An Analysis of Macroeconomic Announcements Across Locations in the DM/dollar Market*

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This paper tests cross market linkages and geographic segmentation in the foreign exchange market in response to the arrival of macro-economic news. I characterize the behavior of DM/$ quotes (spreads, volatility, quote frequency) from banks physically located in Europe versus the United States in response to the arrival of news about the German or American economies. In particular, the focus is on the overlap period in the interbank spot market for foreign exchange located in Frankfurt and New York. The data show strong intra-daily seasonality in activity patterns across regional segments of the spot market. Vector auto-regression estimates are then used to disentangle own and cross market linkages following the arrival of public information. The results support the hypothesis that geographic segmentation plays a role in currency markets despite trading an apparently identical asset suggesting differences between local and foreign trader perceptions about the domestic currency.

Keywords: exchange rates, microstructure, macroeconomic announcements, high frequency data, vector autoregression.

1 Introduction

This paper examines the implications of geographic segmentation in the spot foreign exchange market. We investigate whether traders have imperfect and segmented knowledge of exchange rate fundamentals and competing trader perceptions of these fundamentals. We hypothesize that traders may be more capable of receiving and evaluating exchange rate signals which emanate from their country than from overseas. We argue that operating out of a particular country gives a trader an advantage in interpreting both the nuances in public signals generated in that country and the reactions of other traders in the country to the signal. This asymmetric information view of exchange rate determination parallels that found in the international home bias literature [Brennan and Cao (1998)] and in recent work investigating the role of geography in domestic equity markets [Coval and Moskowitz (1999)]. To examine our hypothesis, we focus on country-specific macroeconomic announcements. Public announcements of macroeconomic fundamentals offer an attractive opportunity to investigate our hypothesis, as their timing is largely predictable, and they convey information which is highly related to exchange rate fundamentals.

Recent evidence suggests foreign exchange markets are highly geographically segmented. In perfectly integrated markets, the arrival of new information which results in increased volatility in one financial center should immediately lead to increased volatility in other financial centers that are simultaneously open. Contrary to this, Hsieh and Kliedon (1996) find that the high volatility witnessed when the foreign exchange market opens in New York or closes in London is not related to the concurrent volatility in the other market. This is despite the fact that both sets of quotes appear on exactly the same trading screens at exactly the same time. This implies that although specific regional segments of the interbank market for foreign exchange obey the usual u-shaped patterns that have been rationalized by the clustering of informed trading[1], other trading sessions do not display any trace of a u-shape at the corresponding point in time. They assume that these differences in regional volatility patterns cannot be due to new information reaching one market but not the other, within standard information frameworks. Since there is a high degree of electronic integration in the foreign exchange market, it cannot be plausible that markets that are "ostensibly closely linked are segmented in important ways not recognized in standard models." Instead, it must be the case that "some phenomenon other than the incorporation of private information is responsible for the behavior of quotes."

An explanation that has received very little attention in the foreign exchange literature is that the regional differences in activity patterns observed in markets that are open at the same time could arise out of geographic segmentation. This implies that agents in different regional markets may have heterogeneous information sets. As a result, traders in different physical locations may have a different understanding or "feel" for the implications of news that reveals information about the fundamental value or future payoffs associated with a particular currency. Since the value of any given currency reflects the relative values of the fundamentals associated with two economies and in turn two monetary policies, the arrival of public information specific to any one economy may be interpreted differently by

[1] Admati and Pfliederer (1988)

domestic versus foreign traders.

Ederington and Lee (1993) and Bollerslev and Anderson (1998) 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. (see Kim and Verecchia (1991)) A potential source of information heterogeneity could stem from geographic segmentation.

There are several reasons to expect systematic differences in the quote behavior and activity patterns of interbank traders located in Germany/Europe as opposed to the United States surrounding the release of macroeconomic news in the foreign exchange market. First, there may be differences in the timing of the arrival of information. Traders located in Frankfurt or London might have a geographic advantage in terms of receiving private information about German macroeconomic announcements before traders situated in New York and vice versa. This implies that there might be a sequential component to the receipt of public information that could include a local leakage of information.

Second, traders may have an advantage in *processing* public signals generated in their own country. For example, as members of central bank committees jockey for support for their own monetary policy stances in the press, local traders may have superior ability to evaluate the consequences of such information for future domestic monetary policy and hence the domestic currency's value. Hence, although the signals themselves are public and simultaneously available to domestic and overseas traders, the "black box" which traders use to interpret public signals (i.e. an econometric model or gut intuition) may be more accurate in interpreting domestic signals than those overseas.

Third, behavioral explanations could account for systematic differences in responses to public information. To the extent that traders located in Germany tend to trade on behalf of people in Germany while traders in the United States act on behalf of investors in the US, a geographic analysis may allow identification of any behavioral differences between German and US investors. For instance, Germans may respond differently to improved fundamentals for Mark, perhaps reacting with greater confidence than investors in the US. Similarly, news about third parties may have varying effects on the behavior of traders located in different markets. News about an intervention by the Federal Reserve in the yen/dollar market may impact the strategy of German traders with respect to the dollar differently from US traders. In the same vein, news about German intervention in support of other EMS currencies could affect German and US traders differentially.

Finally, volatility may change differently in response to German/US announcements in the two markets so that we witness spillover or lead-lag relationships in the volatility transmission depending on where the announcement is made. There could also be leadership or bandwagon effects following news announcements across markets, i.e., US traders may follow the strategy of German traders following a German announcement and vice versa. This paper examines the nature of return (volatility) clustering and spillovers across regional foreign exchange markets during trading hours in which two (or more) markets are simultaneously open. The analysis is conducted in an event study framework around the release of specific macroeconomic news announcements in both domestic and foreign markets.

The paper proceeds as follows. Section 3.3 provides a description of the data sources and the construction of events around the release of U.S. and German macroeconomic announcements. Section 3.2 reviews the literature and Section 3.4 provides a preliminary data analysis of the activity patterns in the different regional segments of the DM dollar market. Section 3.5 presents the results from the event study analysis. Section 3.6 explores avenues for future research and concludes.

2 Related Literature

There is a vast body of literature that tests the implications of geographic segmentation and cross border linkages in international equity markets. The transmission mechanism of stock returns and volatility has been the focus of numerous studies: Bennett and Kelleher (1988); von Furstenberg and Jeon (1989); Hamao, Musulis, and Ng (1990); King and Wadhwani (1990); Neumark, Tinsley, and Tosisni (1991); Becker, Finnerty, and Tucker (1992); and Dravid, Richardson, and Craig (1993) are some examples. Lin, Engle, and Ito (1994) summarize several empirical regularities reported in these studies: (i) the volatility of stock prices is time varying; (ii) when volatility is high, the price changes in major markets tend to become highly correlated; (iii) correlations in volatility and prices appear to be causal from the United States to other countries; and (iv) lagged spillovers of price changes and price volatility are found between major markets. Lagged spillovers are defined as correlations between the foreign daytime return (volatility) and subsequent domestic daytime return (volatility), without any overlapping trading hours.

