The microstructure of the foreign exchange market

the determinants of bid-ask spreads in the foreign exchange market

Nikolaos Tsorakidis

THE MICROSTRUCTURE OF THE FOREIGN EXCHANGE MARKET:

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Thesis Summary

The purpose of this thesis is to shed more light in the FX market microstructure by examining the determinants of bid-ask spread for three currencies pairs, the US dollar/Japanese yen, the British pound/US dollar and the Euro/US dollar in different time zones. I examine the commonality in liquidity with the elaboration of FX market microstructure variables in financial centres across the world (New York, London, Tokyo) based on the quotes of three exchange rate currency pairs over a ten-year period. I use GARCH (1,1) specifications, ICSS algorithm, and vector autoregression analysis to examine the effect of trading activity, exchange rate volatility and inventory holding costs on both quoted and relative spreads. ICSS algorithm results show that intraday spread series are much less volatile compared to the intraday exchange rate series as the number of change points obtained from ICSS algorithm is considerably lower. GARCH (1,1) estimation results of daily and intraday bid-ask spreads, show that the explanatory variables work better when I use higher frequency data (intraday results) however, their explanatory power is significantly lower compared to the results based on the daily sample. This suggests that although daily spreads and intraday spreads have some common determinants there are other factors that determine the behaviour of spreads at high frequencies. VAR results show that there are some differences in the behaviour of the variables at high frequencies compared to the results from the daily sample. A shock in the number of quote revisions has more effect on the spread when short term trading intervals are considered (intra-day) compared to its own shocks. When longer trading intervals are considered (daily) then the shocks in the spread have more effect on the future spread. In other words, trading activity is more informative about the future spread when intra-day trading is considered while past spread is more informative about the future spread when daily trading is considered.

Market microstructure, bid-ask spread, commonality in liquidity, GARCH , vector autoregression (VAR), ICSS

To my grandmother, C*hrysoula*
my parents, *Olga and Aristides*
and my brother, *Jiorgos*

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Chapter 1: Introduction

Section 1.1: Introduction and overview

The purpose of this thesis is to shed more light in the FX market microstructure by examining the determinants of bid-ask spread for three currency pairs, the US dollar/Japanese yen (JP/US), the British pound/US dollar (GB/US) and the Euro/US dollar (EU/US) in different time zones. The main contribution of the empirical work is the examination of the commonality in liquidity with the elaboration of FX market microstructure variables in financial centres across the world (US, UK, JAPAN) based on the quotes of three exchange rate currency pairs (JP/US, GB/US, EU/US) over a ten-year period.

The main motivation for this study is the fact that research on market microstructure issues can prove useful to various market participants such as traders, fund managers and regulators. For example, traders are looking for ways to improve the accuracy of their pricing models and fund managers require relevant information on liquidity when they take portfolio allocation decisions. My empirical work in Chapters 6, 7 and 8 helps in that direction with the examination of spread liquidity and the estimation of the determinants of bid-ask spreads in the FX market. Moreover, regulators are interested in the timing of macroeconomic announcements as unexpected price movements before these announcements may be evidence of asymmetric information in the market and therefore signal market inefficiencies. From an academic point of view, my thesis fills a gap in the current FX market microstructure literature as there is very limited work that examines commonality in liquidity in the FX market over a very long period of time, for three currency pairs and in three financial markets across the world.

I decided to focus on the FX market because it is the world's most active market, in operation twenty-four hours a day, seven days a week. Moreover, it's the largest asset market in terms of volume, and consequently there is a considerable interest in how it operates and how prices are determined. According to recent estimates, on a day-to-day basis an average of USD 3,210 billion worth of currencies are traded, an increase of 71% at current exchange rates.[1] The primary foreign exchange market makers are banks located in money centres, including London, Zurich, New York, Tokyo, and Hong Kong.

The determination of foreign exchange rates requires to be separated in to the determination of long-run exchange rate movements and the determination of short-run exchange rate movements. The explanation of long-run exchange rate movements using macroeconomic variables such as money supplies, interest rates and other has been the subject of considerable inquiry in the literature. However, as Crystal and McDonald (1995) estimate in their paper, the models developed can explain only approximately 50% of monthly and quarterly exchange rates changes. Since the explanatory power of the macroeconomic variables is partial, the attention has moved in the literature of market microstructure and the application of market microstructure concepts to the foreign exchange market.[2] O' Hara (1995) defines market microstructure as "the study of the process and outcomes of exchanging assets under explicit rules". Market microstructure researchers investigate the trading process and how the trading structure and mechanism impacts on the determination of asset prices.

In the empirical part of my thesis, I investigate the determinants of FX bid-ask spreads using an aggregate sample that extends from 01.01.1995 to 31.01.2005 (full sample) and three other sub-samples in order to capture changes over the sample. Since the FX market is in operation 24 hours and trading moves over the

[1] Bank for International Settlements 2007 survey
[2] Flood (1991) reviews the theoretical literature on the market microstructure to see "what lessons it holds for the foreign exchange market".

course of the 24 hour day I segregate the data into three time zones; US time zone (New York), UK time zone (London) and Asia time zone (Tokyo). I use four currencies, US dollar, pound sterling, euro and yen, because they are the most traded ones in the FX market. According to the most recent research results by BIS (2007 survey), published in December of 2007, the most traded currency in all past BIS surveys was the US dollar, being on one side of at least 80% of transactions during the years. In 2007, the actual percentage was 86.3%. The euro remained the second most traded currency (37%) followed by the yen (16.5%) and the pound sterling (15%).

I use Olsen to obtain my data. Many published papers have used the Olsen dataset in the past. For example a number of authors have analyzed realized variance measures of foreign exchange returns computed from the Olsen data sets. These data sets were made available for use in three conferences on the statistical analysis of high frequency data sponsored by Olsen and Associates. The Olsen HFDF-2000 data is the most commonly used data set. Andersen, T., and T. Bollerslev (1998a, 1998b), Andersen, T., T. Bollerslev, F.X. Diebold, P. Labys (2001,2003) and Maheu et. Al (2002) are only a few of the authors who have used the Olsen data sets. The Data set received by Olsen consists of the last bid and ask quotes at 5-minute intervals. I use time-series regressions, ICSS algorithm, and vector autoregression analysis to examine the effect of trading activity, exchange rate volatility and inventory holding costs on both quoted and relative spreads.

Section 1.2: Structure of the thesis

My thesis is organized in nine chapters. Chapter 1 provides the introduction. Chapters 2, 3 and 4 form the literature review. The remaining chapters, 5 to 8, contain the empirical work and present the results of my thesis. In Chapter 9, I summarise my findings and suggest possible future research in the field. More specifically, Chapter 2 reviews the literature of price formation and price discovery. In this chapter, I first discuss the fundamentals of the price setting process and continue by providing definitions of liquidity as well as different types and measures of liquidity from both a theoretical and an empirical framework. The remainder of the chapter focuses on the theories and empirical studies which try to explain the determinants of the bid-ask spread. Chapter 3 reviews market architecture focusing on the different types of structures, auction and dealer markets. I define market architecture and then review two broad issues in the dealer market literature. First, researchers have investigated whether market making improves liquidity and second whether a monopolistic or competitive market making structure should be favoured. The review continues with an examination of auction systems and the comparison between dealer markets and auction markets. The rest of the chapter is focusing on the information and disclosure aspects of market microstructure, and in particular, the pre-trade and post-trade transparency impacts on various market liquidity variables.

Chapter 4 provides a comprehensive review of the literature on FX market microstructure. I discuss the characteristics of the FX market and review the literature on FX market architecture, price formation and discovery. I focus on the differences in the structure of the stock market and the FX market and the role of the order flow as it plays a central role in the FX microstructure. In addition, I discuss bid-ask spread models in the FX market, reviewing the determinants of bid-ask spreads such as exchange rate volatility, trading volume, dealers competition, central bank intervention, seasonality effects and intraday spread behaviour.

In Chapter 5, I describe the data, provide summary statistics on the samples used and present correlation results between spreads and trading activity. First, I explain how I create the date sets and which liquidity and trading activity measures I use. For the daily sample I provide summary statistics for the quoted and relative spread and the number of quote revisions for JP/US, GB/US and EU/US currency pairs in UK, US and Asia time zones. For the intraday sample, I present the results for the mean quoted and relative spreads, as well as the number of quote revisions, per 15-minute interval, in the three sub-periods of my sample for JP/US, GB/US and EU/US currency pairs in UK, US and Asia time zones. In the last part of the chapter I consider three types of correlation: the correlation between spreads of the same currencies in different time zones, the correlation between spreads of different currencies in the same time zone, and the correlation between spreads and their number of quote revisions.

In Chapter 6, I apply the ICSS algorithm to compare exchange rate volatility to bid-ask spread volatility. I use the Inclan and Tiao (1994) Iterated Cumulative Sum of Squares (ICSS) algorithm to identify sudden changes to the unconditional volatility of the exchange rates and spread series of JP/US, GB/US and EU/US for three time zones (UK, US and Asia) in order to identify the number of variance shifts (changes to volatility) and the dates on which these shifts took place. My aim is to examine if there is a relationship between exchange rate volatility and spread volatility and if changes in spread volatility are as often as changes in exchange rate volatility. Chapter 7 reports time-series regressions of daily and intraday bid-ask spreads on various potential determinants. I use autoregressive conditional heteroscedasticity (ARCH) statistical process to model the conditional mean and variance of the spreads. To that end I use five types of explanatory variables: i) interest rate differentials, ii) exchange rate volatility iii) trading activity iv) seasonality variables and v) macroeconomic announcements.

Chapter 8 presents results from simultaneous equation models (vector autoregressions) both for the daily and intra-day sample including impulse responses and variance decomposition analysis. I examine the effect of trading activity, exchange rate volatility and inventory holding costs on both quoted and relative spreads using vector autoregression analysis. In the first part of this chapter I describe a simple vector autoregression model and provide a concise review of its main applications. The remainder of the chapter presents results from simultaneous equation models both for my daily and intra-day sample including impulse responses and variance decomposition analysis. Chapter 9 is the last one, and its purpose is to summarise what I have analysed, provide a summary of the methodology, review main findings and their implication for theoretical and empirical literature, and suggest areas for future research.

Section 1.3: Main findings of this thesis

This work is the result of my interest in the FX market. In June 2009, an earlier work of mine (co-author Patricia Chelley-Steeley) in the FX market "*Volatility changes in drachma exchange rates*" was published in the Journal of Applied Financial Economics (June 2009, Vol 19). Part of this thesis, was presented in June 2009 as a paper titled "Spreads, microstructure and macroeconomic announcements: An examination of the foreign exchange market" at a market microstructure conference in Aix, France.

To the best of my knowledge there is very limited empirical work to address commonality issues in the FX market. I show that that intraday spread series are much less volatile compared to the intraday exchange rate series using the ICSS algorithm. Moreover, most of the current literature on the determinants of the bid-ask spread in the FX market is fragmented. I consider the effect of a wide range of variables (both inventory-based and asymmetric information-based) on the spread over a ten-year period. Regression results from both the daily and intraday samples show that quoted and relative spreads respond to changes in trading activity. An increase in the number of quote revisions would decrease the spread. As far as asymmetric information in the FX market is concerned, I find good evidence that intraday spreads in US time zone depend on scheduled macroeconomic announcements. UK and Japan macroeconomic announcements seem to play a less important role in the determination of spreads than US macroeconomic announcements.

Finally, in the last empirical chapter I find that there are some differences in the behaviour of the variables at high frequencies compared to the results from the daily sample. These results are very important as they improve our understanding of the FX bid-ask behaviour and assist in the formation of more accurate pricing models in the FX market. A shock in the number of quote revisions has more effect on the spread when short term trading intervals are considered (intra-day) compared to its own shocks. When longer trading intervals are considered (daily) then the shocks in the spread have more effect on the future spread.

Overall, in this work I provide evidence of commonality in liquidity in major world financial centres, New York, London and Tokyo based on the quotes of the three most active exchange rate currency pairs JP/US, GB/US, EU/US over a ten-year period. The presence of commonality has important implications to regulators and investors. Investors, speculators and liquidity providers can understand better the risk of their trading, for example the effect of a sudden shock to market-wide liquidity, and how they should account for the premium for bearing liquidity risk in their FX return models. The next three chapters present the literature review of this thesis.

Section 1.4: Summary and conclusions

In this thesis I investigate the commonality of liquidity in the FX market using three currency pairs, the US dollar/Japanese yen (JP/US), the British pound/US dollar (GB/US) and the Euro/US dollar (EU/US) across the three financial centers, New York (US), London (UK) and Tokyo (Asia), over a ten-year period. The concept of co-movement in liquidity in equity markets has attracted a lot of attention by researchers, however liquidity in the FX market has mostly been neglected. My results show that liquidity co-moves across the three currency pairs and across the three financial markets under examinations. In the next chapters I review the relevant market microstructure literature, present the data and methodology of my research and discuss the empirical results and their implications for theoretical and empirical literature, regulators and market participants.

Chapter 2: Price Formation and Price Discovery

Section 2.1 Introduction and overview

This chapter is the first of three chapters that will review the relevant literature. The purpose is to provide a thorough understanding of what determines a price, from both a conceptual and empirical perspective. I first discuss the fundamentals of the price setting process and continue by providing definitions of liquidity as well as different types and measures of liquidity from both a theoretical and an empirical framework. The remainder of the chapter focuses on the theories and empirical studies which try to explain the determinants of the bid-ask spread. This chapter is of high importance in this thesis as it explains the necessary information set to understand the motivation of my work, the gaps in the literature that I am trying to fill and the use of my selected variables in the following empirical chapters.

Section 2.2: The price setting process

The determination of a market price is a key question in economics. The determination of the price can be potentially complicated even when considering simplified scenarios of trading a single asset between two individuals outside a regulated market: for example, a decision to sell/buy a car. In general we can say that prices are the result of bargaining and negotiation between buyers and sellers. What happens of course in a negotiation between a potential buyer and a potential seller over price is quite complicated and definitely depends on the nature of the underlying asset being traded as well as the regulations governing the particular form of trade.

Bargaining is the process by which two potential parties to a transaction try to find out information about the other party's reservation price. Unfortunately from the moral point of view, there is considerable incentive in a bargain to mislead the other party. The seller wants to convince the buyer that her reservation price is higher than it really is, and the buyer would like to convince the seller that his reservation price is lower than it really is. The only way to predict the outcome of this type of interaction is to know the context in which the bargainers are operating, and in particular the costs each side has in learning correct information about the other's situation.

The key word from the above paragraph is "information" and in particular the cost of the information. We will see later in this work that information plays a crucial role in the process of price setting and is actually one of the factors that make the price setting process so complicated. Looking at the price determination from an economic point of view, we see that traditionally much of the analysis focused on how the two forces of demand and supply interact to determine price in a competitive market. At the equilibrium price the quantity demanded equals the quantity supplied. However, this approach is simple and general. The most important assumption is that the trading mechanism is not affecting the resulting equilibrium. In general, price formation is the process of determination of market prices through the interactions of buyers and sellers in a free market place. In the following sections I describe a different approach to the process of price setting from the general one mentioned above.

Section 2.3: The cost of transacting

According to the French economist Léon Walras and his Walrasian economic theory of markets, orders are collected into batches of either buys or sells by the auctioneer and then analyzed to determine a market clearing price. The actual mechanism of a market organization under which the outcome will be a competitive equilibrium is the following. A market manager (an auctioneer) announces a price, and each participant indicates whether she wishes to buy or sell at that price. If demand is not equal to supply, then a new price is suggested.

No actual trading occurs until a price is found at which demand is equal to supply. A market manager who acts in this way is called a Walrasian auctioneer.

Under the Walrasian framework the auctioneer has a passive role in that he does not take any trading position, and he simply matches supplies and demands in equilibrium. Although this mechanism is rather simplistic, it can be viewed as a good descriptor of the price-setting process and the outcome of exchange in a market for a range of types of market organisation. Since the Walrasian auctioneer has a passive role, he is not facing a potential cost of holding an undesired trading position. In addition, the trading process is costless and the time dimension of supply and demand is ignored. These points suggest that the market-clearing price does not incorporate any costs.

Demsetz (1968) was the first to incorporate some of the above issues such as the cost of transacting and the time dimension in the trading mechanism. A further discussion of Demsetz's analysis is presented later in this chapter (section 2.5.1).

Section 2.4: Definition of liquidity and market liquidity

It is generally accepted that the definition of liquidity is an issue that should be approached differently and according to the segment of the financial system it reflects. Liquidity is a business or economic term that refers to the ability to quickly buy or sell a particular item without causing a significant shift in the price.

