each other. In addition, each proxy of private information should also be orthogonal to the alterative proxy for uninformed trading.

H2: Expected Correlation (Expected Order Flow, Unexpected Order Flow) = 0
H3: Expected Correlation (Expected Volume, Expected Order Flow) = +
H4: Expected Correlation (Unexpected Volume, Unexpected Order Flow) = +
H5: Expected Correlation (Expected Volume, Unexpected Order Flow) = 0
H6: Expected Correlation (Expected Order Flow, Unexpected Volume) = 0

Much market microstructure research is devoted to exploring and explaining two price related variables: the bid-ask spread and return volatility. We too hope to contribute some insight into the determinants of these two variables, using our proxies for private information, as well as their expected counterparts which proxy for uninformed trading activity. Market microstructure theory tells us that bid-ask spreads and return volatility are not unrelated to each other. Roll (1984) used the empirical phenomenon of bid-ask bounce[5] to derive the effective bid-ask spread directly from return volatility. The relationship between bid-ask spread and return volatility is positive in Roll's (1984) model, because larger bid-ask spreads give rise to larger bid-ask bounces, and so higher return volatility. Black (1991) proposed a more elaborate model for transaction costs in FX markets whereby the bid-ask spread is positively dependent on return volatility, but is negatively correlated with volume. Hartmann (1998) formalized Black's (1991) model and found empirical evidence to support it.

The preceding leads us to expect that bid-ask spreads and return volatility should be positively correlated with each other. However, as McGroarty et al (2006) point out, bid-ask spreads in the electronic inter-dealer spot FX market are intrinsically different from those in established market microstructure theory[6] which underlie the models

[5] In financial markets, some prices execute at the ask side of the market and some prices execute at the bid side of the market. The oscillation of transaction prices between bid and ask quotes is known as bid-ask bounce. This phenomenon induces negative serial correlation in high frequency time series traded price data.

[6] McGroarty et al (2006) argue that the existing theory assumes that the bid-ask spread is compensation to a market maker for risking his own capital in order to facilitate trading by other market participants. They find this concept of a market at odds with the electronic inter-dealer spot foreign exchange market, where they say there is no evidence of anybody is acting like a market maker, i.e. providing simultaneous bid and ask limit prices (quotes). Instead, this market consists of FX dealers, who may act

described above. Mainstream market microstructure bid-ask models incorporate the Amihud and Mendelson (1980) idea that market makers shade their prices down(up) to sell(buy) excess inventory. This process dampens volatility in prices because it deliberately targets and entices sequentially opposite sides of the market to trade. A market-maker-less electronic order driven market lacks this price dampening mechanism. If a market order absorbs all the limit order volume at a specific price level, the price behind this is revealed. Subsequent traders are faced with a higher prevailing mid-price on which to base their trading decisions. In a market-maker-less market, an imbalance between buyers and sellers will result in a price disturbance, even if that imbalance does not reflect informed trading. Such price disturbances may well be short-lived, but they will contribute to higher volatility at the high frequency level than would be present if market makers participated.

There remains an observable bid-ask spread in electronic inter-dealer spot FX market. Traders still have to weigh the benefit of immediate execution via market order, against the potential benefit of waiting for a price improvement via limit order, which narrows the bid-ask spread. There will still be a bounce between the bid and ask prices which will contribute to the overall observed return volatility, but the effect should be much weaker than that observed in markets with market makers at their core. We expect to find a weak but positive correlation between bid-ask spreads and return volatility.

H7: Expected Correlation (Bid-Ask Spread, Return Volatility) = +

McGroarty et al (2006) showed that the electronic inter-dealer spot FX bid-ask spread should fall as trading volume rises for a technical reason. They argued that if prices follow a random walk with drift, then bid limit orders and ask limit orders, which arrive independently, will have a shorter time gap between their arrival times when volume is high. The shorter time gap means that the drift component of the mid-price will be smaller, therefore the gap between the bid price and ask price will be lower. In the context of our study, this means that bid-ask spreads and expected volume should

as market makers when dealing with their customers, but who submit either one-sided limit or market orders in the electronic inter-dealer market. In this kind of market, the bid-ask spread is the difference between the best available bid limit order price and the best available ask limit order price.

be negatively correlated. Similarly, bid-ask spreads should be negatively correlated with expected order flow, insofar as the latter is also proxy for uninformed trading activity.

H8: Expected Correlation (Bid-Ask Spread, Expected Volume) = –
H9: Expected Correlation (Bid-Ask Spread, Expected Order Flow) = –

Clark's (1973) Mixture of Distributions Hypothesis (MDH) argues that volatility and volume move together in response to a common unobservable external stimulus, deemed to be public information. The arrival of news pushes both volume and volatility (a measure of absolute price adjustment) in the same direction. Later researchers have elaborated on this idea. Epps and Epps (1976) link intra-day volatility to disparate opinions among traders following a public price signal. Tauchen and Pitts (1983) develop the disparate opinion among traders model more formally. They propose a bivariate mixture model in which volume and price change are jointly distributed due to the presence of a latent variable. This model shows the covariance between volume and price change as zero, while the covariance between volume and price change volatility is positive, which is what has been commonly observed empirically. Order flow is not an explicit focus of these MDH models. However, it is hard to conceive of how price could move more sharply up or down as volume rises, without a corresponding imbalance between buy-side and sell-side trading volume. As such, order flow should prove to be the conduit by which trading volume drives price (volatility). This idea is supported by the research of Copeland (1976) and Jennings, Starks and Fellingham (1981) who develop models based on sequential information arrival. Here, an individual trader receives a signal ahead of the market and trades on it, thereby creating order flow (volume) and moving price (volatility). These ideas lead us to expect that return volatility will be positively correlated with both expected volume and expected order flow.

H10: Expected Correlation (Return Volatility, Expected Volume) = +
H11: Expected Correlation (Return Volatility, Expected Order Flow) = +

McGroarty et al's (2006) characterization of the bid-ask spread in the market-maker-less electronic inter-dealer spot FX market includes no adverse selection component of the bid-ask spread. They argue that the absence of market makers means there is nobody to be compensated for accepting inventory that they do not want, or can not turnover before price changes adversely. Rather, both parties to every executed trade want the outcome of that trade. This means that trades motivated by private information should not affect the bid-ask spread. Instead, trading volume (order flow) generated by private information should directly drive the price up or down. Therefore, our proxies for private information, unexpected volume and unexpected order flow, should be uncorrelated with the bid-ask spread but positively correlated with return volatility.