Correlations in price changes can be associated with the dispersion of beliefs (see Shalen (1993) for a two-period noisy rational expectations model of a futures market). When new information arrives, different prior beliefs about the news create incentives to trade and lead to price changes. As traders observe the new price, they may revise their prior beliefs in response to new information, which leads to continued trading and future price changes. If it takes time for the market to resolve these heterogeneous beliefs when traders revise their prior beliefs in response to new information, this process of searching for the information price may lead to volatility clustering around the arrival of new information. Analyzing volatility correlations across markets also requires an examination of the speed of the market adjustment to new information. Lin, Engle and Ito (1994) devise tests for lagged returns and volatility spillovers to examine how promptly domestic stock prices react to overnight foreign news as the domestic market reopens using global and country specific shocks in return innovations.

Engle et al. (1990,1992) document that news which is revealed when one foreign exchange market is open contributes to the return volatility when the next segment of the market opens. These volatility spillovers are dubbed 'meteor showers' and appear to be present for various time periods for the yen dollar exchange rate. Similar results were found for other currencies by Lin (1989). None of these studies, however, found any evidence that news in one market could predict the mean return in subsequent markets. Susmel and Engle (1994) presume that such effects are arbitraged away by the market.

Information asymmetries around earnings announcements have been examined extensively in equity markets. Morse and Ushman (1983), Venkatesh and Chiang (1986) and Skinner (1991) use daily quoted spreads while Daley, Hughes and Rayburn (1991), Barclay and Dunbar (1991) and Seppi (1992) use block trades to conduct their analysis. Lee, Mucklow and Ready (1993) show that spreads increase dramatically in the half half hour containing the announcement, and remain wider than during non announcement periods for up to one day.[2] They find that spreads widen and depths fall in anticipation of earnings

[2] This is consistent with Patel (1991) who also reports an increase in spreads following earnings announcements.

announcements and that these effects are more pronounced for announcements with larger subsequent price changes. Spreads are also wider following earnings announcements, but this effect dissipates rapidly after controlling for volume. Collectively, their results suggest that liquidity providers are sensitive to information asymmetry risk and use both spreads and depths to actively manage this risk. They suggest that although most extant models would predict an increase in information asymmetry before an earnings announcement, the predictions for the post announcement period are less clear. One hypothesis is that earnings news reduces the information advantage of the informed trader, so spreads should decrease during this time.

Alternatively, Kim and Verrecchia (1991) outline a theoretical argument to suggest that information asymmetry will be higher after earnings announcements because the announcements are noisy signals and certain traders have a superior ability to process the earnings information. However, the post announcement liquidity effects should be interpreted with caution, because extremely heavy trading volumes characterize this period. In the Kim and Verrecchia specification, the asymmetric information risk arises from the public disclosure of the earnings and not the accompanying volume. Their model predicts a drop in post announcement liquidity that is independent of the general relationship between volume and liquidity. Lee, Mucklow and Ready (1993) show that after controlling for the volume increase, the drop in post announcement liquidity is significant for approximately half an hour following the release of the earnings information. This suggests that the information advantage from a superior ability to process earnings news, as formalized by Kim and Verrecchia may be a short-lived phenomenon.

Tanner (1997) documents evidence using intraday data that unanticipated information about the trade deficit and consumer price index had an impact on the DM dollar exchange rate while there was no significant response to news about money supply, industrial production, the producer price index or unemployment. Ederington and Lee (1993) find that scheduled macroeconomic announcements are responsible for most of the observed time-of-day and day-of-the-week volatility patterns in foreign exchange futures markets. While the bulk of the price adjustment to a major announcement occurs within the first minute, volatility remains substantially higher than normal for roughly fifteen minutes and slightly elevated for several hours. Nonetheless, these subsequent price changes are basically independent of the first minute's return.

Consistent with these findings, Bollerslev and Anderson (1998) find that the largest returns in the DM dollar market appear to be linked to the release of public information, and, in particular certain macroeconomic announcements. They conclude that major announcements dominate the picture immediately following the release, but their explanatory power is less than that of the intraday patterns at high frequencies, and much less than that of standard volatility forecasts at the daily level. They present evidence to show that the most significant U.S. announcements, namely the employment report, gross domestic product, trade balance figures, and durable goods orders are all related to the real economy while the important German announcements, the Bundesbank meetings and M3 supply figures, are monetary. This may reflect differences in the perceived central bank reaction functions. Or it could be the case that during their sample period, monetary policy in the United States was relatively stable, while in Germany it was highly controversial.

3 Data Sources and Construction

The main data set consists of tick by tick indicative quotes from the interbank market for foreign exchange. The data set contains 1.6 million quotes for the DM-dollar spot exchange rate from October 1, 1992 through September 30, 1993. Each quote consists of time stamped bid and ask prices along with an identification of the bank advertising the quote and its location. Returns, effective spreads and average quote frequencies are constructed for five minute intervals from the exchange rate indicative quotes that appear on the Reuters's FXFX network over the sample period desegregated by three locations: Frankfurt, London and New York.

For each five minute interval we calculate the number of quotes that appeared on the screen from each market, and use the quote frequency numbers to construct a measure of the effective spread that would have been paid had each indicative quote translated into a transaction for each five minute interval. Since the foreign exchange market is a decentralized dealership market transaction prices and amounts traded are not recorded by a centralized exchange. We assume unit size for all the quotes transaction size while constructing the effective spreads. This is consistent with models of market-maker pricing under asymmetric information that do not incorporate depth information by assuming equally weighted transactions of unit size.[3]

To examine intraday volatility, log returns were calculated over the entire trading day in five minute intervals. Note that these returns only measure price changes and do not represent returns in an investment sense in that no money is actually invested up front. Average returns are constructed by using absolute values of the first difference of the log of the mid price of the spot rate.[4] Standard deviations of these log returns are calculated across 255 trading days (weekends and holidays were excluded from the sample). However, all returns from Friday 21:00 GMT through Sunday 21:00 GMT were excluded from the analysis. See Bollerslev and Domowitz for an explanation for the slow interbank quote activity that justifies this definition of the "weekend." Our total sample consists of $T = 255$ weekdays for a total of $N = 73440$ five-minute return, spread and quote observations (where n=1, 2, ...N and t=1, 2, ...T).

Since intra-daily data exhibits strong seasonal patterns[5] we calculated average returns, spreads and quote frequencies for each five minute interval, j, across 255 trading days. The nth return, spread and quote frequency within day t are $R_{t,n}$, $S_{t,n}$ and $Q_{t,n}$, respectively. All $N = 288$ intervals during the twenty-four hour trading cycle are used. These averages ($N = 288$) were used to deseasonalize the average returns, spreads and quote frequencies for every five minute interval, i, j (N=288*255). The deseasonalized values allow us to capture a measure of excess returns, excess spreads and excess quote frequencies while analyzing the impact of macroeconomic news on trading patterns.

We also constructed a sub sample of the data-set to study the impact of news announcements that appeared during the overlap period when all three markets were simultaneously open. An analysis of the quote activity reveals that the overlap period consists of three hours between 13:00 GMT and 16:00 GMT.