Dow (2001) provides a comprehensive definition of liquidity and describes it as "the ease with which an asset can be exchanged for other assets where "ease" refers both to institutional arrangements and to perceived risk of capital loss". Therefore, from this definition we can conclude that liquidity is partly determined by institutional arrangements and also it is partly a matter of judgment in that it relates to perceived risk in exchange. Thus liquidity depends on market conditions, both in terms of level of activity and in terms of individuals' expectations.

An attempt to provide a single definition or interpretation of market liquidity that would be accepted by the majority of scholars and would satisfy the needs of all segments of the financial system would probably be impossible. In the next section, I provide different definitions of market liquidity in order to understand its nature, role and dynamic.

Section 2.4.1: Market liquidity in market microstructure theory

In principle, market liquidity is related to the ability of a trading mechanism to match the trading desires of sellers and buyers. In that process the role of the market maker in providing liquidity is vital. Grossman and Miller (1988) defined a liquid market as the one in which the demand for immediacy is high and the cost of market makers of maintaining a continued presence is low. In addition, market architecture (rules governing the trading process and level of transparency) can affect the creation of liquidity. In this section we focus on the definition of market liquidity in the market microstructure research and we leave the discussion of the importance of market structure for the following chapter.

A market is considered to be liquid if whenever a trader decides to sell (buy), another trader(s) is willing to buy (sell) with the overall transaction having a small impact on price. Black (1971) defined a market as liquid the one in which "bid-ask price is always quoted, its spread is small enough and small trades can be immediately executed with minimal effect on price." Kyle (1985) provides a review of the definition of market liquidity and describes it as including the following terms:

"*tightness* (the cost of turning around a position over a short period of time), *depth* (the trade size or thickness of the order book-profile[3] required for changing prices) and *resiliency* (the required period of time in which prices recover from a random, uninformative shock or reach a new equilibrium)".

Muranaga and Shimizu (1999) provide another survey of different interpretations of market liquidity and introduce their definition. They define a liquid market as "a market where a large volume of trades can be immediately executed with minimum effect on price. In other words, the liquidity of the market can be recognized by how low the uncertainties of execution price are". Similarly, Mares (2000) suggests that "a market is liquid if uncertainty as to the execution price of transaction is low". Mares further explains that in a liquid market what matters is that market participants can forecast the deviation between the prevailing market price and the actual execution price. Another important characteristic of a liquid market is the ability of market participants to complete large-volume transactions. Lee (2002) describes a liquid market as one in which participants can rapidly execute large-volume transactions with a small impact on prices.

Section 2.4.2: Importance of liquidity

Having provided different definitions of liquidity, one can usefully provide a number of reasons why liquidity and in particular market liquidity attracts much attention. The recent financial crisis raised again the issue of the puzzling behaviour of liquidity before, during and especially after financial crises. The effect on liquidity of the regulations that govern a particular trading system is another important issue. In addition, the cost of reduced market liquidity is large therefore, the improvement and stability of market liquidity is a key issue for policy makers, market participants as well as the whole financial market.

[3] Order book refers to a panel which provides traders with bid-ask prices and volume offered per price.

Finally, it is possible under some conditions, such as insubstantial trading activity or even lack of trades (virtually no liquidity), to experience a market system breakdown[4]. Therefore, liquidity is catalytic in maintaining financial system stability.

Section 2.4.3: Different types of measures of liquidity

According to the definitions provided in the previous sections, it is obvious that liquidity has several dimensions. Therefore, similarly to the definitions of liquidity, the measures of liquidity vary to satisfy the needs, the objectives and the focus of a particular research of a scholar. In addition, although same researchers use common measures of liquidity, the methodology they use to estimate them may differ. In this section, we discuss both theoretical and empirical studies that use different types of measures of liquidity. Liquidity variables range from trade related measures (e.g turnover rate) to order related measures (e.g bid-ask spread). The most commonly used liquidity measure in market microstructure literature are bid-ask spread, depth, trading volume, trade frequency and price volatility.

In a theoretical context, Dupont (1999) investigates the effect of transaction costs on liquidity in a quote-driven market. As measures of liquidity Dupont uses bid-ask spread, depth and mean trading volume. The depth, or quantity limit, is the maximum amount the dealer stands ready to sell or buy at the posted prices. In another study, Ui (1999) develops a model to examine the relationship between market transparency and price volatility and uses both as measures of liquidity. Muranaga and Shimizu (1999) suggest that we should also take dynamic measures of market liquidity into account. They document that past studies of market liquidity focus on static aspects such as those I mentioned above (turnover, bid-ask spread, etc). Their point is that the potential depth of the market, i.e. effective supply and demand, is an indicator which can only be

[4] See section 2.4.4 for more details

recognized dynamically. These dynamic indicators are price changes upon execution (market impact), the speed of convergence from one trade price to the next equilibrium price or bid-ask spread (market resiliency). They explore the factors that affect market liquidity using a simulation model of an artificial market. As important factors in measuring market liquidity, they consider the probability of quote existence, trade frequency, price volatility, bid-ask spread, gross order book volume (buying order volume plus selling order volume) and net order book volume (buying order volume minus selling order volume).

In empirical studies, measures of liquidity include the spread, the trade volume and the number of trades, price volatility and the level of competition in the market. Grossman and Miller (1988) suggest that we can measure the liquidity of a market by looking at "the ability of executing trades under the current price quotes price-and time-wise". Since the market liquidity is the ability to execute a large volume of trades immediately with a minimum effect on price, therefore the ability to execute trades with low uncertainties of the execution price, any variable that represents the extent of "uncertainty of trade execution price" would be a measure of market liquidity. Chordia, Roll and Subrahmanyam (2000) using transaction data for the New York Stock Exchange (NYSE) provide empirical evidence to recognize the existence of commonality in liquidity using five different measures of liquidity: namely quoted spread, proportional quoted spread, depth, effective spread, and proportional effective spread.

Since spread is used as a measure of liquidity and spread depends on some variables, it means that these variables are also measures of liquidity. Stoll (1978), using data from the Over-the-Counter Market (OTC), examines those factors that determine the price of dealer services, in other words the determinants of spreads. In order to find empirical evidence on the determinants of spreads, the proportional spread is regressed against the variance of return, dollar volume, turnover, stock price, number of different dealers. Tinic (1971) in his paper "*The economics of liquidity services",* using data from the New York

Stock Exchange, models and examines the relationship of bid-ask spread and some variables. Specifically, these variables are price, trading volume, institutional concentration, trading continuity, price volatility, competitive pressures, dealer capitalization, and size of specialty portfolios.

Section 2.4.4: Advantages and disadvantages of different types of measures of liquidity

Liquidity measures suffer one or more limitations. This, to an extent, explains the fact that studies using different liquidity measures and methodologies often produce conflicting results. On the other hand, there are also advantages attached to different liquidity measures.

Liquidity is not directly observable, so proxies have been used to examine its role in the price setting process. Liquidity measures can be divided into two broad categories: trade-based measures, such as trading value, trading volume and the turnover ratio; and order based measures such as the bid-ask spread. Trade based measures are problematic in that they are ex-post rather than ex-ante measures. They indicate what people have traded in the past which is not necessarily a good indication of what will be traded in the future. The order based measure of the bid-ask spread represents the cost that investors must incur in order to trade immediately. For small investors this is an accurate method of calculating the liquidity of a stock. However, for larger investors the bid-ask spread may understate the true cost of trading and hence overestimate liquidity. A more complete measure of liquidity would also consider the market impact and opportunity cost of trading.

Chordia, Roll and Subrahmanyam (2000), when examining the cross-sectional variation in liquidity, use daily percentage changes in liquidity measures for an individual stock regressed on market measures of liquidity. They use percentage changes rather than levels for two reasons: first, their interest is in discovering whether liquidity co-moves; and second to avoid the potential problems with time series, such as non-stationarity.

The quoted spread and the depth are announced by the specialist and become known to other traders prior to each transaction, though the lead time may be only seconds. The effective spread is derived to measure actual trading costs. If the effective spread is smaller than the quoted spread, then this reflects within-quote trading.

Despite its limitations a number of studies, such as the ones of Goodhart and Figliuoli (1991) and Bollerslev and Domovitz (1993), use the frequency of quote arrival as a proxy of trading activity These quotes are indicative quotes and not actual trades, and moreover it is not possible to infer from a quote for which volume it is given. In addition, Reuters tick frequency may be low at times of high trading activity and high at times of low trading activity. This is due to the fact that banks act as data providers to programme an automated data input. When an important event occurs, traders are likely to act and trade actively rather than entering data for Reuters.

Section 2.5: Theories which try to explain what determines the bid-ask spread.

The bid-ask spread has been the focus of ample research at both theoretical and empirical levels. In this part we focus on the development of the conceptual approaches and models that have evolved and contributed to the microstructure research. I first discuss the main avenues of research contacted in stock markets. In particular, I concentrate on the main stages of theoretical research starting with the first attempts to explain the reason for the existence of the bid-ask spread and then move to the initial theoretical models that describe the bid-ask spread: the inventory-based and information based models. These two approaches model the general theoretical frameworks used in market microstructure theory.

Section 2.5.1: Initial theoretical analysis

The paper of Demsetz (1968) gave rise to a new development in the area of finance and economics concerning the cost of transacting. The key finding is that the market maker's spread (the difference between the bid and ask price) is the price of "immediacy" in an organized exchange market. In other words, the market maker has a passive role and simply provides the service of immediacy (liquidity) in order to balance the gap between buying and selling orders when bid-ask quotations submitted by outsiders are too far apart to keep trade active without wide jumps in price. Therefore, he will set bid-ask prices in order for the spread to cover the cost of "immediacy".

Another main scope of Demsetz's study was to investigate the extent to which transaction costs are affected by trading activity. Transaction costs are defined as "the cost of exchanging ownership". In other words, it is the cost the buyers and sellers using the NYSE will pay in order to contract with each other. Transactions costs can be roughly divided in brokerage fees and bid-ask spread. The later element of the transaction cost is the cost that a person wishing to sell shares at a particular price and a specific time needs to pay in order for his desire to be satisfied promptly, even in the absence of a buyer, and vice versa. As I mentioned before, Demsetz defines bid-ask spread as the markup paid for predictable immediacy of exchange in organised markets. This service of "predictable immediacy" requires a cost, which is the bid-ask spread. Therefore, the main conclusion of his study is that the bid-ask spread is the price of immediacy.

Demsetz focuses on three forces that affect the bid-ask spread. First,

1. *The frequency of transacting*: a negative relationship between spread and time rate of transactions is to be expected. The time rate of transaction is defined later. It is important to note that the paper focuses on the behavior of spread as the transaction rate increases and not with the absolute level of spread.
2. *The number of markets on which the security is listed:* A negative relationship between spread and the number of competing markets on which a security is listed is expected.
3. *The price per share*: Spread per share will tend to increase in proportion to an increase in price per share.

Demsetz explains why the above three factors are mainly responsible for the determination of the bid-ask spread. However, the basic element that forces bid-ask spread is the first. In order to measure the transaction rate two variables are used, the number of transactions per day based on data for two (nonadjacent) days of trading and the number of shareholders.

An additional theoretical contribution that followed Demsetz was the one of Tinic (1971). Tinic added some additional determinants of the bid-ask to the three variables described by Demsetz to analyse the supply of liquidity service. In particular, Tinic suggested that the variables influencing the inventory carrying costs of the market maker can be divided in to three broad categories; the level of trading activity, the number of institutional investors and the price volatility. In general, he mentioned that, the higher the trading activity, the lower the inventory cost since the need to hold unpreferred positions and the time required are reduced. As for the number of institutional investors, the larger the number holding a stock the greater the probability that order will tend to be offsetting; and therefore, the market maker will not need to deviate much from his desired portfolio. Finally, market makers who hold stock with volatile prices should set a larger spread, since holding undesired positions in these stocks would increase the probability that the equilibrium price will change. Some other factors that are described to influence the inventory positions of the market maker are the specialist's purchasing capacity, the portfolio size, and the nature of competition.

Section 2.5.2: Theoretical models on the determinants of bid-ask spreads

In the sections below, I review the developments of theoretical studies on the determinants of the bid-ask spreads. Many authors contributed to this particular area after Demsetz's paper providing different theoretical approaches on what determines the bid-ask spreads. Two main lines of thought can be identified in the literature: theories that try to explain the determinants of bid-ask spread based on inventory; and theories that try to explain the determinants of bid-ask spread based on special information and liquidity.

The first line of thought follows Garman (1976), who describes the market maker pricing decisions under the assumption that market makers need to pursue a policy of relating their prices to their inventories in order to avoid failure.

The second line of thought follows Bagehot (1971), who describes those who are willing to participate in the market game and transact with the market maker. He identified three kinds of transactors: information-motivated transactors (those possessing special information), liquidity-motivated transactors, and transactors acting on information which they believe has not yet been fully discounted in the market price but which in fact has.

Section 2.5.3: Inventory-based models

Smidt (1971) argued that market makers are not simply passive providers of immediacy, as Demsetz suggested, but actively adjust the spread in response to fluctuations in their inventory levels. In this part of the study I will focus my attention on the theories which follow Smidt's analysis and emphasize the holding cost which is derived from the assumption that the cost is an amount which maintains dealer's level of expected utility of terminal wealth in response to transactions imposed upon him by the public that tend to move him away from his optimal portfolio. In each inventory-based model the market maker is risk averse and therefore the inventory introduces risks for the market maker, and his pricing strategy reflects at least partially his efforts to minimize those risks.

The price-setting process with simple supply and demand specifications

Garman (1976) formally modelled the relation between dealer quotes and inventory levels based on Smidt (1971). Garman begins with a simple supply and demand framework and then turns to the aggregate market behaviour to describe the exchange process. Since Garman assumes that supply and demand are discrete stochastic processes, this gives rise to the temporal imperfections. Order arrivals in the market place, bids and offers, are characterized as individual events occurring in continuous time, and it is also assumed that all exchange takes place within a centralized market place.

Garman describes his models under two different market structures: dealership markets and auction markets. He uses a number of assumptions in order to describe his models. Under Garman's assumption the market maker will set prices in order to clear the market while seeking to maximize expected profit per unit time without facing the possibility of failure. Since it is assumed that the market maker has cash and stock inventories at time 0 the term failure applies to the situation where the market maker will have negative inventories and therefore be unable to perform his function. Garman translates the above assumptions to the following relationships:

$$I_c(t) = I_c(0) + p_B N_B(t) - p_S N_S(t) \qquad \text{Eq. 2.1}$$

$$I_s(t) = I_s + N_S(t) - N_B(t). \qquad \text{Eq. 2.2}$$

Let:

I_c: Inventory of cash at time t

I_s: Inventory of stock at time t

$N_B(t)I$: cumulative number of bids that have been executed by time *t*.

$N_S(t)I$: cumulative number of offers that have been executed by time *t*.

Calculating such probability of the expected time to failure from the equations 2.1 and 2.2 is intractable because of the multiple stochastic processes. Garman however approximates the ultimate failure probabilities as a function of the market maker's price strategy. The "failure probability" refers to the probability of a zero cash position for the market maker. Therefore, in order for the market maker to maintain a positive cash position, he must set a lower price when he buys stock and higher price when he sells. As Garman mentions in his work "…by creating this spread he can protect himself from certain failure without however, eliminating the probability of failure".

The bid-ask spread as a function of a dynamic price-inventory adjustment policy.

The paper by Amihud and Mendelson (1980) falls also in the broad category of the theoretical models structured to treat the liquidity-motivated transactors when the determination of prices and their corresponding bid-ask spreads is the underlying issue.

Amihud and Mendelson used Garman's proposition as the basis of their paper to show that the bid-ask process and the corresponding spread are functions of the market maker's inventory level. In particular, they study the optimal pricing policy in relation to inventory of the market maker in a dealership market following Garman's description. An important assumption (unlike in Garman's study) is that the market maker is not facing the possibility of failure (meaning to run out of inventory).

There are three main suggestions of the model developed in their paper. First, they develop a theorem showing that optimal bid and ask prices decrease as the inventory position of the market maker increases. Such a linkage between prices and inventory had been suggested by several authors: Smidt (1971), Barnea (1974) and Barnea and Logue (1975). The second and most important issue of this paper is to identify if there is a “preferred” inventory position and how this relates to the “preferred” rates and prices. Their theorem suggests that the “preferred” inventory position actually exists and the market maker adopts a policy which produces that inventory position. Following that, they applied the results to the special case of linear demand and supply functions to investigate the behaviour of the bid and ask spread. They found that the bid and ask spread should be minimal when the market-maker is at his preferred inventory level, and widens as he moves away from this preferred position. Finally, they studied the effect of the market-maker’s inventory position on the total volume of transactions. They found that as the inventory level diverges from the preferred position, the volume decreases since the price and the corresponding spread is such as to deter transactors.