H12: Expected Correlation (Bid-Ask Spread, Unexpected Volume) = 0
H13: Expected Correlation (Bid-Ask Spread, Unexpected Order Flow) = 0
H14: Expected Correlation (Return Volatility, Unexpected Volume) = +
H15: Expected Correlation (Return Volatility, Unexpected Order Flow) = +

By laying out our fifteen hypotheses in a matrix of predicted correlation signs, a clear and succinct picture of our predictions emerges:

BA	1					
RV	~+	1				
EV	-	+	1			
UV	0	+	0*	1		
EO	-	+	+	0	1	
UO	0	+	0	+	0*	1
	BA	**RV**	**EV**	**UV**	**EO**	**UO**

Key: **BA** – Bid-ask spread, **RV** – Return Volatility, **EV** – Expected Volume, **UV** – Unexpected Volume, **EO** – Expected Order Flow and **UO** – Unexpected Order Flow.
** - should hold by construction*

3. Data and Methodology

The data used in this study are 5-minute observations sampled from a large spot FX database of tick data provided to us by EBS. This data has not previously been made available to academic researchers. EBS is the larger of the two electronic venues that make up the inter-dealer spot FX market. The other is Reuters 2000-2. EBS is dominant in the large currencies involving the USD, EUR and JPY, whereas Reuters 2000-2 dominates the Commonwealth and Scandinavian currencies.

The foreign exchange market generally, and the electronic inter-dealer spot FX market in particular, are very important financial markets. In 1998, the Bank of International Settlements estimated that the total volume of spot foreign exchange trading was worth almost US$1.5 trillion per day. After EMU, the total value of FX transactions fell. However, the FX market remains the largest financial market in the world, by many orders of magnitude. BIS (1998) and BIS (2001) both show that spot FX transactions account for a little under half of all trading activity in the FX market. In turn, inter-dealer trading accounts for about two-thirds of total global spot FX volume. Over the past decade, the importance of electronic trading venues in the inter-dealer market has risen sharply. BIS (2001) estimates that between 85% and 95% of inter-bank trading occurred over electronic trading systems in 2000. Furthermore, McGroarty et al (2006) argue that the electronic inter-dealer market effectively sets the exchange rates for the rest of the FX market because it is by far the most transparent and up-to-the-second part of the FX market.

The EBS data contains spot FX limit order price data and trade price data for eight currency pairs from the EBS electronic inter-dealer market. The limit order price data comprises the best bid and ask limit order prices per second (Greenwich Mean Time (GMT)). Trade data is also time-stamped to the nearest second (GMT). No information about the size of each transaction is provided. Also, there are no identifiers of the parties to each trade. The data consist of two separate sample periods with five important exchange rates[7] in each. The first covers the period 01/08/98 to

[7] Trading volume is highly concentrated in the spot foreign exchange market. In the period studied here, EUR/USD, USD/DEM and USD/JPY all have trading volume on EBS which is more three times the next most heavily traded exchange rate. The next most important exchange rates include

04/09/98 and consists of the currency pairs USD/DEM, USD/JPY, USD/CHF, DEM/JPY and DEM/CHF. The second covers 01/08/99 to 03/09/99 and contains data on EUR/USD, USD/JPY, USD/CHF, EUR/JPY and EUR/CHF. Each sample contains 20 days of observations. In this study, the EUR is taken to be the linear successor to the DEM on the grounds that, pre-EMU, the DEM was a pan-European vehicle currency (see Hartmann (1998)). This enables us to pair exchange rates involving the DEM with those involving the EUR for the purpose of analysis, giving us in effect five exchange rates to evaluate and two samples (pre-EMU and post-EMU) for each exchange rate.

Our bid-ask spread and return volatility variables are both calculated using the difference in log prices (e.g. see Buckle et al (1998)). Bid-ask spreads use the last bid and ask prices, from series of best quote prices, in each 5-minute interval. Returns are calculated using the last trade prices in the interval. For testing, the absolute return is used as a proxy for return volatility, which is consistent with the method proposed by Andersen, Bollerslev, Diebold and Labys (2001). The other four variables, expected and unexpected order flow, and expected and unexpected volume are derived from our total order flow and total volume variables respectively. Our data does not provide actual volume data, so the number of trades is used as a proxy. Fortunately, our data does provide the side of each trade. Our measure of total volume comprises the total number of buyer-initiated trades over the interval plus the total number of seller-initiated trades. Following Hartmann (1998), our total order flow measure is arrived at by taking the absolute difference between the number of buy (ask side) trades and the number of sell (bid side) trades.

To calculate expected volume, we follow the approach of Danielsson and Payne (2001), who measure it as the across-day average of volume for each time-of-day segment. Unexpected volume is calculated as the difference between the actual volume in each observation and this expected measure. Similarly, expected order flow is computed as the across-day average of absolute order flow per time-of-day segment. Unexpected order flow is the difference between the absolute value of actual order flow and the expected measure. The variables are formally defined as follows:

EUR(USD)/JPY and rates involving CHF and GBP. We focus on CHF rates rather than GBP rates because EBS is stronger in those markets.

(1) $s_{d,t} = \log(a_{d,t}) - \log(b_{d,t})$

Bid-ask spread

(2) $\left|r_{d,t}\right| = \left|\log(p_{d,t}) - \log(p_{d,t-1})\right|$

Return Volatility

(3) $EV_t = \sum_{d=1}^{D} V_{d,t} / D$

Expected Volume

(4) $UV_{d,t} = V_{d,t} - EV_t$

Unexpected Volume

(5) $EO_t = \sum_{d=1}^{D} \left|O_{d,t}\right| / D$

Expected Order Flow

(6) $UO_{d,t} = \left|O_{d,t}\right| - EO_t$

Unexpected Order Flow

In these equations, the measures are shown with two subscripts, *d* which represents the day and *t* which represents the time of day (at 5-minute intervals). *D* represents the total number of days. These variables are computed separately for each of the five currency pairs within each pre-EMU and post-EMU data samples.

Our empirical analysis consists of two steps. The first step is to depict the regular intraday patterns of our four underlying variables (bid-ask spreads, return volatility, volume and (absolute) order flow) in graphs. Our second method is to compute correlation matrices of these six variables for each currency pair and each sample period. Close matches to our predicted correlation matrix would lend credibility to our characterization of the institutional features of the market and to our hypothesized bilateral relationships between the variables. Any major differences would need explanation and would require us to re-evaluate the theory underlying our predictions.

4. Empirical Results

Figures 1 to 5 show the intraday patterns for bid-ask spreads, return volatility, volume and (absolute) order flow. In each panel, the post-EMU (1999) pattern is overlaid on the pattern for pre-EMU (1998). In all cases, both the 1998 and 1999 curves are drawn on the same axes and scale. The Y-axis always the X-axis at 0 in every panel. The X-axis shows time of day in GMT. The intraday data spans 24-hours, since spot FX is a global business.

We believe the intraday pattern for order flow is new, as we know of no other published research which has previously presented such a graph for any financial market. This pattern clearly bears a close resemblance to intraday volume. The M-shaped volume and volatility, and U-shaped or W-shaped bid-ask spread intraday patterns are as we expect from previous empirical research. These patterns reveal a clear inverse relationship between the bid-ask spread and the other three variables.

In four out of our five exchange rates, our shift from pre-EMU to post-EMU volume, volatility and order flow are accompanied by the bid-ask spread moving in the opposite direction. Three of these, EUR(DEM)/USD, USD/JPY and EUR(DEM)/JPY, display a fall in volume, volatility and order flow accompanying an upward in the bid-ask spread move. The fourth, USD/CHF, shows a rise in volume, volatility and order flow alongside a bid-ask spread decline. For our remaining exchange rate, EUR(DEM)/CHF, everything is lower in 1999[8].