3.1 News Releases

The data set also includes all of the news headlines that appeared on the Reuters money news-alert screens. During the sample period from October 1, 1992 through September

[3]See Lee, Mucklow and Ready for a discussion. Copeland and Galai(1983), Glosten and Milgrom (1985),and Easley and O'Hara (1992) provide examples of this modelling strategy.

[4]Mid prices are constructed using the average of the bid and ask prices for any given quote.

[5]See Bollerslev and Anderson (1998, 1997) and Bollerslev and Domowitz (1993)

30, 1993, the total number of headlines that appeared in the screen was 105,065. These headlines are time stamped to the nearest second and constitute the basis for our analysis of announcement effects.

For the DM dollar spot rate, Bollerslev and Anderson (1998) list the employment report, gross domestic product, trade balance figures, and durable goods orders to be the most significant U.S. announcements while the most important German announcements are Bundesbank meetings and M3 supply figures. Ederington and Lee (1993) highlight the employment figures, PPI, gross national product, the trade deficit, durable goods and retail sales figures to have the greatest impact in their analysis of the deutsche mark futures market. We examine a set of announcements that consist of weekly, monthly and quarterly scheduled announcements as well as unexpected news about interventions by the Bundesbank and Federal Reserve. We also include unanticipated news about the ERM as well as stock market developments in the United States. We selected this list of announcements as they could signal a change in the demand for foreign exchange and traders believe that these are important variables that central banks consider while formulating changes to monetary policy. We exclude announcements that are made when overlapping segments of the market have stopped trading-we are left with 105 announcements from the US and 86 from Germany.

The Reuters' FXNB page is used to separate out the announcements by country of origin and two databases are constructed for German and U.S. macroeconomic news. These two databases pin point time stamped news events which are then used to evaluate segmentation effects in trading patterns across locations in response to changes in the public information environment. For example, do banks in New York respond differently from banks in London or Frankfurt to a German rate cut? We use the announcement events to analyze whether volatility levels, spread patterns and quote frequencies evolve differently across regional segments of the market. A second stage of the empirical exercise consists of testing for cross-market linkages in the form of volatility spillovers, lead-lag relationships and possible bandwagon effects in quote behavior.

4 Preliminary Data Analysis

Figures 3.1 documents the trading hours in Frankfurt, London and New York, respectively. This figure depict the quote frequency on the Reuters's screens in five-minute intervals dis-aggregated by market. Hsieh and Kliedon (1996) document that each location shows activity from about 7:00 A.M. (local time) that lasts till about 6:00 P.M. (local time). The data are consistent with Bollerslev and Domowitz (1993) who note that trading activity as measured by the number of quote arrivals in Frankfurt and London begin high and decline until New York opens, then increases until the close of the trading day in London. Activity in New York follows that of London and continues to increase after the London close as New York becomes the main trading center. Tables 3.1-3.3 present t-tests of differences in the mean number of quotes during different intervals in the overlap period.

4.1 Frankfurt, London and New York: Integrated Market

We replicate the analysis in Hsieh and Kliedon (1996) to document the U-shaped patterns in trading activity in each of the three individual markets across the trading day. Figure 3.2 plots the average standard deviations of quote midprices for the half hour intervals and the results confirm the U-shaped patterns documented by Bollerslev and Domowitz (1993) and Hsieh and Kliedon (1996). The average variances are much higher at the opens and closes. Figure 3.3 confirm that the patterns in the bid-ask spread mirror that of the variances for all three markets.

Figure 3.2 plots the standard deviations of the mid price changes in all three markets in GMT and shows that there is no correspondence between the patterns in the European versus US markets. This is particularly striking given that the markets are virtually instantaneously linked in terms of quote information. In addition, there appears to be little coherence in the volatility patterns with the open or close of one market on the other markets.

Tables 3.4-3.6 presents evidence of t-tests of the significance of the difference in spreads across the three market pairs, in fifteen-minute intervals from noon GMT to 5:00 P.M. GMT. Following Hseih and Kliedon (1996), the test assumes that the sub samples are uncorrelated. This indicates that the t-statistic is downward biased if there is a positive correlation across the samples which is a reasonable assumption if there are inter-linkages between quote patterns across the regional segments. The results confirm the pattern from figure Figure 3.3 and show that the indicated spreads show that spreads in Frankfurt are consistently higher than spreads in New York. The results also show that spreads in New York are significantly higher that spreads in London during the overlap period with the exception of the closing of the London market when the reverse is observed.

Studies of the effects of international dual listings in equity markets using intraday data show that spreads do not decrease following a dual listing while the depth of quotes increases as predicted. Noronha, Sarin and Saudagaran (1996) examine the impact on the liquidity of NYSE/AMEX listed stocks when they were subsequently listed on the London or Tokyo Stock Exchanges. They find that the level of informed trading increases, which increases the cost to the specialist of providing liquidity, and explains why spreads do not decline despite increased competition. Consistent with an increase in informed trading, they also document an increase in trading activity. Werner and Kliedon (1996) conduct an intraday analysis of market integration by analyzing the patterns for U.K. and U.S. trading of British cross listed stocks. They document evidence to show that cross border competition for order flows tends to reduce already declining spreads in London during the overlap period. By contrast, New York specialists maintain high spreads during the overlap period and overall, the evidence indicates that the order flow for cross-listed securities is segmented. (note: make a point about how differences in spreads indicate that the order flow for FX is also segmented-although not directly related to segmentation conditonal on differences in interpreting macro announcements it is prima facie evidence for unconditional segmentation-while Hsieh and Kliedon talk about regional U shapes in activity patterns here we find evidence for Frankfurt consistently setting spreads above the other two markets, not just at opens and closes. We are also conducting this exercise to argue for using deseasonalized data to study the impact of announcements).

Tables 3.7-3.9 test for the difference between quote mid-prices in all three markets. Although the indicated spreads data shows a distinct ordering in spread patterns, the pattern does not translate to the mid-price data. T-tests of the difference between mean mid-prices do not indicate a clear pattern although there exist intervals when there are statistically significant differences across the three markets.

Tables 3.10-3.12 examine the difference between the first difference of the log of the mid-prices across the three markets to illustrate differences in variance patterns across the three markets. The results once again confirm the observations from Figure 3.2. From noon to 3:00 PM (GMT) the variance in New York consistently exceeds that of its European counterparts. With the largest average variances in New York at the beginning of the trading day. However, first the variance in Frankfurt followed by the variance in London start edging upwards with the drawing of a close of trading the trading days in the two locales sequentially. The t-statistics are strongly significant at both the 1 and 5 percent levels for all the consecutive intervals between 3:00 PM (GMT) and 4:30 PM (GMT) for Frankfurt and between 4:00 PM (GMT) and 5:00 PM (GMT) for London. These results corroborate the evidence that changes in the volatility in one regional segment are not reflected simultaneously in other segments that are open concurrently.

The cross market variance results from Figure 3.2 and the cross market spread results from Figure 3.3 and Tables 3.4-3.6 suggest that there are strong intra daily seasonal patterns that are distinct across regional segments of the spot foreign exchange market. This constitutes the rationale for using deseasonalized data in our estimations of the responses of different regional segments to the arrival of macroeconomic news.