The dealer’s decision to determine the bid-ask spread

Stoll (1978) develops a model that describes the supply of dealer services in security markets[5]. The rationale behind this model is that the market maker is an individual who holds his desired portfolio based on his expectations as the rest of the traders in the market do but who is willing to provide “immediacy”, a term initially introduced and defined by Demsetz. In other words, the market maker is willing to act as liquidity provider altering his own portfolio in order to balance the gap between buying and selling orders when bid-ask quotations submitted by outsiders are too far apart to keep trade active without wide jumps in price and by setting a price which will compensate him from moving away from his optimal

[5] For a detailed analysis of the underlying assumptions see Stoll (1978, p. 1135).

portfolio. That is, he will set bid-ask prices in order for the spread to cover the cost of “immediacy”.

The cost of immediacy by Stoll is the sum of: a) the cost of holding an undesired portfolio, reflecting the risk he is undertaking since moved from his optimal portfolio, b) the order processing costs, c) the cost of transacting with traders that possess superior information. Stoll includes all of these costs in his modelling process however he concentrates mainly on the holding costs, while the other two are discussed but not to the same extent.

As was previously mentioned, the market maker will transact only if his expected utility after the transaction will remain unchanged. Based on that, Stoll starts building his model by assuming that the terminal wealth of his initial portfolio will be equal to the terminal wealth of his new sub-optimal portfolio after the transaction and by defining those variables that describe the terminal wealth of the initial and new portfolio. Stoll develops a holding cost function in one period context of an individual dealer and from the holding cost function the spread function is derived.

The spread function in the one period context is:

$$S_i = \frac{z}{W_o} \sigma_i^2 \left| Q_i \right| \qquad \text{Eq. 2.3}$$

In the above equation the determinants of the bid-ask spreads are: a) the relative risk aversion (z) and equity of the dealer (W_o). Of two dealers in the same stock, the one with larger risk aversion and/ or smaller equity charges a higher fee for taking a position of given size, b) the size of the transaction in the stock traded (O_i). The spread rises linearly with the size of the transaction, c) the stock variance of return (σ_i^2). The spread rises as the square of the variance of return.

The holding cost function is further modified to include order costs and information costs. Therefore, the spread function includes further determinants of the bid-ask spread. The expected return on the information possessed by those that trade with the dealer (α_i), and a constant dollar amount per transaction which therefore declines per dollar as the size of the transaction increases (M).

$$S_i = \frac{Z}{W_o} \sigma_i^2 \left| Q_i \right| + 2\alpha_i + \frac{2M}{\left| Q_i \right|} \qquad \text{Eq. 2.4}$$

In addition to the above there are some other important issues addressed by Stoll in this paper. The first is the optimal scale of operation by the dealer in each of his stocks. There is an optimal scale for the dealer because falling order costs are offset by rising holding costs. The second is the equilibrium number of dealers in a competitive system. For a given long run demand, the number of dealers is greater in riskier stocks and stocks in which individual dealers are more risk averse; the number is less the greater the order costs incurred by dealers and the greater the wealth of the individual dealer.

The role of inventory in a multiperiod framework

The work of Stoll (1978) was restricted to the supply side of market making and took in consideration only the uncertainty of holding a sub-optimal portfolio in order to derive an optimal pricing strategy for the dealer. Ho and Stoll (1981) filled this gap by developing an optimal pricing strategy model introducing a stochastic demand side to trading and therefore identifying a new uncertainty issue representing the time required by the market maker to hold a portfolio which deviates from his optimal one, since the future transactions are now uncertain.

In other words, in Stoll's model the dealer in order to provide immediacy would set bid and ask prices, which would be at least enough to compensate for the risk of holding the undesired portfolio. It was assumed that the dealer makes one transaction per trading interval during which the stock's price does not change. Prices may change between trading intervals. In a one period world, the dealer buys and sells shares in the first trading interval and becomes subject to one period of uncertainty. The period is assumed to be very short. The world ends in the second trading interval when the dealer's inventory is liquidated at the equilibrium price of the second trading interval (Stoll 1978). Therefore, the dealer will not face the return risk of holding a sub-optimal portfolio for an uncertain time horizon.

In the model of Ho and Stoll this assumption is relaxed and the dealer acts in a world where transactions are assumed to evolve as a stationary continues-time stochastic jump process following Garman. However, the dealer still costlessly liquidates all assets at the horizon date. Since orders, as stochastic future transactions, are uncertain, the dealer faces the uncertainty of holding any inventory position over an uncertain time. Unlike Garman, Ho and Stoll don't require the dealer to maximize expected profits but to maximize expected utility of terminal wealth by adjusting bid and ask prices through time. Total wealth has three components, cash, F, inventory, I, and base wealth, Y. As was just mentioned, the dealer's objective is to maximize the expected utility of his total wealth, $EU(W_T)$, at time T, his horizon. Therefore, the task is to find the bid and ask prices that will maximize the expected utility of terminal wealth.[6] Ho and Stoll

[6] Since $W_T = F_T + I_T + Y_T$ The solution to the maximization problem is the function J() (the function that solves the Bellman equation) such that $J(t, F, I, Y) = \max[EU(W_T) \mid t, F, I, Y]$, where U is the utility function, a and b are the ask and bid adjustments, and t, F, I, and Y are the state variables time, cash, inventory, and base wealth, respectively. The value function gives the level of utility given that the dealer's decisions are made optimally. Since there is no intermediate consumption before time T, the recursion relation implied by the principle of optimality is $dJ(t,F, I, Y) = 0$ and $dJ(t,F, I, Y) = U(W_T)$. To find a solution to the dealer's problem, we need to find the ask and bid adjustments that solve the above for each state.

The solution to this continuous time problem requires application of Ito's Lemma, which gives the formula for calculating the derivative of a function that depends on time and on stochastic process. The solution to the above is not straightforward and requires transformation and approximations so it is perhaps more useful to analyze the resulting optimal policy rather than to concentrate on the mechanics of the approximation.

analyse the factors that determine bid-ask spreads as well as the factors that cause price adjustments. The dealer's spread is defined as a composition of a risk neutral spread and a sum of risk premiums to reflect the uncertainty about the timing of subsequent transaction.

Therefore, the most important factor that affects the dealer's spread is the time horizon of the dealer. When $\tau = 0$, meaning that the next transaction will happen immediately, the dealer is not facing the timing uncertainty mentioned above therefore he will set the risk neutral spread. This spread depends only on the elasticity of demand for dealer services. The more inelastic the demand for dealer services, the larger the spread. When the time until the next transaction begins to increase, other factors become relevant: such as, the dealer's attitude towards risk, the relative value of the transaction and the risk of the stock. As was the case in Stoll (1978a) the spread does not depend on the inventory.

However, inventory becomes relevant with price adjustments. In particular, the price adjustment depends on the inventory, which has been acquired. The degree of price response to an inventory change depends on the same factors that determine the size of the spread, the relative risk aversion, and the riskiness of the stock and of dealer's wealth.

One of the main assumptions is that of symmetric demand. What is important is that if this assumption is relaxed and asymmetric demand is now present meaning that the dealer's perception of the true price, p, differs from the public's perception, p^*, there is no additional effect on the spread considering the risk neutral spread and the expected dealers profit remain the same. While spread is not affected, the same is not true of price. Putting this in a more simple way we can say that if the dealer is facing an imbalance in orders, for example an excess of buy orders, this will decrease his optimal portfolio and increase the portfolio risk; therefore, he will increase the ask price together with the bid price by the same amount to deter more orders on the ask side and attract orders on the bid side. Therefore, the spread will remain constant.

Price setting model with competitive dealers

Previous research on equilibrium market bid-ask spread determination was concentrated on a market with an individual dealer and how he adjusts bid-ask spreads to react to incoming orders. The paper by Cohen, Maier, Schwartz, and Whitcomb (1981) expands on a previous paper of Ho and Stoll (1981) that models the individual dealer's optimal pricing under transaction and return uncertainty and examines the determination of the market bid-ask spread in a market with competing dealers (under one-period horizon assumption). The paper begins with an explanation of the equilibrium market spread and continues with the conditions under which the dealer would trade immediately with another dealer. The paper shows that the equilibrium market spread is not affected by the introduction of heterogeneous opinions about the true price of the stock. The market spread is showed to be determined by the second best dealers.

Section 2.5.4: Information-based and liquidity-based models

The inventory models described in the previous sections dictate that inventory holding costs partially determine the bid-ask spread. The information-based models use the existence of asymmetric information in the market partially to explain the determinants of bid-ask spreads. These models are based on the fact that in the market there are two different types of traders: informed and uninformed. The existence of these two different kinds of traders creates information costs. This cost reflects the loss that the average investor will face when trading against an informed trader. An informed trader is expected to buy when he knows that the price of a particular stock is low and vice versa. In contrast, the market maker must always quote prices to buy and sell. Therefore, the market maker must offset his potential loss when trading against informed traders by gaining from uninformed traders from the existence of bid-ask spread.

Several papers focus primarily on the determinants of bid-ask spread based on the assumption that the dealer faces specially informed traders and liquidity-motivated traders.

The origin of the information models

The foundations of these theoretical approaches were set by Bagehot (1971). He explains the important role of the market maker in the stock market game. The role of the market maker is to provide liquidity by stepping in and transacting whenever equal and opposite orders fail to arrive in the market at the same time (Bagehot 1971). He describes those who are willing to participate in the market game and transact with the market maker. He identified three kinds of transactors: the Information-motivated transactors (those possessing special information), the liquidity-motivated transactors, and the transactors acting on information, which they believe, has not yet been fully discounted in the market price but which in fact has. The market maker will always lose when trading with informed market participants and always gain when trading with liquidity-motivated participants. Therefore, his gains from liquidity-motivated traders must exceed his losses from information-motivated traders. To achieve this, a market maker should set each time a bid-ask spread. A wide spread will deter information-motivated investors from trading and reduce money losses; however it will also reduce the volume of liquidity-motivated transactors, since there is an inverse relationship between liquidity of a market and the bid-ask spread (Demsetz 1968). According to Bagehot the bid-ask spread is determined by the average rate of flow of new information and the volume of liquidity-motivated transactions.

Asymmetric Information and bid-ask spreads

Although market-makers are well-informed about their asset we should not undervalue the existence of individuals who possess special information about that asset. Trading against these specially informed individuals requires the identification of an additional cost that the market maker is facing. Jafee and Winkler (1976) state that previous analyses have ignored that cost. Their paper focuses on this potential cost and shows that a market-maker should expect to lose when trading with a rational individual, even if the market-maker is more knowledgeable and even if the bid-ask spread is included. They present a model and derive a decision rule that can be employed by any investor possessing special information in order to profit from that information. The model sheds light on the process by which special information is incorporated into the market prices.

Copeland and Galai (1983) study the determination of bid-ask spread in the theoretical context of information effects on the bid-ask spread and use a mathematical approach to model this relation. Their approach builds on Bagehot's suggestion who mentioned that the main objective of the market maker is to determine a bid-ask spread that will maximize the gains from the liquidity traders and minimize the losses from the informed traders in order to maximize his profit.

Copeland and Galai (1983) derived a mathematical model (profit maximising spread model) that was based on Bagehot's approach but was extended to predict that the bid-ask spread depends on: the percentage of traders who are informed, the elasticity of demand for liquidity trading, the degree of competition among dealers, the specific risk of the asset being traded, trading volume, and the size of the transaction. The authors developed two models based on the time point that the dealer offers his quote: the instantaneous quote model and the open quote model. The implications for the bid-ask spread are very similar in both cases. That is, if the percentage of informed trader's increases, the bid-ask spread will increase. Moreover, the bid-ask spread decreases as the shift is made from monopoly to a competitive market situation. As the variance of the stock rate of return increases, ceteris paribus, the ask price is raised. There will be a negative correlation between the bid-ask spread and trading volume holding the size of the transaction per unit time constant and there will be a positive correlation between the size of the transaction and bid-ask spread, holding the number of transactions (per unit) constant.

The information of the trade outcome

Glosten and Milgrom (1985) extend the Copeland and Galai (1983) model by incorporating the information revealed by the trade itself. The assumptions of the model are similar to those of Copeland and Galai. The market maker and all market participants are assumed to be risk neutral and act competitively.

What was missing from the model of Copeland and Galai was the information that the market maker possesses following the trade that he has learned from the trade outcome. Therefore, the new price will include also his interpretation of the information of the trade outcome. In order to determine the bid-ask prices they use a standard Bayesian learning.

In particular, the market maker sets bid and ask prices such that

$$a_1 = E[V|\, B_1] = \underline{V}\, Pr\{V = \underline{V}|B_1\} + \bar{V} Pr\{V = \bar{V}|B_1\} \qquad \text{Eq. 2.5}$$

$$b_1 = E[V|\, S_1] = \underline{V}\, Pr\{V = \underline{V}|S_1\} + \bar{V} Pr\{V = \bar{V}|S_1\} \qquad \text{Eq. 2.6}$$

where

$\underline{V}$: when informed agents know that the true value of the stock will be low

$\bar{V}$: when informed agents know that the true value of the stock will be high

S_1: when a trader wants to sell a stock to the market maker

B_1: when a trader wants to buy a stock from the market maker

To determine the bid price and the ask price the market maker must calculate the following:

$$\Pr\{V = \underline{V}|S_1\},\ \Pr\{V = \bar{V}|S_1\} \text{ and } \Pr\{V = \underline{V}|B_1\},\ \Pr\{V = \bar{V}|B_1\} \qquad \text{Eq. 2.7}$$

From the above we can understand that prices depend on the probability of a sale or a buy. Therefore, there may be more sell orders or more buy orders depending on the nature of the information. This contradicts the theoretical models discussed earlier since the assumption in these models was that buys and sells have the some probability. The model derived by Glosten and Milgrom predicts that the bid-ask spread depends on the nature of the underlying information, the number of informed traders, the trader's elasticity and the trade size.

Finally, it is worth mentioning that according to the model, under some conditions, asymmetric information can result to lack of trades reflecting the unwillingness of the market maker to trade with a large number of informed traders and therefore setting a bid-ask spread that is so large that everyone is unwilling to trade. These can result in a breakdown of the market system. An important application of this is whether market structures are such as to prevent this undesirable likelihood.

In another study, Easly and O'Hara (1987) suggest a model where the traders have the ability to choose order sizes and therefore incorporate a strategic element in the process. Moreover, an additional uncertainty issue is considered, which relates with the fact that the existence of new information is not assumed. The market maker and all market participants are assumed to be risk neutral and act competitively. In addition, the fact that someone wishes to trade causes the market maker to revise his expectation of the asset's value and inventory is not relevant. The most important conclusion in their paper is that trades could vary across trade sizes and that when a market maker revises his prices following a trade, he also takes into consideration the trade size.

Section 2.5.5: Other theoretical models

Several other studies contributed to market microstructure literature following the research work discussed in the previous sections. Shen and Starr (2000) developed a theoretical model to explain the bid-ask spread based on asset price variability and order flow. Their model suggests that higher price and order flow volatility increases the bid-ask spread. Gregoriou, Ioannidis and Skerratt (2002) developed a model to describe the bid-ask spread including additional explanatory variables, the reported disagreement amongst market analysts regarding the firms' earnings. The model shows that observed disagreement would increase bid-ask spread as the market makers face higher information asymmetry. This argument was initially introduced by Kim and Verrechia (1994 and 2001). Handa, Schwartz and Tiwari (2003) developed a model of price formation in a non-intermediated, order driven market and found that the bid-ask spread depends on factors such as the difference in the valuation among groups of investors, the proportion of investors in each group and adverse selection. They show that the spread is positively related to the valuation differences between the groups.

Bollen, Smith and Whaley (2004) developed a model for the market maker's bid-ask spread that incorporates a number of factors such as: the effects of the price discreteness induced by minimum tick size, order-processing costs, inventory-holding costs, adverse selection, and competition. Their model shows that "the expected inventory holding premium is a specific nonlinear function of share price, return volatility, and the length of time the market maker expects his position to remain open". Common to the previous literature their model also captures the inventory-holding and adverse selection cost components of the spread.