The same overall story emerges from our graphs via two separate and distinct perspectives (intraday and pre/post-EMU). Trading volume, order flow and return

[8] McGroarty et al (2006) argue that a shift in post-EMU international currency flows has changed the dynamics between USD/CHF and EUR/CHF. They argue that international currency flows shifted away from using DEM/CHF as a vehicle currency to using USD/CHF after EMU, rather than to using EUR/CHF. They contend that post-EMU bid-ask spreads are lower because EUR/CHF must compete for international vehicle currency flow with USD/CHF, which has lower bid-ask spreads post-EMU.

volatility appear to be very closely and positively linked, while the bid-ask spread is inversely related to all three. This constitutes evidence in support of Clark's (1973) Mixture of Distributions Hypothesis which predicted a positive relationship between volume and volatility. It also supports Garman's (1976) intuition that order flow would arise from random imbalances in the numbers of buyers and sellers. In addition, it supports the McGroarty et al (2006) argument that bid-ask spreads in this kind of market are inversely linked to trading volume for a technical reason.

Tables 1 to 10 present our correlation matrices. Tables 1 to 5 cover our five exchange rates and are based on the full data sample which contains 5-minute frequency data sampled from the 24-hour global FX market. Each correlation coefficient in these matrices is derived using around 7,000 observations per variable. The correlation matrices presented in tables 6 to 10 are based on data taken only from the busiest part of the trading day (7.00am(GMT) to 17.00pm(GMT)), when London and New York are operating and trading volumes are at their highest. Each of our ten tables has two parts. Part (a) is based on the pre-EMU data from 1998, while part (b) represents post-EMU data from 1999. All correlation matrices match our predicted matrix remarkably well, which provides additional support to our characterization of the relationships between bid-ask spreads, return volatility, volume and order flow.

In almost all cases, a positive but low correlation is evident between bid-ask spreads and return volatility. Using the full data sample, bid-ask spreads are 5% correlated with return volatility on average. This rises to an average of 7% when we focus on the high volume data alone. This evidence vindicates McGroarty et al (2006) characterization of electronic inter-dealer spot FX bid-ask spreads as being very different from the mainstream bid-ask spread model. The absence of market maker inventory management behavior in particular underlies the weak relationship between the bid-ask spread and return volatility in the present context. The positive average value reflects the contribution of the bid-ask bounce across the small bid-ask spread to overall return volatility.

As we predicted, the bid-ask spread is consistently negatively correlated with normal trading activity proxies: expected volume and expected order flow. In the full data sample, correlation coefficients range from -20% to -40%. These support the

McGroarty et al (2006) assertion that electronic inter-dealer spot FX market bid-ask spreads are determined by the independent arrival time of bid and ask limit orders. In a heavily traded market, limit orders arrive close together, so any drift component in the price generation process has little time in which have an effect. In a thin market, more time between the arrival of best bid and ask limit orders means the drift component of successive prices can make a larger contribution to the bid-ask spread.

The correlation between the bid-ask spreads and our private information proxies, unexpected volume and unexpected order flow, is 0% on average across the twenty correlation matrices. This supports the McGroarty et al (2006) assertion that there is no adverse selection risk component in electronic inter-dealer spot FX market bid-ask spreads and that informed trades should impact prices directly, driving them up or down. This assertion finds strong support in the high positive correlations between return volatility and both of our private information proxies, which range from 29% to 59%.

Clark's (1973) Mixture of Distributions Hypothesis also finds support. Correlations between return volatility and our normal trading activity proxies, expected volume and expected order flow, are all consistently positive. However, with a maximum correlation coefficient of 29%, these variables are less highly correlated with return volatility than our private information proxies. Nevertheless, the evidence clearly shows that private information and uninformed temporary supply/demand imbalances contribute independently to spot FX return volatility. Collectively, on average, the two effects account for well over half of the variance observed at the 5-minute sampling frequency. Indeed, they can account for as much as 77% of return volatility, as is the case for the volume variables for EUR/USD in the 1999 full-data sample.

The very close relationship between order flow[9] and volume that we observed in the graphs is confirmed by the very high correlations we observe between expected volume and expected order flow. Consistent, strong, positive correlations are also evident between unexpected volume and unexpected order flow. The close relationship between these two variables is consistent with our assertion that both are

[9] We computed the correlations of other variables with total (signed) order flow. This variable showed no strong or consistent relationship with any other variable we study. These results here are not shown.

proxies for private information. The independence of our expected and unexpected variables from each other is precisely as we predicted.

5. Conclusions

We found compelling evidence to support fifteen theory-based bilateral relationships between six data variables associated with trading. The six variables are: bid-ask spread, return volatility, expected volume, unexpected volume, expected order flow and unexpected order flow. The evidence was consistently strong across all ten of our sample periods, i.e. across all five currency pairs, for both pre-EMU and post-EMU samples. In particular, the McGroarty et al (2006) characterization of the bid-ask spreads as being very different from that normally assumed in the market microstructure is strongly vindicated by this evidence.

Our analysis added order flow to the list of data variables whose intraday patterns have been documented. Order flow magnitude has an M-shaped pattern which closely tracks trading volume over the day. This is consistent with Garman's (1976) assertion that order flow arises from random temporal imbalances between supply and demand, rather than being a strict proxy for private information, as might have been inferred from Evans and Lyons (2002). This uninformed order flow disturbs price, contributing to return volatility. This contrasts with financial markets which have market makers at their centre, who suppress this source of return volatility by 'shading' quote prices in order to manage the acquired inventory.

Such market-maker-centric markets are more expensive to trade in because the market makers must be compensated for providing this service via wider bid-ask spreads. Our study shows that, while electronic inter-dealer spot FX bid-ask spreads are always of a low general level, they widen and narrow with the normal ebb and flow of trading activity over the day, i.e. they are narrowest when expected volume is high and widen when expected volume falls.

Utilizing Easley and O'Hara's (1992) idea that price signals are associated with deviations from normal trading levels, we used unexpected order flow and unexpected volume as our proxies for private information. Both of these proxies showed private information has almost no effect on the bid-ask spread in this market. This is consistent with the McGroarty et al (2006) assertion that bid-ask spreads in this type of market have no adverse selection risk component and that informed trading feeds directly into price change (return volatility). Our empirical evidence shows that our private information variables contribute return volatility that is separate from and greater than the return volatility generated by normal trading activity alone. The high correlation coefficients lead us to conclude that private information is probably the most important determinant of return volatility in high frequency spot FX data, but it is not the only determinant.