5 Results

5.1 Announcement Effects

In this section we present evidence from regression analyses designed to capture the impact of individual announcements on the volatility, spreads and market activity on different regional segments on the spot foreign exchange market. The analysis is conducted for US announcements and German announcements separately. In particular, we construct a series of dummy variables $D_{k,t}$ where $D_{k,t} = 1$ if announcement k is made on day t and $D_{k,t} = 0$ otherwise. The dependent variable in our regression is the absolute value of the difference between the actual quote frequency, bid ask spread value or return for the five minute interval j on day t and the mean quote frequency, bid ask spread or return for interval j over all 260 trading days in our sample period. Thus the dependent variables are deseasonalized (for time of day effects) five minute quote frequencies, spreads, first difference of the log of the spot midprice. The independent variables are dummies for the announcements and lagged values of the dependent variable to correct for persistence. For the US there are six categories of announcements: CPI, durable goods orders, employment numbers, GDP, retail sales and the merchandise trade deficit and FED interventions. The German announcements are M3 figures, Bundesbank meetings, and interest rate changes and interventions by the Bundesbank.

For example, following Ederington and Lee our sample format for the return regressions is:

$$abs(R_{j,t} - \overline{R_j}) = a_0 + \Sigma_{k=1}^{K} a_k D_{k,t} + e_{j,t} \tag{1}$$

Further, note that if log returns are normally distributed with constant mean and time varying variance, $E|R_{j,t} - \overline{R}_j|=(2/\pi)^{0.5}\sigma_{j,t}$ where $\sigma j, t$ is the standard deviation of returns in interval j on day t.[6] This means that $(\pi/2)^{0.5}a_0$=$1.2533a_0$ provides and estimate of the standard deviation of returns on non announcement days. Furthermore, since we are considering absolute values of deseasonalized returns, regardless of whether or not an announcement provides good or bad news about the economy to the market, the estimated coeffiecient a_k should have a positive value if the announcement has an impact on the market. As a consequence, the figure $1.2533(a_0 + a_k)$ provides an estimate of the standard deviation of returns when announcement k occurs. This also implies that we should expect the coefficient a_k to be approximately zero if it has little news value for the market.

Note also that the set of dummy variables varies across intervals. While an interval earlier in the day only contains dummy variables for announcements that have taken place up until that particular interval, intervals later in the day contain dummy variables for all announcements prior to that interval. This is done to capture the impact of earlier announcements on the persistence of volatility throughout the day.

5.2 Pooled Announcement Effects

In this section we present evidence from regression estimates for pooled announcements across regional markets. The regression format was designed to estimate the impact of news originating from one regional segment on its own market and across markets. Again, the analysis was conducted for market activity as proxied by quote frequency, spreads and log returns. For example, in order to estimate the impact of German news on market

[6] See Ederignton and Lee (1993) for more details.

activity in New York, we estimated the following regression:

$$Q^{NY}_{j+1,t} = a0 + a_1 Q^{FR}_{j,t} * D^{GE}_{j,t} + a_2 Q^{FR}_{j,t} * (1 - D^{GE}_{j,t}) + a_3 Q^{NY}_{j,t} * D^{GE}_{j,t} + a_4 Q^{NY}_{j,t} * (1 - D^{GE}_{j,t}) \quad (2)$$

where:

- $Q^{NY}_{j+1,t}$ is the quote frequency in New York in period $j + 1$.
- $Q^{FR}_{j,t}$ is the quote frequency in Frankfurt in period j.
- $D^{GE}_{j,t}$ is a dummy variable for German news announcements.
- $Q^{NY}_{j,t}$ is the quote frequency in Frankfurt in period j.

The coefficients, a_1 and a_2 are designed to measure cross market effects. a_1 measures the impact of the quote frequency in Frankfurt lagged by one period and interacted with a dummy variable $D^{GE}_{j,t}$, that takes the value of 1 when a German announcement takes place and 0 otherwise. a_2 measures cross market linkages in market activity between Frankfurt and New York during trading interval when no announcement takes place. a_3 and a_4 capture own market effects on the quote frequency in New York. While a_3 measures the impact of the lagged quote frequency in New York interacted with the German announcement dummy, a_4 quantifies the significance of the lagged quote frequency in New York when there is no announcement. A similar exercise was conducted for the impact of German news on the quote frequency in Frankfurt. The regressions were also conducted to measure the impact of US news announcements on market activity in both New York and Frankfurt, respectively. Results from these regressions are presented in Tables 3.13 and 3.14.

We also conducted two additional sets of regressions to estimate the own and cross market effects of German and US news on both bid ask spreads as well as volatility levels to study the impact of these announcements on market uncertainty as well as to assess any regional differences in these responses. The results are presented in Tables 3.15 to 3.18.

The reaction in New York to US news (105 announcements) suggest that the quote frequency, spreads and volatility increase and the coefficient estimates are statistically significant. The reaction in Frankfurt to US news on the other hand shows that while the quote frequency and bid-ask spreads-decrease (negative and significant), the volatility increases but the effect is not statistically significant. The estimates were corrected for autocrorrelation by using lagged quote frequencies, spreads and volatility since without the correction the Durbin Watson statistic was considerably below the benchmark value of 2.0. One lag sufficed in taking care of this problem. The errors were estimated using Newey West heteroskedasticity consistent covariance matrices. A potential rationale for narrowing German spreads could involve the market becoming more competitive following news releases (i.e. German spreads lowering following US announcements to attract US business and US spreads widening following German announcements to extract rents from German traders). Following German news in Frankfurt (68 announcements), the quote frequency falls (negative and significant) while spreads and volatility increase (positive and significant). The reaction in New York from Tables 3.13 to 3.18 suggest that market activity as measured by quote frequency, spreads and volatility all rise significantly in response to German news.

5.3 Vector Autoregression estimates

Next we turn to regression estimates using a VAR framework. The vector autoregression (VAR) is commonly used for forecasting systems of interrelated time series and for analyzing the dynamic impact of random disturbances (here the arrival of macroeconomic news) on the system of variables. The approach sidesteps the need for structural modeling by modeling every endogenous variable in the system as a function of the lagged values of all of the endogenous variables in the system. Since only lagged values of the endogenous variables appear on the right-hand side of each equation, there is no issue of simultaneity, and OLS is the appropriate estimation technique. Note that the assumption that the disturbances are not serially correlated is not restrictive because any serial correlation could be absorbed by adding more lagged dependent variables.[7]

The mathematical form of a VAR is:

$$y_t = a_1 y_{t-1} + ... + a_p y_{t-p} + b x_t + \epsilon t \tag{3}$$

where y_t is a k vector of endogenous variables, x_t is a d vector of exogenous variables, a_1,...,a_p and b are matrices of coefficients to be estimated, and ϵt is a vector of innovations that may be contemporaneously correlated with each other but are uncorrelated with their own lagged values and uncorrelated with all of the right-hand side variables.