Section 2.6: Empirical findings on the determinants of bid-ask spreads

There is a vast amount of empirical work on the determinants of bid-ask spreads for different assets and for different market structures. In general, these papers investigate the effect of a number of market characteristics such as volatility, trading volume, market structure (auction and dealer), level of transparency, degree of competition, seasonality effects and intraday behaviour, on the bid-ask spreads. I discuss studies relating to market structure and transparency in Chapters 3. Moreover, because the purpose of this thesis is to empirically examine the determinants of bid-ask spreads in the FX market I provide a detailed review of the work on the determinants of bid-ask spreads for the FX market in a separate chapter (Chapter 4).

Therefore, in this section I review only the influential empirical papers that examine the determinants of bid-ask spreads in markets other than the FX market. Much of the theoretical and empirical work on market microstructure deals with individual asset characteristics such as transaction costs and liquidity of repeated trading of a single asset. Studies on market-wide trading costs and liquidity are uncommon. I review the empirical findings of the determinants of bid-ask spreads by distinguishing between those studies that deal with the liquidity determinants of single assets and those that focus on the common determinants of liquidity.

Section 2.6.1: Liquidity determinants of single assets (Individual liquidity determinants)

The empirical studies that examine the determinants of bid-ask spreads span different markets including equity spot and options, FX spot and future, interest rates and interest futures markets. Most of the work is concentrated around the equity spot market. In general, these empirical studies show that bid-ask spreads are positively related to volatility and negatively related to the number of trades or volume.

Tinic (1971) in his paper "*The economics of liquidity services"* empirically tests a hypothesis developed. Using data from New York Stock Exchange he models and examines the relationship bid-ask spread and some variables. Specifically, these variables are price, trading volume, institutional concentration, trading continuity, price volatility, competitive pressures, dealer capitalization, and size of specialty portfolios. His results show that the bid-ask spread has a positive relationship with the price of the issue and the level of trading concentration in the New York Stock Exchange. Moreover, he concludes that bid-ask spreads are lower for issues that experience continuous and heavy trading activity. As far as the volatility of price and capitalization of specialist units is concerned, no statistically significant relationship is found with the bid-ask spreads.

As mentioned earlier (Section 2.5.3) Stoll developed a model that describes the supply of dealer services in security markets. In a different paper Stoll (1978), using data from the Over-the-Counter Market (OTC), provides empirical evidence on determinants of spreads applying this theoretical model of dealer cost. In particular, he used closing bid and ask prices for each NASDAQ stock for six consecutive trading days in July 1973 and volume of trading for each dealer in each NASDAQ stock during the same period and different regressions are run. In order to find empirical evidence on the determinants of spreads the proportional spread is regressed against the variance of return, dollar volume, turnover, stock price, and number of different dealers. These variables are used to reflect the theoretically developed variables that describe the three types of costs in Stoll's model: holding costs, order costs and information costs. The holding cost is measured by measuring the risk of the stock using the variance of return and volume of trading. Information costs are measured by turnover (volume/shares outstanding). Order costs are also not directly observable and therefore are measured assuming that this cost is function of the absolute price of the stock. The degree of competition is also measured by the number of dealers in a stock.

The results suggest that all variables (the variance of return, dollar volume, turnover, stock price, and number of different dealers) have the expected sign. In particular, the variance of return and the volume of trading have positive and negative signs respectively and are statistically significant. The turnover variable has a positive and significant effect on spread. The absolute price of the stock variable has a negative sign. Last but not least, the number of dealers variable has a negative effect on spread meaning that the presence of more dealers in a stock reduces spreads.

Following the seminal works by Tinic (1971) and Stoll (1978) many empirical papers have documented similar results in the equity spot market. Mclnish and Wood (1992) using high-frequency data from the NYSE found that bid-ask spreads decrease with an increase in trading activity (observed by higher volume and higher number of traders) and increase with volatility and trade size. Similarly, Lee, Mucklow and Ready (1993) used a broad sample of 209 US stocks and found that spreads increase with volume and decrease with depth. This is further supported by Harris (1994), who finds that higher volatility results to larger spreads while higher volume results in lower spreads.

Many papers try empirically to investigate the significance of the three cost components of the bid-ask spreads: order processing costs, inventory holding costs and asymmetric information costs and to determine the contribution of each to the bid-ask spread. Glosten and Harris (1988) empirically investigated 270 US stocks for a two year period between 1981 and 1983 and found that bid-ask spread is partly due to asymmetric information. This was also documented by Stoll (1989) using data from Nasdaq. He found that asymmetric information and order processing costs are the main components of the spread. Kim and Ogden

(1996) using data from the NUSE (AMEX) provided additional evidence to support the previously documented high importance of asymmetric information in the determination of the spread. Jong, Nijman and Roell (1996) examined ten French stocks and also found that the main components of the bid-ask spread are asymmetric information and order processing costs. In contrast to the empirical papers mentioned above, Bollen, Smith and Whaley (2003) using data from Nasdaq stock exchange find that the main component of the bid-ask spread is the inventory holding cost. The cost of asymmetric information appears to be small. Krinsky and Lee (1996) further explored the components of spread and found that adverse selection costs are higher around earnings announcements, while inventory and order processing costs decline. Similarly to this paper, Acker, Stalker and Tonks (2002) also examine the determinants of bid-ask spread and their behaviour around earnings announcement dates. However, they focus on UK firms over the period 1986-1994. The findings suggest that closing daily spreads are affected by order processing costs, inventory holding costs and asymmetric information.

In another paper, McInish and Van Ness (2002) concentrate on the intraday behaviour of the bid ask spreads using a sample from the NYSE market. They investigate whether variables measuring trading activity, dealer competition, risk and information explain the behaviour of order-processing costs and asymmetric information costs over the trading day. They find that the variables that determine the aggregate bid-ask spread also determine its intraday components.

A number of studies have focused on the futures market. Breedon and Holland (1998), and Frino, McInish and Toner (1998) used data from the interest futures market (Liffe and DTB) and found that spreads increase with volatility and decrease with the number of trades. Frino, Stevenson and Duffy (1998) examined the intraday quoted bid-ask spreads in the Sydney Futures Exchange and found evidence to support the theoretical suggestions of inventory holding costs and asymmetric information costs. In particular, they found that volume and volatility (as the determinants of bid-ask spreads) both increase at the open and the close of trading. In another paper, Domowitz (1999) used data on index futures trading in an electronic limit order book market to investigate "the relationships between information observed through the system by traders, order placement behaviour, and the probability distribution of the bid-ask spread". The results show that the probability distribution of the bid-ask spread is mainly affected by changes in trading activity and in particular the amount of order submission.

Researchers tried to find determinants of spreads other than those relating to order processing, inventory holding and asymmetric information costs, as a portion of the bid-ask component still can't be explained by these factors. For example, the theoretical literature on the bid-ask spread focuses on market risk, but not on accounting risk. Ryan (1996) identifies this issue by studying the relationship between certain accounting ratios (asset size and asset growth) and the bid-ask spread. His empirical results indicate a statistically significant association between certain accounting ratios (asset size and asset growth) and the bid-ask spread.

Differences in trading systems and markets also affect pricing and liquidity and therefore the bid-ask spreads. Brockman and Chung (2003) empirically investigate the relation between investor protection and firm liquidity. They use data from Hong Kong-based and China-based companies and show that in less protective environments (China) spreads are wider and depths thinner because the possibility of trading with an informed trader is higher. Wahal (1997), Klock and McCormick (1999) and Boehmer and Boehmer (2002), studied the equity market and found that both effective and quoted bid-ask spreads decreased after trading began on a competing exchange. Following the same line of thought Fontnouvelle, Fishe and Harris (2005) examined whether bid-ask spreads were higher when option classes were singly listed. Their results support the view that inter-exchange competition reduces option transaction costs. We focus on the market competition and its effect on bid-ask spread in the next chapter.

Concluding, up to date research has identified a negative relationship between the bid-ask spread and price, volume, the number of stockholders, and the number of dealers, and a positive association between the spread and risk as proxied by several accounting and market risk variables (liquidity, leverage, earnings variability, market beta, and price variability). In the next section, I discuss a different approach in the examination of the bid-ask spreads, suggested by Chordia, Roll and Subrahmanyam (2000), that relates to the determinants of the whole market liquidity rather that the liquidity determinants of single assets.

Section 2.6.2: Determinants of the whole market liquidity (common liquidity determinants)

Research on liquidity focuses mainly on individual securities. It is important however to identify the reasons that affect market wide liquidity. Chordia, Roll and Subrahmanyam 2000 deal with the recognition and documentation of the existence of commonality in liquidity. In other words, in this paper the authors try to find evidence to prove market-wide changes in liquidity. The recognition of commonality in liquidity is the key to uncovering the identification of its sources, in other words the identification of common underlying determinants of the correlated movements in liquidity. The latter is the focus of the paper of Chordia and Stoll, who deal with the determinants of liquidity and trading activity. It is important to note that no one else before has documented this issue of market microstructure. The results provide ample evidence that individual liquidity measures co-move with each other and the influences of such commonality remains high even after considering the individual determinants of liquidity such as trading volume, volatility, and price. The authors examine the covariation between individual stock liquidity and market and industry liquidity. Then given the above evidence they ask if time series variation in individual stock liquidity is related to market industry trading activity after controlling for trading activity of individual stock. Finally, they show that the above documented relationship contributes additional explanatory power; in other words the market liquidity is responsible for a fraction of the variation of individual liquidity.

In a later study, Chordia, Roll and Subrahmanyam (2001) examine liquidity and trading activity over a long period on a sample of NYSE-listed stocks. Their empirical examination shows that equity market returns, recent market volatility and short-term interest rates influence liquidity and trading activity. Moreover, they provide evidence of significant day-of-the-week regularities in liquidity and trading activity (decreased liquidity and trading activity on Fridays). One of the most important findings relates with the relationship between bid-ask spreads and market movements. Quoted and effective spreads increase dramatically in down markets, but decrease only marginally in up markets.

Section 2.7: Summary and conclusions

As we can see from the literature review in this chapter the bid-ask spread models went through various stages of development since Demsetz raised the issue of the cost of transacting for the first time in 1968. All the developments though are building around the same modelling approach that considers inventory holding costs and asymmetric information costs the main reasons for bid-ask spread adjustments. What has changed over the years in the development of theoretical and empirical models is the complexity of these models, the addition of new variables and the consideration of the changes in market mechanisms and characteristics.

Very often researchers who are modelling the determinants of the bid-ask spreads will consider only inventory holding costs or only asymmetric information costs in order to study more clearly the effect of the selected variables on the bid-ask spread. The review in this chapter shows that although a considerable amount of work has been done both at a theoretical and an empirical level to investigate the effect of market characteristics such as volatility, trading volume, market structure, level of transparency, degree of competition, seasonality effects and intraday behaviour, on the bid-ask spread, there are often differences in the results reported. These differences may be due to differences in data samples, methodology, market mechanisms, technology, regulatory changes or other undetermined factors.

Therefore, there are still issues that require investigation especially in the area of the FX market microstructure that research is fragmented and has not developed as much as in the field of equity markets. With this work I fill a significant gap in the literature by examining market-wide commonality in liquidity using many variables at the same time and over a long period of time. I use the existing literature to determine which variables are important in my methodology and in order to compare my results to those of other researchers. Of course the determination of bid-ask spreads cannot be discussed without understanding the role and the effect of market architecture which I review in the next chapter.

Chapter 3: Market Architecture, Information Disclosure and Transparency

Section 3.1: Introduction and overview

In this chapter I review the influential papers that discuss the impact of market architecture, information disclosure and transparency on the liquidity of the market. In general, these studies employ theory, experimentation and empirical analysis to examine different trading systems in the stock markets on the basis of their reliance on market makers (monopolistic and competitive dealers), their degree of continuity (periodic “call” auctions and continuous auctions), their transparency and their degree of consolidation/fragmentation. Moreover they investigate how pre-trade and post-trade transparency impacts on various market liquidity variables such as spread and depth and how liquidity traders and informed traders are affected by different levels of transparency.

The markets in which securities are traded have undergone impressive structural, technological and regulatory changes in recent years. The importance of market structure has given rise to a large and growing theoretical and empirical literature. It is commonly accepted that by studying the influence of trading mechanism on prices we can improve our understanding of the process by which transaction prices adjust to asset values, in other words the price discovery process.

Due to competition European exchanges are in process of trading consolidation. The underlying question is whether the heterogeneity in trading systems affects price formation and the costs of trading and what structures offer the greatest liquidity and least trading costs.

Section 3.2: Market architecture definition

Market architecture (or market structure) should be considered as the sum of all those characteristics, rules and procedures that describe in detail the dimensions and chain of the trading mechanism. Trading systems may vary depending on the degree of continuity (the frequency of trade in a security, e.g continuous versus batch trading), the reliance on market makers and the degree of automation (the order submission procedures and its technology). These three characteristics form the market type of a trading system. In addition, other characteristics that define the market structure are:

- Price discovery: Use independent price discovery or use prices determined in another market as the basis for transactions
- Order forms (i.e., market, limit, stop, upstairs crosses, baskets).
- Protocols (i.e., choice of minimum tick, special rules for opens, re-opens, and closes)
- Transparency: the quantity and quality of information provided to market participants during the trading process.
- Extent of dissemination of information (brokers, customers, or public)
- Speed of dissemination (real time or delayed)
- Degree of anonymity (hidden orders, counterparty disclosure)
- Possibility of off exchange or after hours trading.

Lee (2002) defines market structure of a single trading system as the collection of rules governing the way the trading system delivers the functions of data dissemination, order routing and order execution.

Section 3.3: Definition of market transparency

Transparency is nowadays a key factor in competition between financial markets. In past years a number of papers have been published that study its relationship with various measures of market quality. Transparency can be defined as the real-time and market-wide publication of information regarding the trading process. The accuracy and speed at which information about trading opportunities becomes available to market participants have a potential effect on their ability to trade, and so, on the prices and quantities at which securities are traded. A key question is how much transparency is optimal in a market, as the level of transparency can have both a favourable and unfavourable effect on market performance. A market with high transparency will be more efficient as asset information will be incorporated in the price of the asset faster and more accurately. On the other hand, increased market transparency may have an adverse impact on the performance of the market as market participants with private information will be less willing to trade in this market, decreasing its liquidity.

Transparency is divided into pre-trade and post-trade transparency. *Pre-trade* transparency refers to visibility of information about orders prior to execution; On the other hand post-trade transparency is essentially the publication of executed trades. When trading information (eg. size of executed trade) is immediately available, market participants can incorporate this information into their asset valuation procedure, therefore access to this information may be important to the trading process. The many papers that have been published referring to this issue have used both theoretical and empirical designs to examine various aspects of pre-trade and post-trade transparency. Another area of market transparency studies examine the relationship between transparency and competition between markets where the same assets are traded. In the following sections we review the papers that focus on pre-trade transparency (quotes), post-trade transparency (trades), transparency and trader anonymity, and the relationship between transparency and competition between markets.

Section 3.4: Dealer systems (dealership market)

A dealer is an individual or firm who buys and sells stocks as a principal rather than as an agent. The dealer's profit or loss is the difference between the price paid and the price received for the same security (the bid-ask spread). In a dealership market, public investors cannot trade directly among themselves. The market maker is expected to sell from his own portfolio when prices go up and add (buy) into his own portfolio when prices decline in order to act as “price stabilizer”. Moreover, in a dealership market prices incorporate new information immediately as market makers adjust their quotes, therefore traders have smaller probability of misestimating the true value of an asset. Of course, all these advantages come at a price (cost), which is the existence of bid-ask spread.

There are two broad issues under examination in the dealer market literature. First, researchers have investigated whether market making improves liquidity and second whether a monopolistic or competitive market making structure should be favoured. In both streams of research, findings are mixed. Theoretical studies suggest that market-makers stabilize prices and reduce the observed return variances (volatility). However, empirical studies are unable to provide secure conclusions on whether the presence of the market maker improves liquidity since there are also many other parameters that affect liquidity such as trading volume and information asymmetry. I discuss this issue in more detail in section 3.6.

Dealer markets (also called quote driven markets) can operate with either one monopolistic market maker or more market makers that compete with each other. Pagano and Roell (1990),Christie and Huang (1994) and De Jong, Nijman and Roell (1995), all find that trading costs are lower with a monopolistic specialist acting as a market maker. In addition, Huang and Stoll (1996), Bessembinder and Kauffman (1996) and Keim and Madhavan (1995) find that a monopolistic market provides more liquidity. However, other research findings (Bochow et. al.

1999) favour the competitive market maker. Many markets such as Nasdaq and London Stock Exchange feature competition between market makers. Models of competition among market makers have been developed by Ho and Stoll (1983) and others. Reiss and Werner (1996) provide empirical evidence that inter-dealer trading reduces spreads by allowing dealers to move closer to optimal inventory levels.