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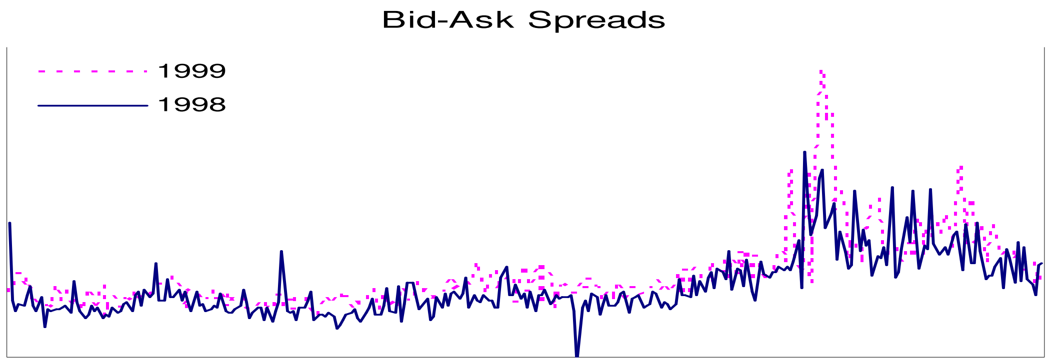

Figure 1(a): USD/JPY Bid-Ask Spreads

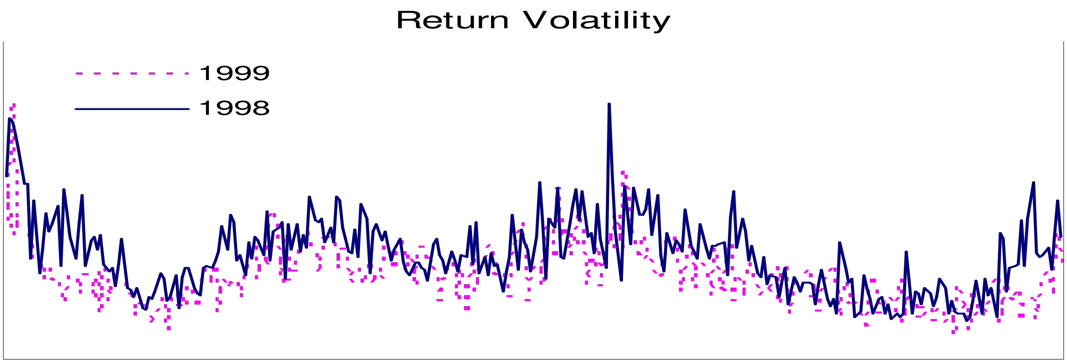

Figure 1(b): USD/JPY Return Volatility

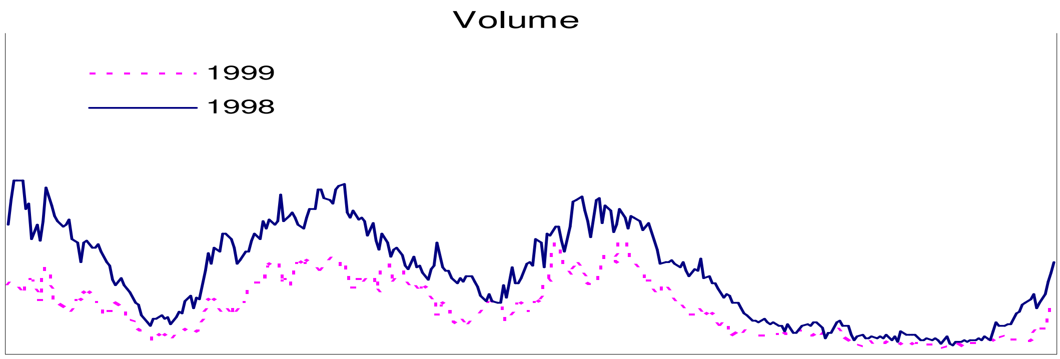

Figure 1(c): USD/JPY Trading Volume

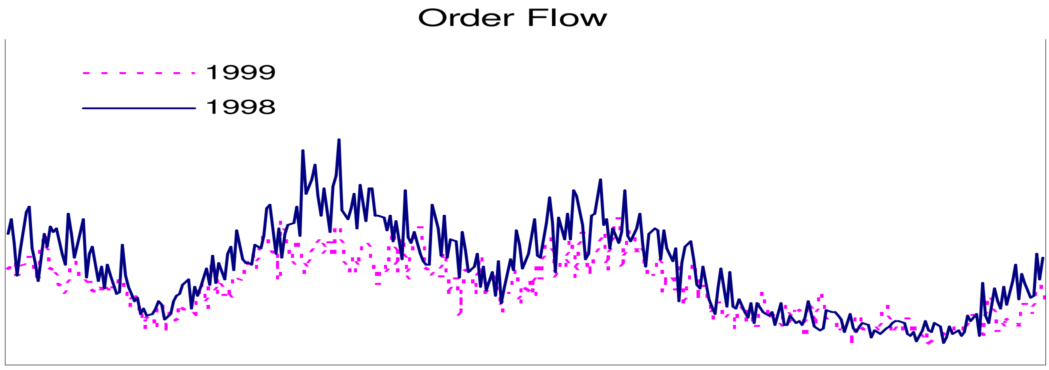

Figure 1(d): USD/JPY Absolute Order Flow

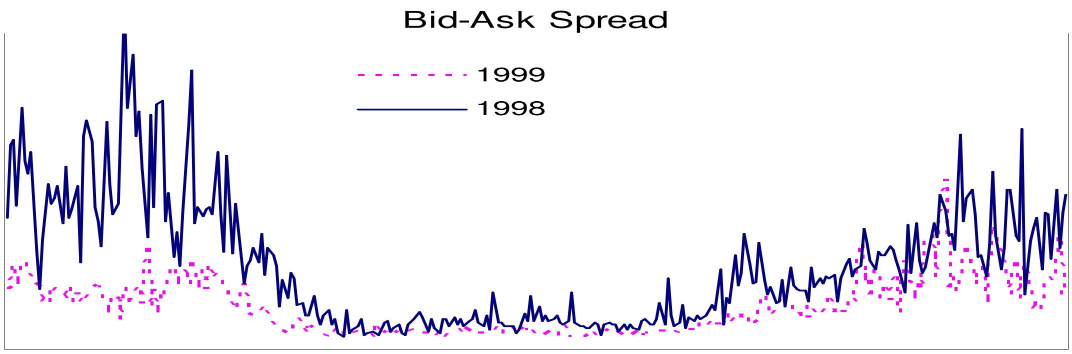

Figure 2(a): USD/CHF Bid-Ask Spreads

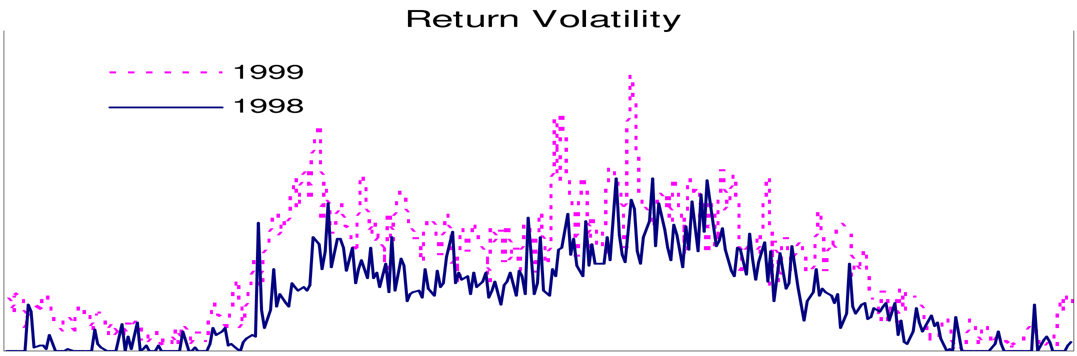

Figure 2(b): USD/CHF Return Volatility

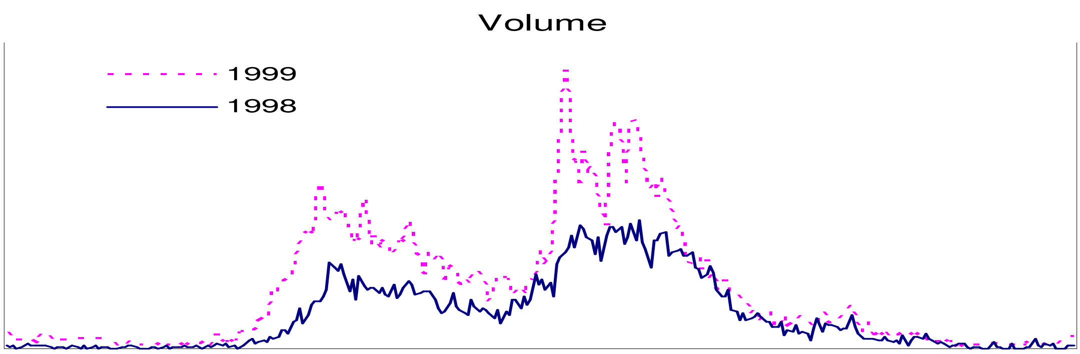

Figure 2(c): USD/CHF Trading Volume