[7] See Hamilton (1994) for further details

We assume that quote frequencies in Frankfurt and New York are jointly determined by a two variable VAR along with a dummy for news and a constant as exogenous variables. The system of equations we estimated uses two lags of the dependent variables and a lagged dummy variable for German or US news. We arrived at the two lags specification after constructing cross corrollelograms to study the pattern of autocorrelations in the two regional segments. The VAR specification is as follows:

$$Q^{NY}_{j+2,t} = a_0 + a_1 Q^{NY}_{j+1,t} + a_2 Q^{NY}_{j,t} + a_3 Q^{FR}_{j+1,t} + a_4 Q^{FR}_{j,t} + a_5 D^{US}_{j,t} \tag{4}$$

$$Q^{FR}_{j+2,t} = a_0 + a_1 Q^{NY}_{j+1,t} + a_2 Q^{NY}_{j,t} + a_3 Q^{FR}_{j+1,t} + a_4 Q^{FR}_{j,t} + a_5 D^{US}_{j,t} \tag{5}$$

where:

- $Q^{NY}_{j+2,t}$, $Q^{NY}_{j+1,t}$, $Q^{NY}_{j,t}$ are quote frequencies in New York for intervals $j+2$, $j+1$ and j, respectively.
- $Q^{FR}_{j+2,t}$, $Q^{FR}_{j+1,t}$, $Q^{FR}_{j,t}$ are quote frequencies in Frankfurt for intervals $j+2$, $j+1$ and j, and
- $D^{US}_{j,t}$ is a dummy variable fore US news announcements.

The exercise for repeated using a dummy for German news announcements. In addition VARs were estimated to study the impact of these two categories of announcements on spreads and volatility as well. Results for these estimates are presented in Tables 3.19 to 3.22. The results for the quote regressions show that while lagged values of own market activity have a positive impact on quote activity, lagged values of cross market activity have an opposite impact. This is evidenced by the positive and significant coefficients for $Q^{NY}_{j+1,t}$ and $Q^{NY}_{j,t}$ and the negative, significant and much lower magnitudes for the coefficients for $Q^{FR}_{j+1,t}$ and $Q^{FR}_{j,t}$. The results also show that while US news leads to a significant increase in quote activity in New York the result is reversed for the Frankfurt market. Surprisingly, the trend remains the same following German news announcements. These results suggest that traders in New York tend to become more active, while traders in Frankfurt shut down and perhaps adopt a wait and see strategy following the release of macroeconomic news.

The results for the VAR estimates for quote revisions in the two markets bear out these results and once again provide evidence that the New York market responds by increasing activity following the release of macroeconomic news while the Frankfurt market shows depressed activity. Interestingly, while quote revisions in New York are significantly impacted by own market quote revisions, the results lose significance for the coefficients on the cross market quote revisions from Frankfurt. However, the cross market impact of quote revisions from New York to Frankfurt continue to be significant. These results seem to indicate evidence of price leadership by the US following US announcements but there is little if no evidence of the converse result following German news.

The VAR estimates for the impact of lagged own and cross market volatility following news announcements suggest that volatility in any one regional segment is affected by persitence in its own market volatility as well as spillovers from other regional markets (albeit with coefficients of lower magnitude) following the release of news. A somewhat puzzling result is evidenced by the statistical insignificance of the dummy for US news on the Frankfurt market. A potential explanation could be that as evidence from the quote frequency VARs suggest that the German market shows reduced activity following the release of US news, volatility is reduced as well. However the same result does not hold for the impact on volatility in Frankfurt following the release of German news.

Estimates from VARs for bid ask spreads show that while lagged own market spread effects tend to be positive and significant, cross market lagged spread effects are significantly negative. Again, the magnitudes for cross market effects are lower. The coefficient for the impact of US news on bid-ask spreads follows the same trend as that of the volatility regression estimates with traders in New York widening spreads and traders in Frankfurt lowering them. An explanation for the lowered spreads by Frankfurt traders could be that since spreads in Frankfurt tend to be statistically significantly greater than spreads in New York during the overlap period (except for the Frankfurt close), traders in Frankfurt lower spreads in order to become more competitive following the release of US news. Interestingly, German news leads to a widening of spreads by both US and German traders.

6 Future Research

Since the overlap period between the trading hours in London and Frankfurt is longer (8:30 GMT to 16:00 GMT), future research could study the impact of German macroeconomic news that appeared when the New York market was closed. This would allow us to analyze the impact of news that was specific to Europe on the two markets and since this was a particularly turbulent period for the European Monetary System it would also allow us to study the inter-market linkages within European financial markets.

Preliminary evidence indicates the presence of intra-daily seasonality in the price leadership pattern with certain segments leading the market at different points of time in the trading day. This evidence could be used to compare how price leadership patterns change around event windows surounding the release of macroeconomic news. According to the efficient market view asset prices incorporate rational assessments of the fundamental values underlying the assets and reflect future payoffs. This implies that the arrival and processing of new information must result in changes in asset prices. In turn, since financial markets display a high degree of integration, standard information models (Admati and Pfliederer (1988), Subrahmanyam (1991) suggest that if the arrival of new information results in increased volatility in one financial center, then the high volatility should be observed in other financial centers that are simultaneously open.

Future research could describe the price leadership dynamics more thoroughly as well as examine differences in the efficiency and speed of adjustment in different regional segments of the spot FX market. Attention could be focused on disentangling the price formation dynamics with precision to determine whether a greater percentage of price adjustments take place in the regional segment of the FX market where the announcement was made. Comparisons could also be made with the reaction of London market in order to check for robustness. Furthermore, Granger causality tests could be conducted to describe the direction of spillovers and price leadership.

Table 1: Test of Difference in Quotes, Frankfurt and New York

	Frankfurt		New York		
Time	Quotes	$Stdc^{FR}$	Quotes	$Stdc^{NY}$	T-stat
12:00	1580	2.7409092	132	0.95914699	7.124014803
12:15	1582	2.8653483	182	1.2392879	7.151240857
12:30	1508	2.8999742	255	1.2673986	6.925729134
12:45	1440	2.84109	271	1.3931724	6.681729228
13:00	1364	2.7205381	322	1.3565184	6.516356191
13:15	1392	2.7316443	331	1.4381597	6.633717721
13:30	1474	2.9199975	414	1.5161322	6.58308708
13:45	1416	2.8870027	475	1.5701398	6.115190994
14:00	1381	2.7263206	499	1.6865908	6.067519609
14:15	1402	2.6231473	537	1.7837203	6.219024866
14:30	1351	2.7143168	610	1.8515628	5.306069399
14:45	1356	2.7574313	642	1.8966097	5.087626796
15:00	1336	2.30406	772	2.0742211	4.677895459
15:15	733	2.6590984	887	2.3807226	-1.076042127
15:30	630	2.3806383	968	2.517182	-2.375903799
15:45	564	2.4338207	1002	2.4676884	-3.046823985
16:00	581	2.6659351	1058	2.6235887	-3.117794133
16:15	156	1.1947469	1097	2.6366205	-5.036425669
16:30	157	1.3837318	1104	2.9082623	-4.595813772
16:45	141	1.2020902	1082	2.9874577	-4.339732221