Section 3.5: Auction systems

Auction systems are called also order-driven systems because the best available price is defined by submitting orders**.** In contrast to dealer markets, in an auction market there is an absence of dealers to hold inventory. Traders send buy and sell orders to a centralized order book. Auction markets are classified into call auctions (batch auctions) market and continuous auctions (limit order book) market according to their degree of continuity.

In batch auctions, traders submit buy or sell orders which accumulate during some time interval and are then executed simultaneously at a price which equates the quantity supplied to the quantity demanded. Theory suggests that, call auctions are especially valuable when uncertainty over fundamentals is large and market failure is a possibility. Indeed, many continuous markets use single-price auction mechanisms when uncertainty is large; such as, to open, close or to re-open following a trading halt. The opening call auctions in Milan, Paris, Madrid, New York and Tokyo are examples of such auctions.

Despite the above-mentioned benefits of call auctions, trading is often formed using the continuous mechanism (bilateral systems) relying on dealers to provide liquidity, instead of the periodic, multilateral system. In continuous auctions, market orders are executed one by one immediately upon placement. In determining limit order prices, speculators observe past transactions and other limit orders. In continuous markets, trading can be accomplished relaying on dealers or as a limit order market without intermediaries. Examples of continuous auction markets are Paris (CAC: Cotation Assistee en Continu) and Toronto (CATS: Computer Assisted Trading System).

In active securities, pure limit order book markets are clearly feasible. Yet most markets, including very active ones such as the foreign exchange market, rely upon market makers to act as intermediaries. Therefore, two questions require answers: what are the functions of market makers that make their presence valuable and why can't public auction markets provide the same functions?

Section 3.5.1: Kyle's auction model

I start by describing Kyle's auction model as it sets the basis for other auction structure models. Kyle's is a batch-trading model since it considers a single trading period in which the informed trader submits his optimal order along with the orders submitted by uninformed traders. After developing this model he extends it to consider sequential-auction and continuous auction frameworks.

The theoretical models discussed in previous sections describing the price discovery process (information models only) present a commonality in that in all models agents act competitively. These models assume that the information processed by informed traders is not used by them to act strategically to maximise their profits. In other words, the trader with superior information in the previous models would take advantage of this "benefit" by simply submitting orders until prices eventually adjust in a competitive market. What these models ignore is that an informed trader in reality would not simply submit an order whenever he has information since he knows that the order flow would signal to the market maker that he is trading against an insider, making the market maker to protect himself by adjusting his quotes accordingly. The informed trader would rather choose a strategy since the market maker cannot separate informative from uninformative orders. In other words he considers before submitting an order the effect of this order on price at that auction and the trading opportunities available in future auctions. The informed trader's strategy will aim to trade in such way that his superior information is incorporated into prices gradually.

This consideration is incorporated in Kyle's model and this is what it makes it distinct from the previous ones. He is modelling the trading strategy of an insider in a dynamic model of efficient price formation. His model assumes that the trader having superior information would use this information and trade strategically against the market maker. Kyle's model consists of a "privileged" auctioneer (also known as the market maker), a single risk neutral informed strategic trader and many uninformed non-strategic liquidity traders, the so-called noise traders. They trade a single risky asset for a riskless asset in a single trading period.

Since the description of the model starts with the analysis of a batch auction, all trades are cleared at a single price (market clearing price); therefore, there is no bid-ask spread. The information available to market participants is that the market-maker does not see individual orders submitted by informed and uniformed traders rather than just an aggregate order flow, and he does not have any other kind of special information. The informed trader knows the distribution of uninformed orders but doesn't know the actual orders. These have the following implications: the informed trader may use his knowledge of the distribution of uniformed trades to camouflage his trades and the market maker's pricing decisions depends on the contribution of the informed traders order flow to the aggregate order flow.

Lyons (2001) explains the three features of the Kyle model that limit its applicability when analyzing the FX market. First, the Kyle model is based on asymmetric information costs where in the FX market inventory holding costs play a key role in market makers' decisions. Second, the Kyle model does not include a bid-ask spread, wherees the FX markets are dealership markets and therefore, the bid-ask spreads are present. Nevertheless many researchers (like Madhavan, 1996) have used Kyle's model for spread analysis by calculating the "implicit" spread. Last but not least, in Kyle's batch auction model individual orders cannot be analysed. In contrast, for major FX markets the trading data include individual orders.

Section 3.5.2: Comparison of periodic (batch) and continuous trading systems

In this section, I review the research that has been undertaken at theoretical, empirical and experimental levels into how differences between periodic and continuous trading systems, may affect price efficiency, volume, return volatility and liquidity. Each trading system should be examined based on the advantages and disadvantages it provides to different types of traders. In other words, it is the traders' motive (e.g. whether a trader is liquidity motivated or has insider information) that matters when advantages and disadvantages are discussed. Moreover, most papers focus on a particular characteristic of a market structure and compare the two market structures on that basis, for example they compare the liquidity properties of two different trading systems.

Theoretical approach

An obvious difference is that continuous auctions provide greater immediacy than batch ones, since auctions are held in frequent time intervals. Kyle (1985) compares the liquidity properties of a continuous auction equilibrium with the corresponding properties of a sequential auction equilibrium. To describe liquidity he uses different elements of transaction costs, including "tightness", "depth", and "resiliency". He finds that in the continuous auction equilibrium, the trader can turn over his position very quickly; therefore, it is costless. In contrast, in a sequential auction equilibrium, the cost of turning over a position is higher the quicker the trader wants to turn over his position. As for the ability of the market to absorb quantities without having a large effect on price (depth), in the continuous auction equilibrium it is constant. In a sequential auction equilibrium, depth is not constant over time. Moreover, Kyle models a continuous market and a single call auction and measures the trading costs occurring in market organisations in the case of noise traders. He finds that, noise traders' (trading not based on fundamentals) losses are double in the continuous market relative those in a single call auction.

Pagano and Roell (1996) find that the greater transparency of the call auction leads to lower expected trading costs for noise traders than in a continuous auction mechanism. Madhavan (1992) employing a very different modeling approach, shows that a periodic trading system is less likely to close down than a continuous trading system when a significant number of informed traders are present.

Empirical and Experimental Evidence

Amihud and Mendelson (1987) empirically investigate the effects of trading structure on stock returns (price behaviour). The two different structures they examine are a periodic trading system and a continuous trading system. They employ data from the opening (representing the periodic trading system) and the closing (representing the continuous trading system) of stocks in the NYSE. In particular, the opening is a clearing procedure where market participants submit limit or market orders, which are cleared by a single price. On the other hand, the closing is a dealership market where trading is relies on market-makers who quote bid-ask prices. They find that the trading mechanism has a significant effect on stock returns. In particular, they found that opening exposes traders to a greater variance than closing and the nature of lagged price adjustment and the level of transitory noise are different. Lauterbach and Ungar (1997) investigate the effect of different trading mechanisms on liquidity. In particular, their study empirically investigates the impact of transferring 29 stocks in Israel from a single daily auction to a more continuous trading system on daily volatility of the stock return. The results show that changing from a single daily batch auction to a more continuous trading decreased volatility of stock returns and increased volume of trade.

Schnitzlein (1996) experimentally investigates the influence of trading mechanisms on insider traders' behaviour and whether their optimal trading policies depend on the market organisation. Moreover, the existence of systematic differences in market liquidity is also examined. He finds important differences in the performance of the call and continuous trading mechanisms in the presence of insider trading. A significant result is the greater liquidity of the call markets in the sense that the markets are deeper, and noise traders incur lower losses. This result is consistent with the theoretical models that examine the influence of temporal consolidation and market transparency on market performance.

Section 3.6: Comparison of dealer markets and auction markets

As I explained in previous sections, the key functions of the market makers are price discovery, liquidity and continuity, and price stabilization. The question and the basis of this comparison is whether a pure auction market can achieve the same outcomes as dealer markets but at a lower cost.

Auction and dealership markets have many significant differences. In auction markets traders send buy and sell orders to a centralized mechanism and they are cleared at a single price, whereas in dealership markets orders are placed with individual dealers, who execute them at preset quoted prices. In an auction system, unlike the dealership system, there is no difference between the buying and the selling price. Therefore, there is no noise in stock returns from the existence of the bid-ask spread. In contrast to the dealership market, in an auction market new information is more slowly reflected in prices; therefore, there might be an error in determining the price since prices may not reflect all available information. One main disadvantage of a pure auction system is that once a market participant provides a limit order, he “locks” at that price, being exposed against possible exogenous shock that could cause changes in values. The market participant then would “offer” a free option to the market that can be hit. Therefore, the limit order trader needs to use more resources to protect himself from this possibility, something that could result in high costs. This may be why dealers arise in auction markets. Pagano and Roell (1992) provide an appropriate basis for the understanding of the main differences between auction and dealership markets. Their paper focuses on three functional differences between the trading systems: the speed of dissemination of order flow information, the degree to which traders’ identities are known before trade, and the extent of public limit order exposure

Speed of dissemination of order flow information

The order flow provides market participants information in order to form their estimates of the true price. The more trading information available at the time the price is formed, the more of this information is included in the price. In dealership markets the publication of trading information is not immediate, therefore the market maker forms the transaction price without knowing his competitors’ recent order flow. In contrast, in auction type markets trading information is published immediately. This difference in the speed of dissemination of order flow information creates differences in the trading cost and execution risk for the two different trading systems. Under this perspective in dealership markets the trading cost will be higher than in the auction market since the market maker has less information about the recent trading history. Moreover, in dealership markets the execution risk is lower than in the auction market since the market maker provides the role of immediacy. Actually the execution risk in a dealership market is zero.

Of course when considering the above, the two main types of investors must be also considered. For liquidity traders the auction market on average is cheaper than the dealership market when the trading cost is considered. For an informed trader the dealership market on average is cheaper, since prices do not include much of the history of the order flow.

The degree to which traders' identities are known before trade

In an electronic auction system the identities of the market participants are not disclosed. On the other hand, in dealership markets the market maker has the ability to identify at least some traders as liquidity or informed traders. This implies that on average the transaction cost for a liquidity trader will be lower when participating in a dealership market.

The extent of public limit order exposure

The main difference between these two market organizations is identified in execution risk. When referring to execution risk we mean the possibility of not finding a counterparty to trade. Even if there are a few to trade execution risk still exists by taking the form of the uncertainty on the actual price at which the order will execute. However, when referring to execution risk we mainly mean the uncertainty of the actual execution of the order.

In dealership markets execution risk is not present since dealers have the obligation to quote firm prices publicly. Therefore, at any given time during the market operation there is someone willing to buy or sell against an incoming order at a specific bid and ask price. This means that execution risk in both forms (order execution uncertainty and price execution uncertainty) is not present. In an auction market, in contrast, execution risk is present. A trader can place a market order or a limit order as we have explained in the previous sections. By placing a market order, the order execution uncertainty is not so relevant (but still exists) but execution price uncertainty is very high since the order may be executed in a price much lower (sell order) or much higher (buy order) than the desired one. In order to avoid this risk the trader can place a limit order specifying the minimum or maximum price at which he is willing to trade, but then he immediately faces the risk the trade not being executed at all.

It is obvious from the above that the key issue is whether dealership markets offer higher liquidity from auction markets, where liquidity refers to price stabilization and continuity of trades. Of course this liquidity by the market makers is offered at a price (the bid-ask spread), a cost that is absent from auction markets. Therefore, it is important to examine whether it is meaningful for the traders to pay that price or to trade in an auction market and bear this risk themselves.

Another difference is that auction markets are more transparent than dealer markets, in the sense that more information can be made directly available to all market participants. They provide greater pre-trade transparency. More specifically, they provide greater visibility of the best price at which any incoming order can be executed. In electronic auction markets, brokers can scan the limit order book and see exactly at what price an order would execute. In contrast, dealer markets display very limited information, namely the ‘’firm quotes’’ at which market makers must deal for up to the posted size. Post-trade transparency, such as real-time trade publication, is not feasible in dealer markets as a deal takes a few minutes to be reported to the exchange and for the latter to publish it on screen. On the other hand, in electronic auction markets trades are subject to publication on time.

In the following section I review some of the main studies that deal with the comparison of auction and dealership markets under both a theoretical and empirical perspective. The comparison between these two market types includes the comparison of trading costs (measured by the bid-ask spread), the customer’s choice according to the risk-type of the customer (e.g. risk neutral), the price formation at the opening of a trade market, the informed and uniformed traders preference, the degree of transparency, information efficiency, market depth, and market thickness.

Section 3.6.1: Theoretical comparison

Theories contrasting auctions and dealership markets are quite rare, possibly because these two trading systems differ in rather subtle ways. The theoretical study of Naik, Neuberger and Viswanathan (1999) shows that in a dealership market, order flow is informative and dealers will compete for that information by offering preferential prices. This means that sometimes the spread declines with the information content of the trade. Their model shows that spreads are narrower for uninformed investors when there is full disclosure because the latter facilitates more efficient inventory risk sharing. Trades with little information can be priced better in a dealership market with full disclosure than in a standard auction market. However, auctions appear to be best where trades contain intermediate amounts of information, while dealership with limited disclosure favours informed trades.

Section 3.6.2: Empirical comparison

The difficulty with empirical comparison is that different markets trade different assets and these assets are traded in different environments; hence it’s hard to discern differences resulting from the trading mechanism itself or from differences due to dissimilarities of securities and environments. In other words the comparison may reflect differences, due to factors other than the trading mechanism, such as differences in the securities themselves, differences in the regulatory and economic environment, etc. To eliminate this possibility, the comparison between the liquidity offered by two markets must be examined on the same stocks and over the same time period.

Viswanathan and Wang (1997) analyse the customer's choice among a limit order book and a dealership market. A risk neutral customer prefers to trade in a limit order market. On the other hand, a dealership market is preferred by risk neutral customers when the number of market makers is large and the average order size is large. In 2002 they noted that a significant distinction arises in the nature of price quotations across dealer markets and limit order books. Dealers can quote an array of prices at which they are willing to complete orders of various sizes. Therefore, quotations for orders of a given size need not affect revenues from executing orders of a different size. On the other hand, because large orders walk up the limit order book, revenues from executing large orders submitted to the limit order book depend on limit prices for smaller orders as well. Foucault, Biais, and Salanie (1998) analyse and compare price formation, trades and risk sharing in limit order markets and dealer markets. They explain that in quote-driven markets the allocation of risks can be efficient, but spreads are generally high. On the other hand, in limit order markets the risk sharing is efficient and spreads are competitive. Also in quote driven markets market makers are free to negotiate the price with their customers, and for example, offer a discount. In limit order markets, liquidity suppliers must post convex schedules. Blennerhassett and Bowman (1998) present evidence that a move from a market-maker system to a screen based order book on the New Zealand stock exchange reduced trading costs. However, their results also suggest that the spread became more "sensitive" to trade size that might result in higher trading costs for large transactions. Theissen and Wolfgang (1997) report the results of 18 market experiments in order to compare the call market, the continuous auction and the dealer market. They found that the opening prices in dealer markets and continuous markets are further from the true value of the asset than the opening prices in the call market, although the difference between the call auction and the continuous auction is not important. This result is in line with the empirical work of Amihud, Mendelson and Lauterbach (1997) and theoretical models such as the Kyle's (1985). Execution costs are highest in the dealer market and lowest in the call market.

Pagano and Roell (1992) examine the advantages of order-driven and quote driven markets focusing on the level of transparency. They argue that in dealership markets market makers would indentify informed traders and therefore they would trade with those uninformed. The informed traders would choose to trade in the order book or face a higher trading cost for trading large quantities with dealers. Bennouri (2003) proved that auction markets are less sensitive to asymmetric information problems. They also show that the relative magnitude of price variance, market depth and informed trading aggressiveness in both structures depend on the market thickness.

A recent study by Snell and Tonks (2003) examines the relationship between auction and dealer markets to determine which delivers the lowest trading costs for institutional investors. The results suggest that neither trading system benefits the institutional investors in terms of providing lower trading costs. Actually both trading systems reduce the trading costs under the following conditions. When a market is dominated by informed traders the dealer system would reduce trading costs since the market maker can identify from the order flow the possibility of inside information. On the other hand, when a market is dominated by liquidity motivated traders then trading costs are reduced since the institutional investors trade directly with each other; therefore increased competition reduces trading costs.

Section 3.7: Consolidation in financial markets

Another controversial issue in the market structure literature is whether markets should be consolidated or fragmented. For example, stock exchanges are transitioning from national level to an international level, such as the merger in 2000 of the exchanges of Amsterdam, Brussels and Paris. There are many arguments in favour of consolidation however, many markets are fragmented. The argument for consolidation lies behind the fact that consolidated markets reveal more information. In general, theory suggests that fragmentation reduces liquidity, however, empirical evidence is inconclusive.