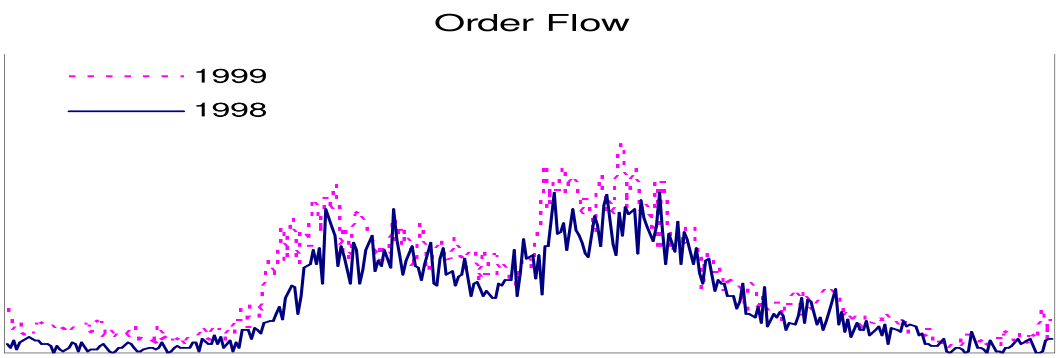

Figure 2(d): USD/CHF Absolute Order Flow

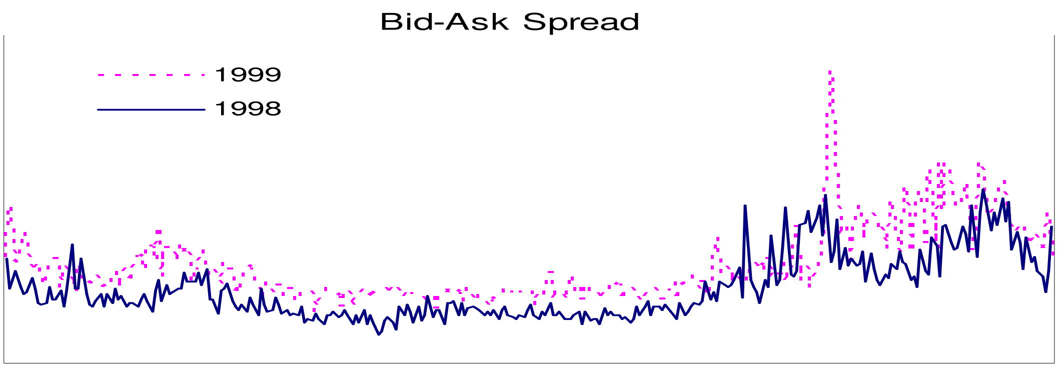

Figure 3(a): EUR(DEM)/USD Bid-Ask Spreads

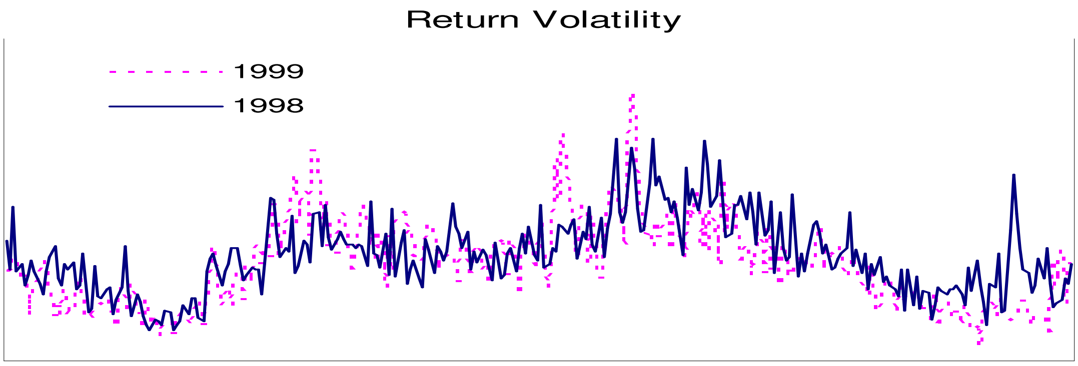

Figure 3(b): EUR(DEM)/USD Return Volatility

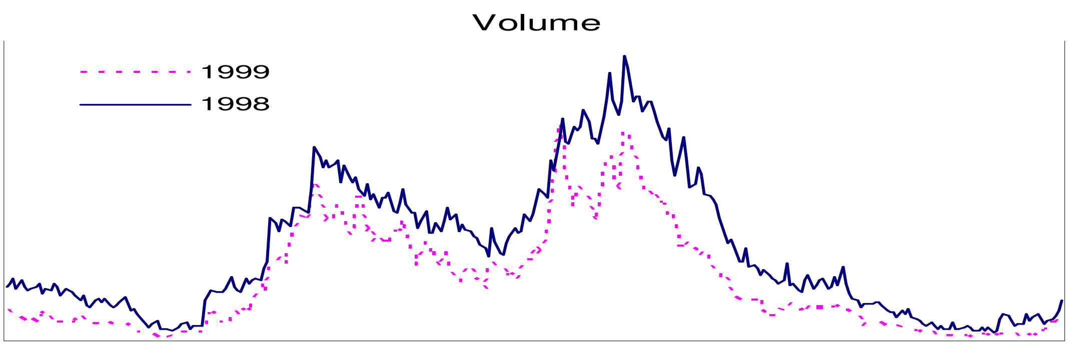

Figure 3(c): EUR(DEM)/USD Trading Volume

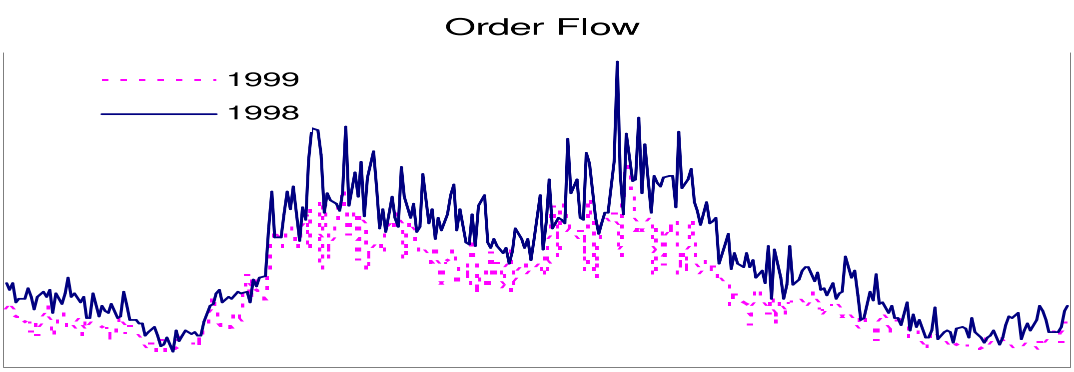

Figure 3(d): EUR(DEM)/USD Absolute Order Flow

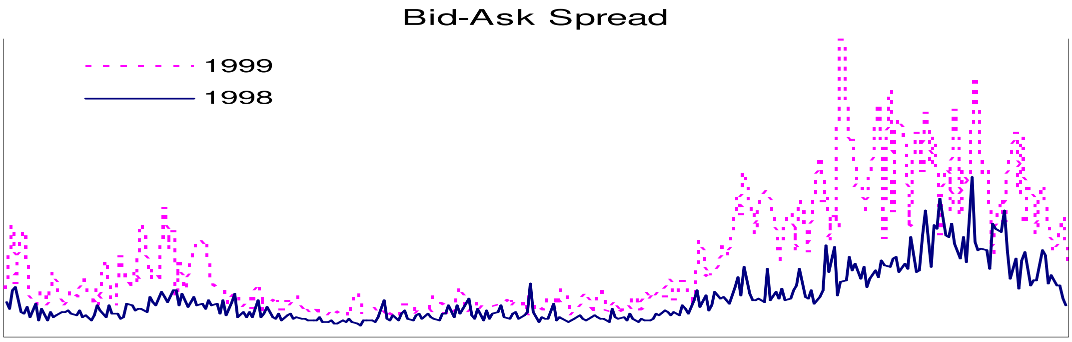

Figure 4(a): EUR(DEM)/JPY Bid-Ask Spreads

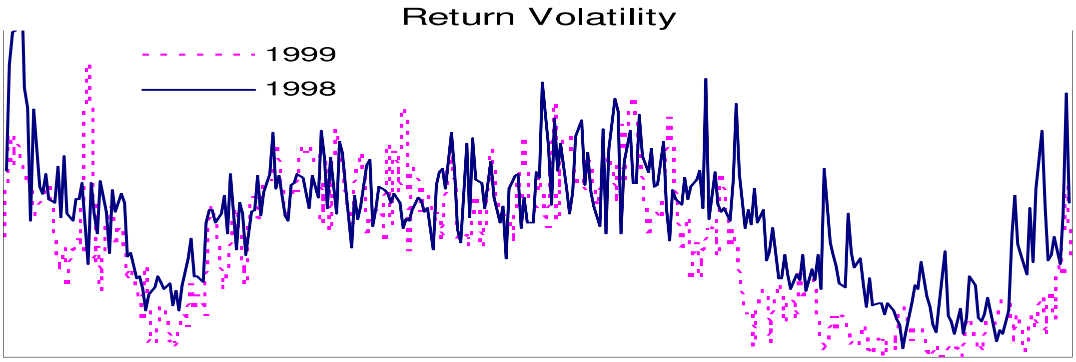

Figure 4(b): EUR(DEM)/JPY Return Volatility