Table 2: Test of Difference in Quotes, London and Frankfurt

Time	London Quotes	$Stdc^{LN}$	Frankfurt Quotes	$Stdc^{FR}$	T-stat
12:00	1636	3.2807823	1575	2.862367	0.412891113
12:15	1630	3.3735798	1582	2.8653483	0.319653659
12:30	1722	3.27808	1508	2.8999742	1.437693052
12:45	1786	3.7589767	1440	2.84109	2.132329228
13:00	1856	3.5144423	1364	2.7205381	3.189460786
13:15	1727	3.5365403	1392	2.7316443	2.160812894
13:30	1709	3.5821897	1474	2.9199975	1.484272914
13:45	1830	3.665684	1416	2.8870027	2.576545795
14:00	1742	3.3973989	1381	2.7263206	2.390829356
14:15	1809	3.4193412	1402	2.6231473	2.731283498
14:30	1800	3.5472722	1352	2.5716114	2.924350133
14:45	1945	3.411195	1290	2.4926014	4.402670805
15:00	1971	3.6802994	1336	2.30406	4.137113586
15:15	1930	3.6276221	733	2.6590984	6.647724879
15:30	1853	3.7289391	630	2.3806383	6.494651746
15:45	1510	4.1688909	564	2.4338207	4.419552939
16:00	1301	4.1389969	581	2.6659351	3.371996277
16:15	1183	4.3010747	156	1.1947469	3.393598639
16:30	899	4.0164937	157	1.3837318	2.639982311
16:45	559	2.6647187	141	1.2020902	2.183836189

Table 3: Test of Difference in Quotes, London and New York

Time	London Quotes	$Stdc^{LN}$	New York Quotes	$Stdc^{NY}$	T-stat
12:00	1636	3.2807823	109	0.85206521	5.976657999
12:15	1630	3.3735798	182	1.2392879	6.297389895
12:30	1722	3.27808	255	1.2673986	7.176699093
12:45	1786	3.7589767	271	1.3931724	6.571925964
13:00	1856	3.5144423	322	1.3565184	7.447694253
13:15	1727	3.5365403	331	1.4381597	6.788519355
13:30	1709	3.5821897	414	1.5161322	6.606236717
13:45	1830	3.665684	475	1.5701398	7.00134727
14:00	1742	3.3973989	499	1.6865908	6.976720473
14:15	1809	3.4193412	537	1.7837203	7.205540217
14:30	1864	3.3500062	610	1.8515628	7.463054534
14:45	1838	3.373113	642	1.8966097	7.155661506
15:00	1971	3.6802994	772	2.0742211	6.89545895
15:15	1930	3.6276221	887	2.3807226	6.17714942
15:30	1853	3.7289391	968	2.517182	5.180794771
15:45	1510	4.1688909	1002	2.4676884	2.74924518
16:00	1301	4.1389969	1058	2.6235887	1.322291125
16:15	536	2.8844881	1077	2.912273	-3.176630872
16:30	526	2.7357333	1037	2.9442769	-3.009870417
16:45	456	2.4707459	1047	3.0000926	-3.430966427

Table 4: Test of Difference in Spreads, Frankfurt and New York

Time	Frankfurt Spreads	N^{FR}	New York Spreads	N^{NY}	T-stat
12:00	9.61835443	1580	8.439393939	132	3.531587365
12:15	9.656131479	1582	8.230769231	182	3.277621461
12:30	9.523872679	1508	8.31372549	255	3.49613736
12:45	9.58125	1440	8.616236162	271	2.659745129
13:00	9.573313783	1364	8.468944099	322	2.94974375
13:15	9.510775862	1392	8.531722054	331	2.641137815
13:30	9.500678426	1474	8.620772947	414	2.262603643
13:45	9.668785311	1416	8.557894737	475	3.357618994
14:00	9.656770456	1381	8.663326653	499	2.853279449
14:15	9.737517832	1402	8.836126629	537	2.813408688
14:30	9.797187269	1351	8.586885246	610	3.609469666
14:45	9.752949853	1356	8.816199377	642	3.149154376
15:00	9.782185629	1336	8.797927461	772	3.720587511
15:15	9.814461119	733	8.851183766	887	2.900502616
15:30	9.853968254	630	8.857438017	968	2.89087264
15:45	9.838652482	564	8.831337325	1002	0.329053451
16:00	9.903614458	581	8.962192817	1058	2.739403977
16:15	9.634615385	156	9.029170465	1097	1.294877449
16:30	9.713375796	157	8.904891304	1104	1.4333544
16:45	10.18439716	141	9.012014787	1082	2.390881805

Table 5: Test of Difference in Spreads, London and Frankfurt

Time	London Spreads	N^{LN}	Frankfurt Spreads	N^{FR}	T-stat
12:00	7.031784841	1636	9.652063492	1575	-3.08454528
12:15	6.979141104	1630	9.656131479	1582	-3.19603079
12:30	7.045876887	1722	9.523872679	1508	-2.865671571
12:45	6.996080627	1786	9.58125	1440	-2.761318506
13:00	6.826508621	1856	9.573313783	1364	-3.066108759
13:15	6.996525767	1727	9.510775862	1392	-2.720045134
13:30	6.939730837	1709	9.500678426	1474	-2.778762608
13:45	6.984153005	1830	9.668785311	1416	-2.933102828
14:00	7.19804822	1742	9.656770456	1381	-2.619861457
14:15	7.239911553	1809	9.737517832	1402	-2.700558621
14:30	7.187222222	1800	9.774408284	1352	-2.888153779
14:45	7.318251928	1945	9.848837209	1290	-2.60898366
15:00	7.34906139	1971	9.782185629	1336	-2.619049977
15:15	7.534196891	1930	9.814461119	733	-1.9514529
15:30	7.740960604	1853	9.853968254	630	-1.745230479
15:45	8.070198675	1510	9.838652482	564	-0.624650572
16:00	8.219830899	1301	9.903614458	581	-1.442171657
16:15	8.267962806	1183	9.634615385	156	-0.848746208
16:30	8.147942158	899	9.713375796	157	-0.912187678
16:45	9.43470483	559	10.18439716	141	-0.946924574

Table 6: Test of Difference in Spreads, London and New York

Time	London Spreads	N^{LN}	New York Spreads	N^{NY}	T-stat
12:00	7.031784841	1636	8.335443038	109	-0.653666077
12:15	6.979141104	1630	8.230769231	182	-0.76826638
12:30	7.045876887	1722	8.31372549	255	-0.834814952
12:45	6.996080627	1786	8.616236162	271	-1.027227629
13:00	6.826508621	1856	8.468944099	322	-1.167022262
13:15	6.996525767	1727	8.531722054	331	-1.051884039
13:30	6.939730837	1709	8.620772947	414	-1.213701567
13:45	6.984153005	1830	8.557894737	475	-1.203772529
14:00	7.19804822	1742	8.663326653	499	-1.120774447
14:15	7.239911553	1809	8.836126629	537	-1.259321726
14:30	7.186158798	1864	8.586885246	610	-1.106522514
14:45	7.344940152	1838	8.816199377	642	-1.223939065
15:00	7.34906139	1971	8.797927461	772	-1.283700638
15:15	7.534196891	1930	8.851183766	887	-1.184145359
15:30	7.740960604	1853	8.857438017	968	-1.046568162
15:45	8.070198675	1510	8.831337325	1002	-0.745933982
16:00	8.219830899	1301	8.962192817	1058	-0.756465517
16:15	9.546641791	536	9.038068709	1077	1.092756081
16:30	9.275665399	526	9.00192864	1037	0.500722154
16:45	9.429824561	456	8.903533906	1047	1.004140447