Cohen, Maier, Schwartz and Whitcomb (1982), Cohen, Conroy and Maier (1985), and Mendelson (1987) find evidence to support the theoretical proposition that fragmentation reduces liquidity as this is reflected both in an increase of bid-ask spreads and increase in price volatility. In particular, Cohen, Maier, Schwartz and Whitcomb (1982), examine the role of an off-exchange floor in addition to the main market. Their results show that although off-exchange floor trading benefits brokers, spreads and price volatility are higher compared to a consolidated market. Cohen, Conroy and Maier (1985) provide evidence that bid-ask spreads are higher in a fragmented market because there is a higher risk, as the expected time a limit order has to wait until it is executed may be greater or it may not be executed at all. In addition, Mendelson (1987) shows that “the overall gains from trade decline as the market becomes more fragmented”.

However, Madhavan (1995) argues that if a market discloses too much information about a trader’s identity and motivations for trade that might prevent large traders from trading since, there is the likelihood that their strategies are revealed. Such trades would thus be executed using upstairs markets. Moreover, Hendershott and Mendelson (2000) show that when trading takes place in multiple markets, liquidity often suffers as the bid-ask spread is set in a “market of last resort.”

Khan and Baker (1993) find mixed results regarding the benefits of consolidation. They investigate the liquidity of stocks traded in different markets. Regional exchanges attract trades in listed stocks away from the main exchanges, such as the NYSE. Their results show that low-liquidity and high liquidity stocks behave differently depending on the degree of market consolidation. In particular, they find that competition of regional exchanges favours low-liquidity stocks, whereas the liquidity of large, actively traded stocks is hurt by fragmentation. Nielson (2008) empirically investigates how exchange consolidation has affected stock liquidity and whether there are asymmetric liquidity gains. He examined the Euronext stock exchange merger analysing nearly 1,200 firms during the period 1996-2006 and found that liquidity increased for big firms and firms with foreign exposure. In another study, Pagano and Roell (1993) provide evidence that spreads on French stocks traded in London narrow after the opening in Paris, and widen again after the Paris trading closes.

Lee (1993) provides further evidence that fragmentation reduces liquidity; his results show an increase in transaction costs for trades of stocks on the NYSE and off-board, in regional exchanges and on NASDAQ. Furthermore, Fang (1997) investigates the price impact on stocks that are dually-listed on the Hong Kong Stock Exchange and on the Shanghai Stock Exchange. He compares the pre-listing prices of the dually-listed stocks to their prices 40 days after the dual listing and finds that the prices of the dually-listed stocks decline as a result of the dual listing.

Trading consolidation is also the focus of the work by Amihud, Lauterbach and Mendelson (2003). They examine the exercise of deep in-the-money corporate warrants in terms of liquidity and stock price effects. As they mention in their work, “when the trading mechanism enables continuous trading and rebalancing, the loss (benefit) from fragmentation (consolidation) is much smaller than when stock trades in a single daily call auction”. They also suggest that recent advances in technology allow market participants to move between markets at low cost, therefore, the negative effects of fragmentation are reduced. Neal (1987) finds that fragmentation in options trading is beneficial. His results show that American Stock Exchange (AMEX) options that are also traded in other markets have narrower bid-ask spreads than options that trade exclusively on the AMEX.

To conclude, it is important to note that the results from the studies that examine the effects of consolidation may be affected by the institutional differences between the markets being compared.

Section 3.8: Pre-trade transparency and its influence on the trading process

Market transparency is not a field of recent literature. Papers such as the one by Garbade and Silber (1978) are considered to have opened up the interest in this field. They examined how technological advances have impacted on the integration of different markets. They found that technological advances such as the transatlantic cable (1866) reduced the price differentials between the markets. Since then a vast number of studies that employ theory, experimentation and empirical analysis, to study transparency have been published.

Madhavan (1992) is using two different market structures, quote driven and order driven, to address the key issue in pre-trade transparency: the degree to which the size and direction of order flow is visible to market participants. As discussed in the previous chapter, in dealership markets, dealers have the obligation to post prices at which they are willing to trade, while in an auction market orders are submitted and then trading prices are determined. Therefore, market participants have more information in an order driven market than in a batch auction market. Another, important issue in market transparency is how different degrees of transparency affect the distribution of gains among traders. Pagano and Roell (1993) examine how transparency can affect the trading costs (losses) of uninformed traders. Using a simple market structure that assumes one informed trader and many uninformed traders on Kyle's model, they show that the expected trading costs of uninformed traders in the transparent market are always less than or equal to their expected trading cost in the dealer market. If however, there are as many informed traders as uninformed the origin of the trades can't be determined and therefore, the trading costs in the two markets will be the same. Pagano and Roell analyse further the issue of transparency taking in to consideration the order size of uninformed traders. They find that uninformed traders are unlikely to trade large orders in a transparent market.

Flood, Huisman, Koedijk and Mahieu (1998a) investigate quote transparency in a setting in which trade information is never revealed, quote data may be available, and trading activity is dominated by interdealer trades. They find that quote transparency reduces opening bid-ask spreads and therefore, reduces the cost of asymmetric information. In Flood, Huisman, Koedijk and Mahieu (1998b) the authors find that trade transparency increases bid-ask spreads and increases market efficiency.

According to Anand and Weaver (2003), transparency has significant impact on market quality and the behaviour of traders. Their paper examines one type of pre-trade transparency – the ability to hide a portion of an order. The authors analyse the issue from the perspectives of market quality and trader behaviour. Examining confidential order data following the reintroduction of hidden limit orders reveals that total depth increases dramatically. They find support for their hypothesis that traders who actively monitor the market use hidden limit orders less often than other traders. They also find that while traders appear to use hidden size to reduce the option value of limit orders stocks of all activity levels, informed traders are more likely to use hidden limit orders if the risk of non-execution is small. In particular, while stocks at all activity levels exhibit an increase in hidden limit order usage, actively traded stocks experience the largest increase as well as the most aggressive order placement. Tuttle (2002) studies the use of hidden orders in the highly fragmented environment of the Super SOES system implementation in NASDAQ. She finds that hidden liquidity accounts for 22% of the inside depth for the NASDAQ 100 stocks, and mitigates adverse selection costs for limit order traders. She also documents an increase in depth around the implementation of the Super SOES system and attributes this increase to the ability to hide depth in the system. As the author notes, the NASDAQ market is highly fragmented and alternative systems such as ECNs allow a much higher degree of anonymity (for example, Island allows traders to hide all of their order size).

Scalia and Vacca (2001) discuss the influence of a decrease in transparency resulting from anonymous trading on the Italian MTS electronic trading system, a dealer system. The study is in line with the theoretical evidence that a decrease in transparency makes liquidity traders worse off whereas large informed traders are favoured because they can hide their private information. Their work shows that lower transparency will increase market liquidity, reduce trading costs and price volatility and will increase market efficiency.

Madhavan, Porter and Weaver (2005) conduct an empirical study on the impact on market quality of a new rule on the Toronto Stock Exchange that allowed the dissemination of real-time information on the contents of the limit order book. They find that an increase in pre-trade transparency is associated with wider spreads and that higher transparency does not improve market quality. In particular, their analysis shows that transaction costs increased after the introduction of the rule change, even when controlling for other factors that may affect trading costs, such as volume, volatility, and price. Admati and Pfleiderer (1991) provide a model of *sunshine trading* where some liquidity traders can *preannounce* the size of their orders while others cannot. They show that traders willing to provide information about their trading intentions before the trade, face narrower bid-ask spreads because market participants believe these investors are liquidity motivated and do not possess private information. However, the costs for liquidity traders who are unable to preannounce their trades rise. Therefore, any preannouncement is considered by market participants to be information free, but increases the adverse selection costs for other traders. Benveniste, Wilhelm, and Marcus (1992) describe a system where market makers can indentify liquidity driven and information driven traders. They show that the ability of dealers to identify the motive of the trader can lower spreads compared to an anonymous market. If liquidity traders are price sensitive, they trade more if their trading costs are lowered. Rindi (2003) studied the impact of pre-trade transparency on liquidity in an order-driven market with informed and uninformed risk-averse investors and liquidity traders. Her study concluded that the more transparent the market, the more liquid it is.

Section 3.9: Post-trade transparency and its influence on the trading process

The main issue under examination in research focusing on post-trade transparency is whether information about executed trades should be delayed or not. Support for the delayed publication of information is based on the argument that market-makers are willing to trade large blocks of shares because their identity and intentions are hidden until they explore the trading opportunity. On the other hand, the argument against delayed publication is that reduced market information will cause trading to move to other markets. Therefore, in examining this issue we have to consider who is going to benefit from post-trade information. In general, trade information delays will favour market makers and large trades.

Bloomfield and O'Hara (1999) show that "an increase in post-trade transparency leads to greater informational efficiency, to an increase in spreads and poorer execution for informed and uninformed traders to the benefit of market makers". Bloomfield and O'Hara (2000) further analyse the issue of trade reporting from the perspective of competing dealers and find that low transparency dealers are typically more aggressive and more profitable than their high transparency counterparts. Gemmill (1996) examined the effect of block trades on the price of the 50 most active stocks on the LSE for one month in each of the six years 1987-1992. He found no evidence of a decrease in the speed of price response (and no effect on spreads) following the sharp reduction in transparency which came with the change in the publication regime in February 1989. Gemmill's findings are similar those presented by Breedon (1993), who analysed a small sample of stocks in the two publication regimes in 1989 and 1991. Therefore, these studies show that a decrease in post-trade transparency has little effect on the price setting process. Gemmill also examined the link between volatility and post-trade transparency and found no relationship between the two. Board and Sutcliffe (1996) show the percentage of trades (by value) subject to delayed publication fell from 59.7 per cent, in the first half of 1995, to 27.7 per cent, in the first half of 1996, but this had no apparent effect on the size of their median bid-ask spreads.

Porter and Weaver (1998a) examine the role of transparency in the Toronto Stock Exchange (TSE) on April 12, 1990 when the TSE provided real-time public dissemination of the best bid and offer and associated depth (bid and ask size) as well as prices and sizes for up to four levels away from the inside market in both directions. They find that both effective spreads and the percentage bid-ask spread widened after the introduction of the system, suggesting a decrease in liquidity associated with transparency, even after controlling for other factors that may have affected spreads in this period, including volume, volatility, and price. That shows that limit order traders avoid markets with high transparency as their trading intentions (price at which they are willing to trade) will be observed by other traders. Chowdhry and Nanda (1991) suggest a model where dealers decide to disclose trade information to the public to discourage insider trading. At the same time uninformed traders feel safe to trade in this market as the risks of trading with an informed trader are reduced. In the long run, the market can develop a reputation of being “clean” and offer a platform for narrower spreads to liquidity traders.

Concluding I can say that post-trade transparency as reflected in the speed of trade publication has little effect on the market characteristics such as bid-ask spreads, volume, volatility and the spread of price adjustment.

Section 3.10: Transparency and trader anonymity

Another useful piece information regarding transparency is who submitted the order as this can affect the strategies of market participants. The main paper in this field is the one by Forster and George (1992), who model the effect of anonymity in securities markets. They base their work on the argument that the usual assumption that traders are anonymous is unlikely to hold and therefore, allow market makers to have in advance of trading some idea about the future direction and size of trade. This is very reasonable in many markets, especially those with trading floors. They use a Kyle-based model to show that information regarding traders' motivations can significantly affect asset prices. Specifically, when dealers have some idea about the direction of liquidity trades, this lowers trading costs for liquidity traders. Intuitively, the cost of trading reflects adverse selection costs that arise because some traders may possess private information.

Section 3.11: Transparency and its impact on competition between markets.

Another interesting area of research regarding market transparency is the comparison of trading the same asset in different markets characterized by different levels of transparency and how this difference affects competition between markets.

Drudi and Massa (2005) empirically examine the behaviour of informed dealers who operate simultaneous markets and trade the same asset but with different degrees of transparency. They use data from the Italian Treasury bond market from September 1994 to February 1996. They show that the existence of a less transparent market may increase the liquidity of the more transparent one. Their results supports earlier studies by Bloomfield and O'Hara (1999,2000). Kofman and Moser (1997) examine the trading of a derivatives contract, the Bund futures contract, which is traded simultaneously at two competing exchanges, London (LIFFE) and Frankfurt (DTB). They argue that because in automated systems typically the identity of trader is not revealed, that results in a higher degree of information asymmetry.

3.12 Summary and conclusions

In this chapter I review the literature on the implications of trading systems (dealer versus auction) for speed, depth, trader anonymity, information quality and transparency, and the implications of these on liquidity. Investors obviously prefer markets that provide high liquidity with the lowest possible cost. Of course when considering the above, we must consider the two main types of investors, the liquidity traders and the informed traders who have different objectives. Overall, findings from theoretical and empirical studies are mixed. This is to a large extent due to the fact that different markets trade different assets and these assets are traded in different environments. Therefore, the comparison may reflect differences, due to factors other than the trading mechanism, such as differences in the securities themselves, differences in the regulatory and economic environment.

The literature review of market architecture, information disclosure and transparency is very important to understand the main characteristics of the FX market discussed in the next chapter. The FX market is a dealer market, therefore I review the role of the market maker in the price stabilization and the continuity of trades process. Moreover, the FX market is not as transparent as the stock market due to the lack of a single global regulatory framework. In the following chapter I discuss the market architecture of the FX market and cover the literature on the determinants of the bid-ask spread in this market.

Chapter 4: Foreign Exchange Market Microstructure

Section 4.1: Introduction and overview

In this chapter I discuss the characteristics of the FX market and review the literature on the FX market architecture, price formation and discovery.

In the past researchers used macroeconomic variables such as interest rates, money supplies, inflation etc, to create models that would sufficiently explain the movements of exchange rates. Although there is evidence[1] that these models (like purchasing power parity (PPP)) provide some explanation of long-term exchange rate movements, they almost totally fail to explain short term variation. In reality the explanatory power of the traditional macro-models is essentially zero. Economists have realized that this direction of research had limited possibilities to give credible answers to understand the short-run behaviour of exchange rates. Therefore, models like Covered Interest Parity (CIP), the portfolio balance model and general equilibrium model were developed but they have also failed to explain the short-run behaviour of exchange rates.

In the last few years, market microstructure models developed for the stock market have attracted the attention of researchers in the FX market as another strategy to explore the dynamics of exchange rate determination. In microstructure literature, attention is placed on market structure and the activities of agents within the market structure. The primary question is how information is incorporated into market prices. Flood (1991) reviews the theoretical literature on the market microstructure to see "what lessons it holds for the foreign exchange market". To date empirical research, although not developed to the extent of the stock market, provides encouraging evidence that this time

[1] These models can explain approximately 50% of monthly and quarterly exchange rates changes as Crystal and McDonald (1995) estimate in their paper.

researchers are moving in the right direction. It seems that price adjustments in high frequency data are more likely to be explained by microstructure issues, like the behaviour of traders, trading flow, order type, market transparency and so on. However, the application of the models developed for the stock market and the adaptation of these from the FX market is not easy or straight forward.

In the next sections, I look at the main institutional features of the FX market, the differences in the structure of stock market and the FX market and finally the price formation and price discovery process in the FX market.

Section 4.2: FX market architecture, main institutional features and the structure of the FX market

The foreign exchange market is the world's largest and most active market and is in operation twenty-four hours a day, seven days a week. Trading begins each day in Sydney, and moves around the globe as the business day begins in each financial centre, first to Tokyo, then London, finally New York. Foreign exchange markets are the largest asset markets in terms of volume. According to recent estimates the daily average turnover is well over US$ 3 trillion worth of currencies traded, much more than all of the global equity markets combined. Consequently there is a considerable interest in how FX markets operate and how prices are determined.

The FX trading activity is concentrated in the world's major financial centres and the primary foreign exchange market makers are banks located in these centres, including London, New York, Zurich Tokyo, and Hong Kong (Table 4.1). The most actively traded spot rate before the introduction of the euro was the Deutschemark/Dollar spot rate. After the introduction of Euro the most actively traded spot rate is the Dollar/Euro spot rate (Table 4.2).