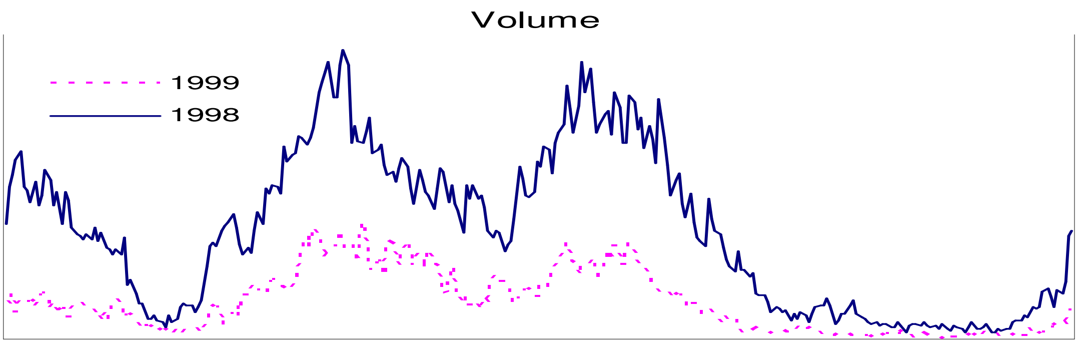

Figure 4(c): EUR(DEM)/JPY Trading Volume

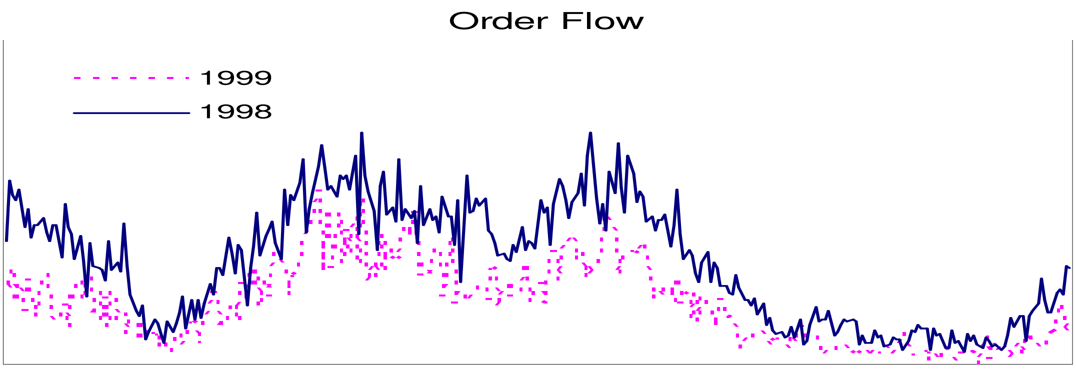

Figure 4(d): EUR(DEM)/JPY Absolute Order Flow

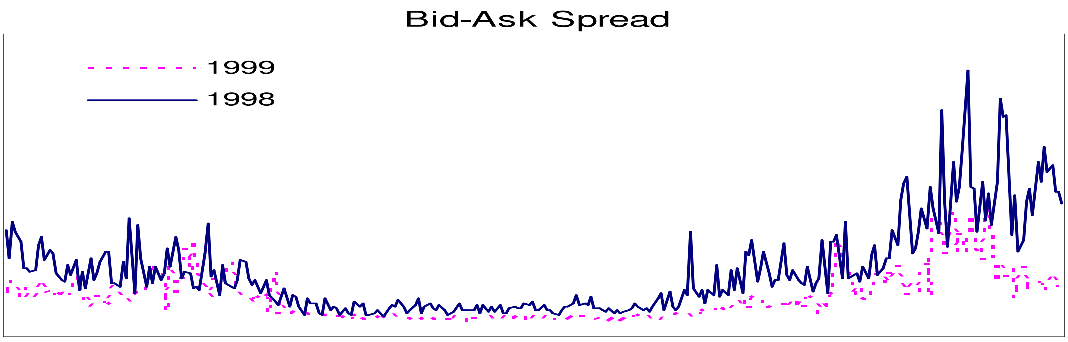

Figure 5(a): EUR(DEM)/CHF Bid-Ask Spreads

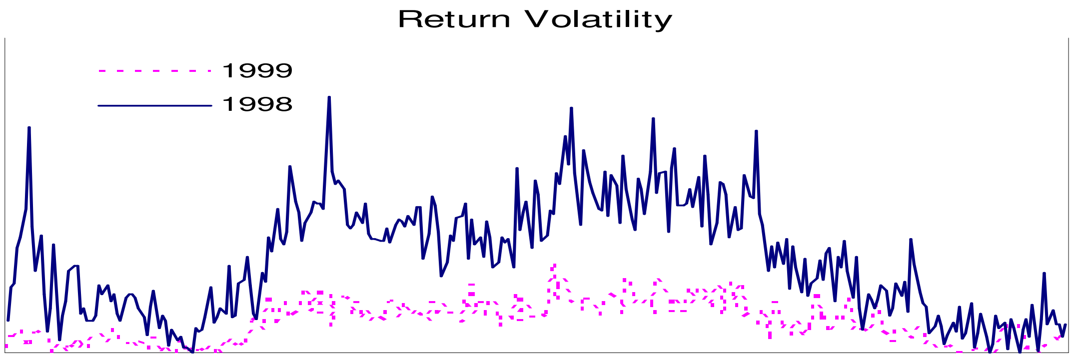

Figure 5(b): EUR(DEM)/CHF Return Volatility

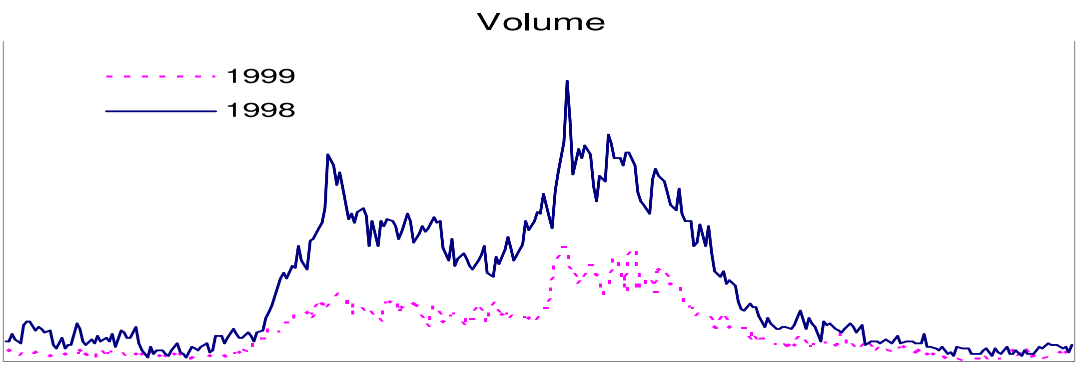

Figure 5(c): EUR(DEM)/CHF Trading Volume

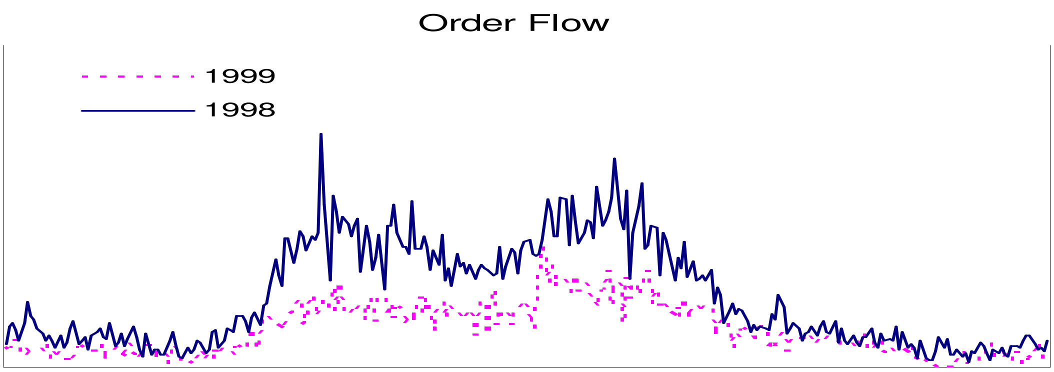

Figure 5(d): EUR(DEM)/CHF Absolute Order Flow

BA	1					
RV	0.05	1				
EV	-0.23	0.21	1			
UV	-0.01	0.53	0	1		
EO	-0.22	0.19	0.89	0	1	
UO	-0.01	0.35	0	0.38	0	1
	BA	**RV**	**EV**	**UV**	**EO**	**UO**

Table 1(a): USD/JPY, 98

BA	1					
RV	0.04	1				
EV	-0.2	0.19	1			
UV	-0.03	0.52	0	1		
EO	-0.2	0.18	0.9	0	1	
UO	-0.03	0.39	0	0.41	0	1
	BA	**RV**	**EV**	**UV**	**EO**	**UO**

Table 1(b): USD/JPY, 99

BA	1					
RV	0.08	1				
EV	-0.36	0.08	1			
UV	-0.02	0.42	0	1		
EO	-0.4	0.07	0.93	0	1	
UO	-0.02	0.33	0	0.54	0	1
	BA	**RV**	**EV**	**UV**	**EO**	**UO**

Table 2(a): USD/CHF, 98

BA	1					
RV	0.01	1				
EV	-0.3	0.19	1			
UV	-0.02	0.43	0	1		
EO	-0.33	0.19	0.95	0	1	
UO	-0.03	0.37	0	0.45	0	1
	BA	**RV**	**EV**	**UV**	**EO**	**UO**