Table 7: Test of Difference in Mid-prices, Frankfurt and New York

Time	Frankfurt Mid-prices	N^{FR}	New York Mid-prices	N^{NY}	T-stat
12:00	1.648452455	1580	1.779025121	132	-0.90222484
12:15	1.643865377	1582	1.798970012	182	-1.15558076
12:30	1.658273005	1508	1.78921062	255	-1.045188585
12:45	1.652633387	1440	1.747134249	271	-0.763975462
13:00	1.65106344	1364	1.76742559	322	-0.973922966
13:15	1.65886385	1392	1.752870899	331	-0.791553068
13:30	1.659905563	1474	1.732684911	414	-0.643932877
13:45	1.642232276	1416	1.752857358	475	-1.002303566
14:00	1.645226022	1381	1.743652336	499	-0.896322081
14:15	1.638442177	1402	1.73120063	537	-0.85539253
14:30	1.633498338	1351	1.754746427	610	-1.141717471
14:45	1.638808993	1356	1.731311699	642	-0.877066213
15:00	1.63431209	1336	1.728243229	772	-0.919835216
15:15	1.615229969	733	1.727663363	887	-1.054073818
15:30	1.613223019	630	1.727268952	968	-1.053493041
15:45	1.617949891	564	1.726138776	1002	-0.985692644
16:00	1.604702376	581	1.713879732	1058	-1.00676508
16:15	1.627205736	156	1.707161939	1097	-0.568750846
16:30	1.60638908	157	1.718874853	1104	-0.804057486
16:45	1.579365178	141	1.702221846	1082	-0.859987758

Table 8: Test of Difference in Mid-prices, London and Frankfurt

	London		Frankfurt		
Time	Mid-prices	N^{LN}	Mid-prices	N^{FR}	T-stat
12:00	1.618066259	1636	1.644936664	1575	-0.311214637
12:15	1.619126135	1630	1.643865377	1582	-0.281292924
12:30	1.620604355	1722	1.658273005	1508	-0.43919134
12:45	1.616849552	1786	1.652633387	1440	-0.400138053
13:00	1.619160614	1856	1.65106344	1364	-0.369117327
13:15	1.622590909	1727	1.65886385	1392	-0.424589446
13:30	1.622951083	1709	1.659905563	1474	-0.437576179
13:45	1.623793497	1830	1.642232276	1416	-0.222879787
14:00	1.624799024	1742	1.645226022	1381	-0.241664545
14:15	1.622008181	1809	1.638442177	1402	-0.200787622
14:30	1.619780667	1800	1.634628668	1352	-0.171204959
14:45	1.624787969	1945	1.627568159	1290	-0.035050258
15:00	1.625841958	1971	1.63431209	1336	-0.107014168
15:15	1.623238497	1930	1.615229969	733	0.092028337
15:30	1.619969941	1853	1.613223019	630	0.076742935
15:45	1.615400397	1510	1.617949891	564	-0.029759697
16:00	1.611521829	1301	1.604702376	581	0.076429435
16:15	1.612090533	1183	1.627205736	156	-0.160038637
16:30	1.612159177	899	1.60638908	157	0.070912031
16:45	1.61119034	559	1.579365178	141	0.31043975

Table 9: Test of Difference in Mid-prices, London and New York

Time	London Mid-prices	N^{LN}	New York Mid-prices	N^{NY}	T-stat
12:00	1.618066259	1636	1.784239737	109	-1.193851765
12:15	1.619126135	1630	1.798970012	182	-1.398636403
12:30	1.620604355	1722	1.78921062	255	-1.475742854
12:45	1.616849552	1786	1.747134249	271	-1.080421016
13:00	1.619160614	1856	1.76742559	322	-1.348774194
13:15	1.622590909	1727	1.752870899	331	-1.227078582
13:30	1.622951083	1709	1.732684911	414	-1.09241822
13:45	1.623793497	1830	1.752857358	475	-1.34532056
14:00	1.624799024	1742	1.743652336	499	-1.223850312
14:15	1.622008181	1809	1.73120063	537	-1.18230347
14:30	1.623201931	1864	1.754746427	610	-1.404396126
14:45	1.624189064	1838	1.731311699	642	-1.219314951
15:00	1.625841958	1971	1.728243229	772	-1.22047486
15:15	1.623238497	1930	1.727663363	887	-1.219447531
15:30	1.619969941	1853	1.727268952	968	-1.2772424
15:45	1.615400397	1510	1.726138776	1002	-1.351278693
16:00	1.611521829	1301	1.713879732	1058	-1.194678396
16:15	1.61801278	536	1.704701242	1077	-0.885160485
16:30	1.613770817	526	1.702651457	1037	-0.881547448
16:45	1.612227412	456	1.714453918	1047	-1.02066984

Table 10: Test of Difference in Volatility, Frankfurt and New York

Time	Frankfurt Volatility	N^{FR}	New York Volatility	N^{NY}	T-stat
12:00	3.097029077	1580	6.406593407	132	3.309564329
12:15	3.027581783	1582	6.064171123	182	3.03658934
12:30	4.100195185	1508	6.773662551	255	2.673467366
12:45	3.628998609	1440	5.150337838	271	1.521339229
13:00	3.588002874	1364	4.587613293	322	0.999610419
13:15	3.602442334	1392	4.605072464	331	1.00263013
13:30	3.937146893	1474	4.849473684	414	0.912326792
13:45	3.955829109	1416	4.728456914	475	0.772627804
14:00	4.027104137	1381	4.554003724	499	0.526899587
14:15	4.156065089	1402	4.724960254	537	0.568895166
14:30	4.336046512	1351	4.724137931	610	0.388091419
14:45	5.203148426	1356	4.587719298	642	-0.615429128
15:00	4.566848568	1336	4.422773393	772	-0.144075174
15:15	4.666666667	733	4.327995868	887	-0.338670799
15:30	7.027777778	630	4.089041096	968	-2.938736682
15:45	6.356687898	564	4.0625	1002	-2.294187898
16:00	6.514184397	581	4.16728281	1058	-2.346901588
16:15	6.724770642	156	4.040389972	1097	-2.68438067
16:30	7.011363636	157	4.049662488	1104	-2.961701148
16:45	6.705607477	141	3.863896848	1082	-2.841710628