Table 4.1: Trading Activity per Country

Aston University

Illustration removed for copyright restrictions

Table 4.2: FX Market Turnover by Currency Pair
(Daily averages in April, in billions of US dollars and percent)

Aston University

Illustration removed for copyright restrictions

About 5% of daily turnover is from companies and governments that buy or sell products and services in a foreign country or must convert profits made in foreign currencies into their domestic currency. The other 95% is trading for profit, or speculation. Liquidity is very important for speculators. High liquidity helps ensure price stability and traders can almost always open or close a position at a fair market price. This is because the average daily percentage move of a major currency is less than 1%. Moreover, the high liquidity of the FX market (in major currencies) results in narrow dealing spreads. Another feature of the FX market is that trades have a very short lifespan. Approximately 80% of all currency transactions last a period of seven days or less, while more than 40% last fewer than two days.

Section 4.2.1: Participants in the FX market

The major participants of the FX market are the dealers, the brokers and the customers. The FX market can be divided into an inter-dealer market, called also inter-bank market and customer market. Further, the inter-dealer market can be broken to direct market (dealer to dealer) and indirect market (dealer to broker). Dealers provide bid and ask prices to both customers and other dealers. The term broker has a different meaning for the FX market than for equity markets. In the FX market, brokers do not trade for themselves and therefore, they do not take any inventory positions. Brokers receive prices from dealers and they identify the best available prices on both bid and ask price and communicate those prices back to dealers. A dealer then can decide to trade at these prices through the broker. The broker will reveal the two dealers involved only if the transaction is completed. Then the two dealers will settle the transaction and the broker will receive a commission from both parties. The customers in the FX market can be central banks, corporations, individuals who trade for themselves.

Table 4.3: FX Turnover by Counterparty

Section 4.2.2: Trading formation in the FX market

Before the 1990's, the FX market still operated in a very traditional way, which had not changed much since the 1930's. At that time, all brokers were real persons and they therefore were also called “voice brokers”. In 1992 electronic brokers were introduced into the inter-dealer market. Since then, traditional voice brokers have been replaced by the electronic ones and most of the turnover is now conducted through order-matching systems. The introduction of electronic brokers systems has changed the market structure dramatically. Until recently, large international banks dominated the FX market. But on the last few years online foreign exchange trading gained popularity when online trading firms provided individual investors with direct access to the largest market in the world.

Section 4.2.3: Differences in the structure of stock market and FX market

Understanding the structural differences between the stock market and the FX market is essential for exploring the differences in the microstructure models. The simplest thing to say is that the structure of the FX market is completely different from the structure of the stock market. The FX market is a dealer market and the stock market is an auction market. The two differ in the following ways:

1) The FX market is quote-driven market, while the stock market is order-driven. This means that in the FX market dealers must quote bid and ask prices at which they are willing to trade, while in the stock market, participants place their orders and these orders are executed by an algorithm that matches the best available buy and sell orders on a time priority basis.

2) The FX market is decentralized, while the stock market is a centralized. This means that there is not a single location, a common trading floor, where trades take place. Moreover, this decentralized nature of the market explains the absence of a single person or a regulatory agency acting as a global controller

though individual countries may impose restrictions on banks of that located in that country. Since the FX market is decentralized what happens in the market is determined by the interaction of many dispersed and possibly heterogeneous agents acting simultaneously.

3) The FX market operates 24 hours a day, seven days a week. Therefore, the FX market provides market participants with the opportunity of continuous trading.

4) The FX market is not as transparent as the stock market. The lack of a single global regulatory framework marks the absence of information disclosure requirement, therefore information aggregation is slower and noisier in comparison with the stock market.

5) The FX market is characterised by lower transaction costs than the stock market. Both commissions for stock trades and the width of the bid/ask spread are smaller in the FX market. In general, the width of the spread in a FX transaction is less than 1/10 that of a stock transaction.

6) The FX is characterized by non-equilibrium or out-of-equilibrium dynamics because in this complex system equilibrium can never be reached.

Section 4.3: Price formation and price discovery in the FX market

Microstructure theory has been comprehensively studied for the stock market. Only in the past few years scholars attempted to develop microstructure models for the FX market, and empirical research is also much less developed. One reason is that good data on the FX market were until recently not available and up to date empirical researchers lack good data on foreign exchange trading volume at high frequencies.

Many studies on the microstructure of the FX market examine the relationship between trading volume, volatility and bid-ask spreads and look at these issues from both a theoretical and empirical point of view. Chapter 2 describes the history and developments of market microstructure theory in the stock market. In this section I review the recent developments both at a theoretical level and empirical level in the market microstructure research for the FX market looking first at a key variable in FX microstructure, the order flow.

The role of order flow

Order flow plays a central role in the FX microstructure, so understanding it is essential. In an earlier section we saw that macro-variables failed to explain short-term exchange rate movements. Therefore, when one moves from a macro perspective to a micro perspective, two variables ignored in the macro approach become highly relevant. These variables are order flow and bid-ask spreads. I have already discussed the latter in Chapter 2 but the focus was on microstructure literature developed for the equity markets. I will examine how bid-ask spreads are relevant in the FX market microstructure but first focus on order flow.

It may be helpful at the outset to define order flow or rather to explain what it is not. Order flow is not transaction volume. Order flow is transaction volume that is signed. The sign is used to show whether over time there is selling or buying pressure on the dealer. The trade is signed according to the active side, or put differently, the initiating side of the trade. If for example a dealer receives a sell order of $10 million from a customer, this would be signed as negative. The transaction volume would be $10million but the order flow would be -$10 million.

Order flow builds in microstructure models as follows. Prices change due to new information. Part of the information is public but part is private. Since dealers have the obligation to quote bid-ask prices at any time they can expect to lose money on trades with individuals that possess superior information, and if this is the case, they adjust the bid-ask quotes accordingly. In order to do that, the dealers read the order flow. The order flow conveys information about fundamentals, because it contains the trades of those who analyse fundamentals. Of course order flow will reflect also non private information and therefore uninformative trades, making the task of identifying informative trades rather complex. There is ample evidence that order flow is the main explanation proxy of exchange rate movements. However, it's only a proximate cause. What initiates price movements is information and actually non public information. Put differently, order flow is the intermediate link between information and price.

One question could be: when is order flow informative? Order flow would convey information when its effect on price is long-lived. A common empirical assumption for distinguishing information from pricing errors is that information's effects on price are permanent. Papers by Evans(1997), Evans and Lyons (1999), Payne (2003), and Rime (2000) show that order flow has significant, persistent effects on exchange rates. There are also other different methodologies that evolved in the literature to generate evidence that order flow is informative. For example, one way is to look at the behaviour of the bid-ask spreads and the adverse selection component.

Another question could be: how can one identify which orders are the most informative? This is done by relating order flow to price changes. There are basically two approaches to relate order flow to price changes. One is to decompose aggregate order flow and examine the price impact and the magnitude of it for each order flow component (e.g mutual funds, non financial corporations etc). Examining the order flow under this approach can identify whether some orders are more informative than other. The second approach according to Lyons (2001) is to link order flow to underlying determinants based on the idea that order flow measures individuals' changing expectations.

The way that order flow affects short-term price changes is explicitly analysed in section 4.3.1 where I present the market microstructure models developed for the FX market.

Section 4.3.1: Microstructure models in the FX market

Market microstructure theory was first developed for the stock market to explain the price setting process and the determinants of bid-ask spreads. However, the structure of the stock markets, deviates widely from that of the FX market. Therefore, fitting the existing models directly to the FX market would not be the correct practice. In particular the main features of the FX market that the models described in Chapter 2 are unable to capture are the following:

- Interdealer trading: BIS survey marks that almost every second transaction in the FX market is between dealers (see Table 4.3). The models described so far do not consider the implications of interdealer trading.
- The nature of private information: Due to its decentralized structure, dealers cannot have the concentrated type of private information that dealers in equity markets can have. For example, it is impossible for a dealer to know future interest rates in the FX market.
- Dealer risk aversion: the dealers in sequential-trade models are risk-neutral. Dealer’s risk aversion is a key feature of the FX market since dealers pass undesired positions to other dealers. This happens because incoming orders may shift their position in an unpredictable way since the simultaneous trading prevents dealers from using the incoming orders to unfold the intentions of other dealers. (Traders place their own trades in the same time).

Only recently did researchers attempt to develop microstructure models for the FX market. Remember that in Chapter 2, I reviewed the core microstructure models, the explicit auctioneer, by Kyle (1985) and the sequential trading model, by Glosten and Milgrom (1985). These models fail to capture some key features of FX market structure (e.g multiple-dealer trading). A model that addresses the features of the FX market structure is the simultaneous trading model introduced by Lyons (2001).

Below, I review theoretical and empirical research in the FX market microstructure focusing especially on the determinants of short-term exchange rate movements, such as order flow, and the determinants of bid-ask spreads such as exchange rate volatility, trading activity etc. In addition the last section of this chapter looks at the volume-volatility relationship in the FX market.

The simultaneous trading model

In this part of my work I review the recent FX microstructure models introduced by Lyons, Evans and Lyons, Ding that try to capture theoretically the main features of FX trading. The models are based on the rational that short-term exchange rates are in principle determined by order flow.

Lyons among others argued that order flow is likely to be the main determinant of short-run exchange rate movements. He presented a multiple-dealer simultaneous trading model, which is compatible with FX market structure. He shows that order flows conceal information that is not publicly available, understanding them can reveal market participant intentions and therefore, dealers can use order flow information to adjust their quotes. In other words, prices are driven by the revelation of information and the degree of informativeness of prices (consistent with information based models for the stock market).

The assumption built in the models is that the dealer only quotes one single price (bid-ask spread does not exist). In reality, dealers must quote bid and ask prices.

Moreover, the only way private information is identified is through observing interdealer order flow. Empirical research, though, shows that in multiple-dealer markets private information is identified by individuals both from order flow and dispersion in prices. In addition, rational quotes are the same across dealers therefore, there is no place opportunity for arbitrage. In reality, arbitrage opportunities may exist since different dealers quote different prices and because of transaction costs and inadequate information disclosure in the market. Another assumption is that dealers trade only with customers or other dealers. In practice, both trades may occur simultaneously. Last but not least, dealers quote only for interdealer market or customer market in each round. In practice, dealers can give quotes for both markets at any time, and they need not to be the same. The process of the two-period trading model is described in Appendix 1.

Based on the two-period procedure, Lyons develops the dealer's utility function in order to show how a dealer determines his quotes and demands for the risky asset. The objective for the dealer is to set his quotes and determine the demands for the risky asset to maximize a negative exponential utility function defined over nominal wealth at the close of period two. Finally, Lyons defines the dealer equilibrium trading strategies. In another study, Evans and Lyons (1999) presented a model that is a variant of Lyons simultaneous trading model.

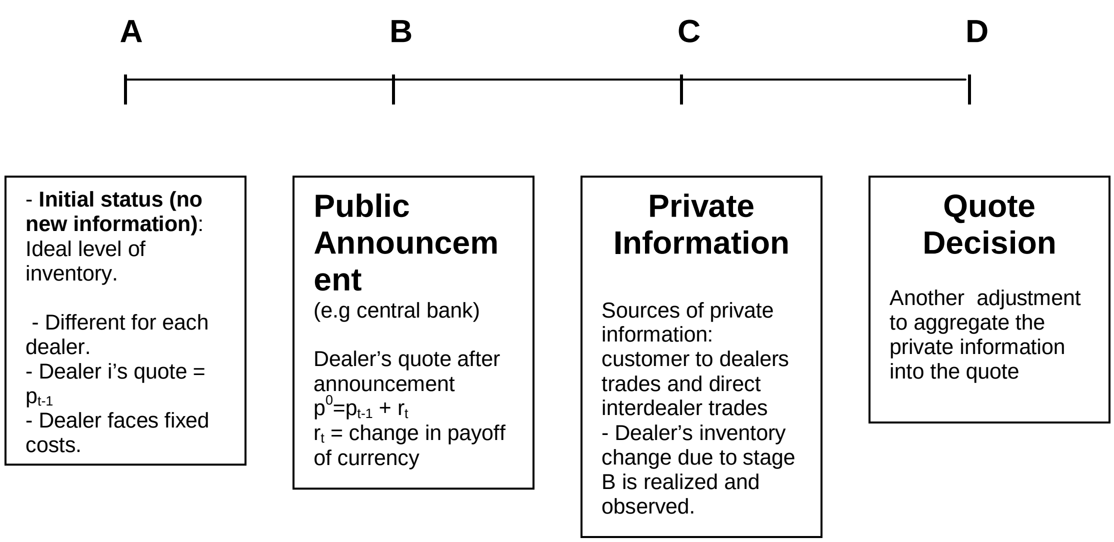
In another study, Ding (2004) models the relationship of order flow and exchange rate movements and explains the formation of exchange rate and the spread, in a decentralized dealership market. The model extends the Lyons model by relaxing some of its assumptions build. In particular, in Ding's model dealers quote both bid and ask prices, different for each market (inter-dealer market, customer market) and therefore the equilibrium in their model is not a single price but a distribution.

According to the model if a dealer has higher than desired inventory (dealer buys more than sells) market participants expect exchange rate fall. Therefore, dealer order flow information is a vital tool to assess market participants expectations at that particular period. Transaction information for the dealer comes from two directions. Transaction information is collected while trading with customers from trading with other dealers. The interdealer order flow is intuitively more informative than the customer one, mainly because interdealer trading volume is much larger than customer trading. Moreover, as Ding notes because “every dealer has his own customer group, they can aggregate customers’ order information to form their own belief, in which way the noise in customer’s belief will be squeezed out and dealer’s belief becomes more accurate”.

Ding’s model captures the empirically reported features of the FX market such as the positive relationship between exchange rate volatility and the spread, the negative relationship between the spread and the number of dealers (dealer competition) and the fact that customer to dealer trading has higher costs (spreads) that direct interdealer trading. Section 4.5 provides empirical evidence that support the above theoretically proposed relationships.

Ding models a market where dealers (M active dealers) and customers are the only participants. Dealers trade in the interdealer market and customers trade only with dealers.

Graph 4.1: Dealer’s Process of Optimal Quote Decision



The four stages presented in the graph read as follows. In stage A, dealer i is considered to posses cash C_i, and he operates in a market with fixed costs (for administration and for an electronic trading system). It is further assumed that the dealer holds an optimal level of inventory ("ideal" by the author), which is normalized to zero. The level of inventory is essential for the dealer to perform his role as a liquidity provider. For simplicity, it is assumed that the optimal level of inventory is unchanged. (No adjustment is made to reflect different degrees of risk in the market). Since, no new information is realized at this stage (the beginning), the mid-point of dealer's quote will be p_{t-1}, the same as the mid-point of the last period quote.

In stage B, public information is realized in the form of an announcement from the central bank for example on interest rates. This is of course observable by all market participants. Therefore, the dealer will adjust his quote to incorporate the effect of the public announcement.

In stage C, dealer i, begins to receive market orders and execute them. Private information though will rise in this stage as a consequence of two factors. The first is the heterogeneous expectations of market participants; and the second that some market participants have information that other people don't have. The information that some market participants may have and some other may not have comes from the transparency (disclosure of information) in the FX market. As we already discussed, customer-dealer orders are not observable by other market participants, and dealer to dealer trades are observable only by the two sides of the transaction.

In the last stage (D), the dealer will use the private information he has obtained in the previous stage to adjust his quote.

Therefore, the task of the dealer is to set his quote in order to maximize the expected utility of his private information set. Since, Ding models, not a single price (as Lyons), his quote will be an ask price and a bid price. Moreover, there must be two different sets of bid-ask prices, one for the interdealer market and one for the customer to dealer market. Therefore, the model provides the proposition for four different prices. The details of the model are provided in Appendix 2.

It is clear again that inventory carrying costs and information costs play important roles in the determination of exchange rate movements. Hence the next section examines the extent to which these theories hold for the FX market. In addition I review theoretical models developed to capture the complex structure of the FX market.

Section 4.4: Bid-Ask spread models in the foreign exchange market

The structures of equity markets and the FX market are significantly different. Therefore, the theories developed in the market microstructure literature (e.g theories of bid-ask spreads) for the stock market do not automatically hold for the FX market. In this section, I discuss which aspects of the models developed for the stock market hold for the FX market and review the theoretical models developed in the FX market to explain the behaviour of bid-ask spreads together with empirical evidence. Empirical results, in general confirm theoretical arguments and findings are in line with the proposition that higher exchange rate volatility leads to wider spreads. Moreover, empirical results show that dealer competition, trading volume and trading activity are additional determinants of bid-ask spreads.

Finance microstructure theory implies that the bid-ask spread must cover three costs incurred by providers of immediacy: order-processing costs, inventory carrying costs and asymmetric information costs. Order-processing costs in the FX market due to economies of scale are rather insignificant [Jorion (1996)]. The importance of asymmetric information is already pointed by the role it plays in affecting order flow. I focus on the literature that investigates whether order processing costs, inventory carrying and asymmetric information costs can significantly explain time-series variation in currency spreads and finally discuss the role of key market variables in the determining the bid-ask spread.