Table 2(b): USD/CHF, 99

BA	1					
RV	0.05	1				
EV	-0.21	0.2	1			
UV	-0.01	0.52	0	1		
EO	-0.2	0.19	0.91	0	1	
UO	-0.01	0.35	0	0.35	0	1
	BA	**RV**	**EV**	**UV**	**EO**	**UO**

Table 3(a): USD/DEM, 98

BA	1					
RV	-0.06	1				
EV	-0.24	0.29	1			
UV	-0.04	0.48	0	1		
EO	-0.25	0.29	0.93	0	1	
UO	-0.03	0.38	0	0.33	0	1
	BA	**RV**	**EV**	**UV**	**EO**	**UO**

Table 3(b): EUR/USD, 99

BA	1					
RV	0.08	1				
EV	-0.3	0.13	1			
UV	0	0.38	0	1		
EO	-0.31	0.14	0.94	0	1	
UO	0.02	0.36	0	0.46	0	1
	BA	**RV**	**EV**	**UV**	**EO**	**UO**

Table 4(a): DEM/JPY, 98

BA	1					
RV	0.05	1				
EV	-0.32	0.1	1			
UV	-0.02	0.39	0	1		
EO	-0.33	0.12	0.94	0	1	
UO	-0.02	0.41	0	0.62	0	1
	BA	**RV**	**EV**	**UV**	**EO**	**UO**

Table 4(b): EUR/JPY, 99

BA	1					
RV	0.09	1				
EV	-0.27	0.12	1			
UV	0.03	0.46	0	1		
EO	-0.28	0.12	0.94	0	1	
UO	0.01	0.38	0	0.51	0	1
	BA	**RV**	**EV**	**UV**	**EO**	**UO**

Table 5(a): DEM/CHF, 98

BA	1					
RV	0.08	1				
EV	-0.35	0.04	1			
UV	-0.02	0.41	0	1		
EO	-0.36	0.04	0.94	0	1	
UO	-0.02	0.34	0	0.52	0	1
	BA	**RV**	**EV**	**UV**	**EO**	**UO**

Table 5(b): EUR/CHF, 99

Full Data Sample Correlations: Tables 1 to 5 are based on the full 24-hour global spot FX data from EBS. Part (a) uses pre-EMU data from 1998, while part (b) uses post-EMU data from 1999. Each correlation coefficient is computed using approximately 7000 observations per variable, sampled at the 5-minute frequency. (Key: **BA** – Bid-ask spread, **RV** – Return Volatility, **EV** – Expected Volume, **UV** – Unexpected Volume, **EO** – Expected Order Flow and **UO** – Unexpected Order Flow.)

BA	1					
RV	~+	1				
EV	-	+	1			
UV	0	+	0	1		
EO	-	+	+	0	1	
UO	0	+	0	+	0	1
	BA	**RV**	**EV**	**UV**	**EO**	**UO**

Predicted

BA	1					
RV	0.04	1				
EV	-0.16	0.11	1			
UV	0	0.56	0	1		
EO	-0.16	0.08	0.79	0	1	
UO	0.02	0.34	0	0.4	0	1
	BA	**RV**	**EV**	**UV**	**EO**	**UO**

Table 6(a): USD/JPY, 98

BA	1					
RV	0.02	1				
EV	-0.18	0.14	1			
UV	-0.01	0.59	0	1		
EO	-0.14	0.12	0.77	0	1	
UO	0.01	0.41	0	0.4	0	1
	BA	**RV**	**EV**	**UV**	**EO**	**UO**

Table 6(b): USD/JPY, 99

BA	1					
RV	0.09	1				
EV	-0.08	0.1	1			
UV	-0.01	0.47	0	1		
EO	-0.08	0.08	0.79	0	1	
UO	-0.02	0.36	0	0.53	0	1
	BA	**RV**	**EV**	**UV**	**EO**	**UO**

Table 7(a): USD/CHF, 98

BA	1					
RV	0.03	1				
EV	-0.15	0.16	1			
UV	-0.03	0.47	0	1		
EO	-0.15	0.15	0.87	0	1	
UO	-0.01	0.4	0	0.44	0	1
	BA	**RV**	**EV**	**UV**	**EO**	**UO**

Table 7(b): USD/CHF, 99

BA	1					
RV	0.13	1				
EV	-0.1	0.11	1			
UV	0.06	0.55	0	1		
EO	-0.1	0.06	0.64	0	1	
UO	0.04	0.29	0	0.3	0	1
	BA	**RV**	**EV**	**UV**	**EO**	**UO**

Table 8(a): USD/DEM, 98

BA	1					
RV	0	1				
EV	-0.06	0.17	1			
UV	-0.05	0.53	0	1		
EO	-0.08	0.15	0.75	0	1	
UO	0	0.38	0	0.3	0	1
	BA	**RV**	**EV**	**UV**	**EO**	**UO**

Table 8(b): EUR/USD, 99

BA	1					
RV	0.11	1				
EV	-0.19	0.07	1			
UV	0.01	0.42	0	1		
EO	-0.18	0.06	0.81	0	1	
UO	0.03	0.39	0	0.44	0	1
	BA	**RV**	**EV**	**UV**	**EO**	**UO**

Table 9(a): DEM/JPY, 98

BA	1					
RV	0.05	1				
EV	-0.28	0.1	1			
UV	-0.02	0.46	0	1		
EO	-0.27	0.11	0.88	0	1	
UO	-0.02	0.48	0	0.59	0	1
	BA	**RV**	**EV**	**UV**	**EO**	**UO**

Table 9(b): EUR/JPY, 99

BA	1					
RV	0.14	1				
EV	-0.13	0.08	1			
UV	0.11	0.51	0	1		
EO	-0.13	0.07	0.76	0	1	
UO	0.06	0.41	0	0.49	0	1
	BA	**RV**	**EV**	**UV**	**EO**	**UO**

Table 10(a): DEM/CHF, 98

BA	1					
RV	0.12	1				
EV	-0.17	0.06	1			
UV	0.02	0.43	0	1		
EO	-0.13	0.06	0.8	0	1	
UO	0.03	0.36	0	0.5	0	1
	BA	**RV**	**EV**	**UV**	**EO**	**UO**

Table 10(b): EUR/CHF, 99

High Volume Only Sample Correlations: Tables 6 to 10 are based on EBS data taken from the busiest part of the day (7.00am(GMT) to 17.00pm(GMT)), spanning London and New York business hours. Part (a) uses pre-EMU data from 1998, while part (b) uses post-EMU data from 1999. Observations are sampled at the 5-minute frequency. (Key: **BA** – Bid-ask spread, **RV** – Return Volatility, **EV** – Expected Volume, **UV** – Unexpected Volume, **EO** – Expected Order Flow and **UO** – Unexpected Order Flow.)

BA	1					
RV	~+	1				
EV	-	+	1			
UV	0	+	0	1		
EO	-	+	+	0	1	
UO	0	+	0	+	0	1
	BA	**RV**	**EV**	**UV**	**EO**	**UO**

Predicted