Table 11: Test of Difference in Volatility, London and Frankfurt

Time	London Volatility	N^{LN}	Frankfurt Volatility	N^{FR}	T-stat
12:00	2.966564417	1636	3.097029077	1580	0.13046466
12:15	2.903640929	1630	3.027581783	1582	0.123940854
12:30	4.126805315	1722	4.100195185	1508	-0.026610129
12:45	3.368131868	1786	3.628998609	1440	0.260866741
13:00	3.279675738	1856	3.588002874	1364	0.308327135
13:15	3.313341135	1727	3.602442334	1392	0.289101199
13:30	3.75	1709	3.937146893	1474	0.187146893
13:45	3.70608496	1830	3.955829109	1416	0.24974415
14:00	3.774184632	1742	4.027104137	1381	0.252919505
14:15	3.916388889	1809	4.156065089	1402	0.2396762
14:30	4.053213368	1800	4.336046512	1351	0.282833144
14:45	4.409736308	1945	5.203148426	1356	0.793412117
15:00	4.021502591	1971	4.566848568	1336	0.545345977
15:15	4.597949271	1930	4.666666667	733	0.068717395
15:30	4.877455566	1853	7.027777778	630	2.150322212
15:45	4.541156841	1510	6.356687898	564	1.815531057
16:00	5.661001789	1301	6.514184397	581	0.853182608
16:15	6.003731343	1183	6.724770642	156	0.721039299
16:30	5.378326996	899	7.011363636	157	1.63303664
16:45	5.589912281	559	6.705607477	141	1.115695196

Table 12: Test of Difference in Volatility, London and New York

Time	London Volatility	N^{LN}	New York Volatility	N^{NY}	T-stat
12:00	2.966564417	1636	6.406593407	132	3.440028989
12:15	2.903640929	1630	6.064171123	182	3.160530194
12:30	4.126805315	1722	6.773662551	255	2.646857237
12:45	3.368131868	1786	5.150337838	271	1.78220597
13:00	3.279675738	1856	4.587613293	322	1.307937555
13:15	3.313341135	1727	4.605072464	331	1.291731329
13:30	3.75	1709	4.849473684	414	1.099473684
13:45	3.70608496	1830	4.728456914	475	1.022371954
14:00	3.774184632	1742	4.554003724	499	0.779819092
14:15	3.916388889	1809	4.724960254	537	0.808571365
14:30	4.053213368	1800	4.724137931	610	0.670924563
14:45	4.409736308	1945	4.587719298	642	0.17798299
15:00	4.021502591	1971	4.422773393	772	0.401270803
15:15	4.597949271	1930	4.327995868	887	-0.269953404
15:30	4.877455566	1853	4.089041096	968	-0.78841447
15:45	4.541156841	1510	4.0625	1002	-0.478656841
16:00	5.661001789	1301	4.16728281	1058	-1.493718979
16:15	6.003731343	1183	4.040389972	1097	-1.963341371
16:30	5.378326996	899	4.049662488	1104	-1.328664508
16:45	5.589912281	559	3.863896848	1082	-1.726015433

Figure 3.1: Quote Frequency; Frankfurt, London & New York

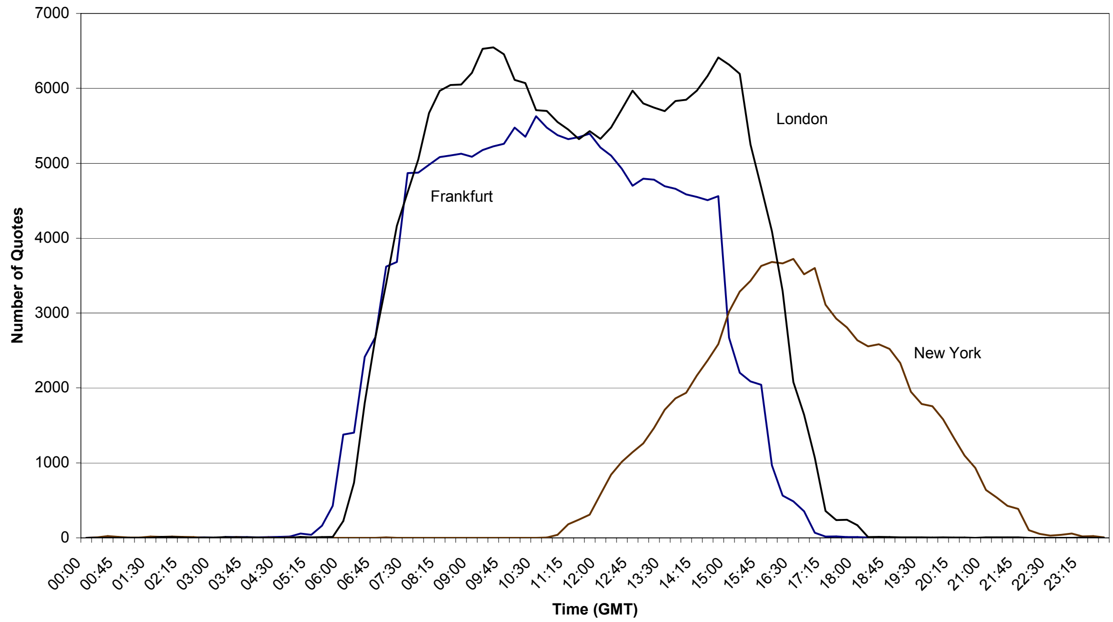

Figure 3.2: Midprice Volatility; Frankfurt, New York

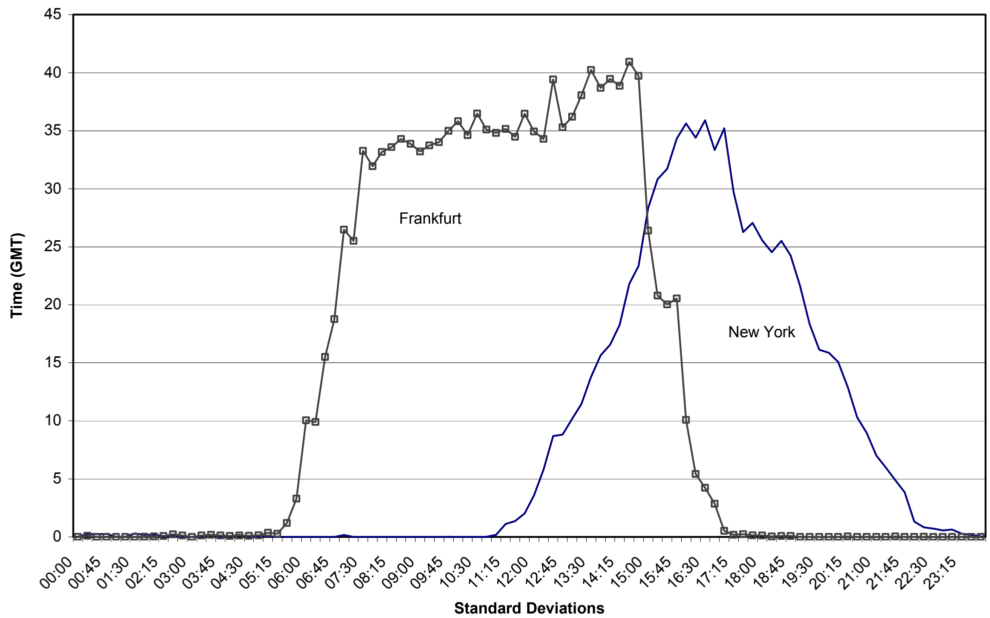

Figure 3.3: Bid-ask Spreads; Frankfurt, London & New York