Section 4.4.1: Order processing cost models

Order processing costs models, initiated by Demsetz (1968), recognize the existence of some fixed costs when trading with a market maker in order to compensate him for providing "immediacy". These costs are for example to cover the subscriptions to electronic information and trading systems and other administration costs by the market maker. These costs give rise to economies of scale for market making. If the dealer expects trading activity to increase at a given spread, his expected profit will go up. Inter-dealer competition though, will force him to narrow his spread to make sure that customers will not choose another dealer who is quoting a "better" spread. Therefore, predictable volume should reduce spreads through this order processing cost effect. Papers that capture this issue are those by Stoll (1978), Black (1991) and Hartmann (1994).

Section 4.4.2: Inventory carrying cost models

Inventory costs models presented by Stoll (1978), Ho and Stoll (1981, 1983), O'Hara and Oldfield (1986) among others, describe dealers as having two functional roles in the market. First, dealers are providers of immediacy (they stand ready to trade in a security at any time); and second dealers act also as optimizers of their own portfolio. Under this framework, dealers try to choose the best possible portfolio, the one that maximizes their utility (for more details see Chapter 2). While a dealer is performing the above two functions the role of volatility in trading volume in determining dealers spreads becomes relevant. When a dealer provides immediacy his portfolio will deviate from what he considers optimum, hence he will adjust his bid-ask quotes to deter more transactions on the side of the non-optimum portfolio direction and make sure that the bid-ask spread is at least enough to compensate for the further utility losses. This implies that larger transaction sizes in the order flow expected will lead to larger spreads. However, if trading volume is expected to come in many smaller, independent orders, then increased (predictable) volume could decrease spreads through an opposite inventory cost effect. Taking in to consideration that larger volume is not necessarily driven by larger transaction sizes since dealers may break down large transactions in several smaller ones, it is unlikely that inventory cost effects can be identified though daily volumes and spreads.

To summarise we can say that models that explain bid-ask spreads in terms of inventory costs establish a link between bid-ask spreads, volatility and trading volume. One determinant of inventory costs is the cost of maintaining open positions. Therefore, exchange rate volatility will increase price risk and thereby push spreads up.

Another determinant of inventory costs is trading activity. Empirical research shows that trading volumes can have different impacts on spreads depending on whether they are expected or unexpected. Black (1991) introduces a theoretical approach to estimate the impact of volume on bid-ask spread. In particular, the author is using a model of transactions costs in the interbank foreign exchange market and a model of vehicle currency use to explore the interaction between transaction costs and vehicle currency use.

Chakrabarti (2000) builds a model of bid-ask spreads in the foreign exchange market based on the idea that dealers learn in a Bayesian fashion about the excess demand situation from one other’s quotes and their inventory positions (their overnight costs). He develops a dealer’s objective function and is assumed that the dealer task is to maximize this function. The function includes the expected gains during the day, the cost of bearing the risk during the day and the cost of expected overnight exposure. The assumptions built in to the model are that trading takes place for a few hours each day, that individual dealers are risk averse, and that two currencies are traded at a particular financial centre (DM and US dollar). The objective function of a representative dealer at the beginning of a trading and the model are presented in Appendix 3.

The dealer is faced with two inventory risks. The risk of taking a position at any point in a day until he receives or succeeds in making another call and the risk of holding an inventory position overnight. Obviously, the risk of holding inventory overnight is much higher due to the longer time period; therefore, the dealer will set a higher price.

To study the extent to which dealers behave according to this model, the author created artificial traders and provided them with beginning positions in DM as well as beginning prior beliefs about the end-of-day value of DM and made them to act according to the model in a virtual market. The results from the simulations show that trading according to the model in many cases produces a U-shaped pattern in spread, spread volatility, and return volatility. This is in line with empirical research [Hsieh and Kleidon (1996), Bollerslev and Domovitz (1993)]. In particular, from the simulation they find that the spread in the morning is about 138% higher than the average spread, excluding the beginning and end, during the day. At the close of the trading the spread is about 95% higher than the spread measured in the rest of the day. Similar results are obtained for spread volatility. The return volatility at the beginning and close of a trade exceed the daytime average by about 7% and 38% respectively. Therefore, we conclude that the theoretical model presented by Chakrabari provides a more than acceptable framework to explain the U-shape pattern observed in most intra-day trading data.

In an empirical paper, Bessembinder (1994) used regression analysis to examine the relationship between spreads and inventory costs. To investigate whether spreads depend on inventory costs he uses three proxies for inventory costs:

forecasts of price risk, interest-rate based measures of liquidity costs, and a non-trading indicator to capture Fridays and the last trading day before holidays. Results are generally consistent with the implication that currency bid-ask spreads widen with inventory carrying costs. In particular, the estimated coefficient for the effect of forecasted risk on currency bid-ask spreads is positive and significant for all currencies examined and end-of-day spreads are positively related to the anticipated riskiness of holding a position in the currency over the next trading day. Finally, the results are also consistent with currency bid-ask spreads varying positively with the opportunity costs of maintaining a liquid inventory. The estimated coefficient of the interest-rate based proxy for opportunity cost of liquidity is positive for all currencies considered.

Section 4.4.3: Information cost models

Information cost models, such as those of Copeland and Galai (1983), Glosten and Milgrom (1985) and Kyle (1985), describe the link between bid-ask spreads and information arrival and the presence of market participants with superior information (insiders). These models highlight the role of trading volume and provide the theoretical basis that spreads increase with volume. According to these models the dealer is facing the risk that on the other side of the transaction is an informed trader; and therefore he widens the spread in order to deter some informed traders. The higher the non-public information arrival during a trading period the higher the dealers' information costs, hence the larger the spread. But the rate of information arrival is unobservable, so the models can't be tested directly. As an alternative, researchers (e.g Hartmann, 1999) used unpredictable foreign exchange volume as a proxy for information arrival.

The models developed for the FX market by Lyons (among others) are in the same direction, since order flow is the reason for quote adjustment, and the arrival of new information will affect the order flow, and therefore, trading activity. However, as we will see, later empirical research shows that when trading volume is decomposed to predictable and unpredictable the impact on spreads is opposite in sign.

Bollerslev and Melvin (1994) provide a theoretical framework describing the effect of uncertainty (volatility) on spread and test the implications of the theory.[7] Their model is based on previous microstructure models of Glosten and Milgrom (1985), Admati and Pfleiderer (1989), and Andersen (1993) which assume that the market consists of liquidity traders and information-based traders. As these previous studies also suggest when the market-maker trades against an informed trader, on average he will experience losses. He will offset these loses however, by trading with the uninformed traders. Based on that, the authors calculate the expected loss from informed trading and the expected gain form uninformed trade. Combining the profit and loss and considering that under competition the profit of the market maker will go to zero, they estimate the determinants of spread. They found that in equilibrium the spread should widen proportionally to the conditional standard deviation of the true fundamental value of the exchange rate (in the presence of uncertainty), but no change in the spread should be observed when trading is simply driven by good or bad news.

Another interesting feature is the information cost that dealers face due to government foreign exchange interventions. From this different perspective a market microstructure model was developed by Bossaerts and Hillion (1991). The model follows the concept of asymmetric information in the financial markets - initially introduced by Bagehot[8] (1971) - and describes the bid-ask spread for the foreign exchange market subject to occasional government interventions. Naranjo and Nimalendran (2000) provide another theoretical model and empirical evidence that government foreign exchange interventions create significant adverse selection problems for dealers. Their model shows that the adverse selection component of the foreign exchange spread is positively related to the

7 The theory is tested by using order probit analysis and GARCH estimates for exchange rate volatility.

8 An innovative paper by Jack Treynor writing under the pseudonym of Bagehot.

variance of unexpected intervention and that expected intervention has no impact on the spread. In contrast, Osterberg (1992) finds that spreads are lower around periods of expected intervention but does not find a causal relationship between intervention and spreads using the Granger causality method.

In addition, information plays a key role also when it takes the form of differential access to information on the state of the market among the dealers. In the FX market small banks see little of the aggregate order flow, while large banks observe a much greater portion of this order flow. Large banks tend to quote more aggressively than smaller banks due to their information advantages. Therefore, when a significant number of large banks is in the market, we expect more aggressive pricing of liquidity services.

In their empirical work Hsieh and Kleidon (1996) examine the performance of these standard asymmetric information models using intraday data form Reuters on deutsche mark/dollar trades. They find that asymmetric information models fail to explain the data. Based on their findings they believe that inventory adjustments by market-makers may be responsible for some bid-ask spread characteristics (e.g large spreads at the close).

Section 4.5: Determinants of bid-ask spreads in the FX market.

The models that explain bid-ask spreads in terms of order processing costs models, inventory costs and information costs models establish a link between bid-ask spreads, volatility, trading activity and trading volume. Therefore, in this section I extend the review of the literature that examines the effect of key market variables on bid-ask spreads in the FX market.

Section 4.5.1: The effect of exchange rate volatility on bid-ask spreads

Much of the theoretical and empirical research in the FX microstructure focuses on the effect of exchange rate volatility on spreads. Theoretical and empirical literature is in accord that there is strong positive relationship between volatility and spreads. As a proxy of exchange rate volatility most researchers use Generalised Autoregressive Conditional Heteroskedasticity (GARCH) models to model volatility. Another measure of volatility is the variance of bid-ask midpoint quotes within each 15 or 30 minute time interval.

Bollerslev and Melvin (1994) develop a model that relates changes in the spread to changes in exchange rate volatility. In particular, the theoretical proposition is that greater exchange rate volatility is associated with greater spread. The theoretical framework is based on the market microstructure models presented by Glosten and Milgron (1985), Admati and Pfleiderer (1989), and Andersen (1993), who describe the implications from a simple asymmetric information model for the bid-ask spread. They also present empirical evidence that the size of the spread in the foreign exchange market is positively related to exchange rate volatility. Their model assumes that the foreign exchange market consists of two types of traders: liquidity traders motivated by the need to buy or sell goods and services, financial assets and realise profits internationally; and informed traders who trade for speculation in order make profit. The details of the model are provided in Appendix 4.

Empirical papers find a positive and statistically significant relationship between volatility and spreads, suggesting that volatility influences bid-ask spreads through its effect on inventory costs. An early paper by Glassman (1987) examined the short-term relation between transaction volume and transaction costs, measured by bid-ask spreads in the foreign exchange market showed that spreads increase with volume at constant volatility. Bessembinder (1994) contributes to the understanding of spread behaviour in the FX market. Bessembinder finds that spreads widen with proxies for inventory-carrying costs. One of the proxies used in the paper is the forecast of price volatility. Existing literature supports the fact that financial market volatility is autocorrelated meaning that future prices depend on past prices and therefore, a forecast of price volatility can be constructed. Based on this, the author is assessing whether spreads vary with this price forecast. Previous papers by Glassman (1987) and Boothe (1988) report that spreads rise with recent volatility. In order to construct the forecast of price volatility, Bessembinder is uses the conditional variance from the GARCH(1,1) specification[7] led by one day. The GARCH(1,1) specification is used since, as reported by Baillie and Bollerslev (1989), the conditional heteroskedasticity in daily spot exchange rates is well represented by this specification. Results show that the estimated coefficient for the effect of forecast risk on currency bid-ask spreads is positive and significant for all four markets (British pound, Swiss franc, German mark, and Japanese yen against the U.S dollar) implying that higher exchange rate volatility will produce widening in the spread. It is important to note that in both studies by Glassman (1987) and Bessembinder (1994) the volume effects on spreads do not appear to be statistically strong. The explanation given by researchers is that future volumes are used as a proxy for global spot volumes (see Section 5.6.2 for more details on the limitation of futures volume as a proxy for spot volumes).

Bollerslev and Melvin (1994) used bid-ask quotes for the DM-dollar rate from Sunday, April 9 to Friday, June 30,1989, obtained from Reuters' network screens. Over that period, quotes appeared from 125 participating banks in the market. This data set is the same that Bollerslev and Domovitz (1993) used in analyzing high frequency data. In order to examine the theoretical proposition that greater volatility in exchange rates is associated with greater spread, a proxy for the time varying volatility must be developed. They use GARCH modeling to model volatility. In particular, they employ a two-stage estimation procedure in which the conditional variance for the spot exchange rate is first estimated as a GARCH process. These estimates for conditional variance are then used as a proxy for exchange rate volatility in the second-stage model for the temporal behaviour of the spread. The assumption is that the market makers use GARCH models to forecast volatility. The empirical results show that there is a strong positive relationship between volatility and spreads.

Goodhart and Payne (1996) also examined the relationship between spread and volatility by estimating the same system as Bollerslev and Melvin (1994), but using standard Maximum Likelihood techniques, rather than the Ordered Probit. The data used in their study is from Reuters D2000-2 electronic broking system focusing on the Deutsche Mark/Dollar spot rate based on a 7 hour period on June 16th 1993. The main difference between the data set used by Bollerslev and Melvin (1994) and this work is that spreads in the latter are the market's inside spread, that is the spread resulting from the combination of the lowest quoted ask and highest bid and not spreads quoted by individual dealers. Their results are in line with those of Bollerslev and Melvin (1994) showing a high correlation between the inside spread and volatility (GARCH) in the market.

Huang and Masulis (1999) study spot FX rates for the DM/$ exchange rate using quote data for the period from October 1992 to September 1993. They regress bid-ask spreads on the number of dealers and exchange rate volatility. They find that bid-ask spreads are positively related to the predicted exchange rate volatility and therefore further support the well documented relationship between spreads and volatility. Hartmann (1999) estimates the determinants of dollar/yen bid-ask spreads applying a Generalized Method of Moments (GMM). Among the explanatory variables that Hartmann uses to estimate the determinants of spreads he uses GARCH(1,1) forecasted volatilities (Bessembinder, 1994) from daily log returns to measure predictable volatility. Results are in line with Bessembinder findings but much more significant. The volatility effect is positive and strongly significant. Melvin and Tan (1996) provide empirical evidence from the foreign exchange market on how the bid-ask spread is influenced as spot rate volatility and country risk vary. The cross-section evidence demonstrates how spreads vary across thirty-six industrial and developing countries. The results indicate that the spread across the countries at a particular time appear to be significantly related to countries' risk differences and exchange rate volatility.

A number of papers investigate the effect of exchange rate volatility on the spread in emerging markets. Galati (2000) finds that the coefficient on the GARCH variance forecast is positive and statistically significant. Therefore, volatility influences spread. He uses a data set that includes daily data on trading volumes for the dollar exchange rates of seven currencies from emerging market countries over the period January 1998 to June 1999. Another study that looks at the volatility-spread relationship at exchange rate of emerging markets is the one by Kouki (2003). In particular, Kouki investigates the effect of the empirical relationship between trading, volumes, volatility, order flow and bid-ask spread of a Tunisian private commercial bank. The data set includes daily spot data for the dollar and euro exchange rates of January 2001 to November 2002. Results show the dollar exchange rate in line with the microstructure theory. They find that a positive relationship between volatility and spread. Martin (2003) uses a sample of 21 emerging and developed country currencies to investigate the impact of the Asian crisis, currency volatility, and exchange rate regimes on currency spreads. Results show that the increased volatility due to the crisis affected and in particular increased the spreads of Asian currencies but none of the developed countries showed significant changes in spreads.

Section 4.5.2: The effect of trading volume (expected and unexpected) on bid-ask spread

Another relationship that has received much attention in the FX market is the one between trading volume and bid-ask spreads (implied by both inventory costs and asymmetric information models). However, due to the lack of good data on foreign exchange trading volumes at high frequencies, few studies have been focusing on the FX market. Therefore, empirical work on foreign exchange markets suffers from the fact that different data sources have been used to describe the time series behaviour of trading volume and all of these data sets have drawbacks.

Measures of trading volume in the FX market

A number of studies [Grammatikos and Saunders (1986), Batten and Bhar (1993), Bessembinder (1994) and Jorion (1996)] have used data on futures contracts as a proxy for interbank trading volumes. A drawback of these data sets is that trading activity in futures is very small compared to OTC volumes (Dumas,1996). Therefore, the behaviour of spot and futures market may be different although there is some positive correlation between the two. Moreover, as Dumas (1996) points out, the choice of futures volume for an organized market to measure total volumes of a market working mostly over the counter may also induce an omitted-variable problem in the estimations. Finally, Hartmann (1999) argues that another source of possible biases in parameter estimates, when using futures volume, may be that the endogeneity of unpredictable turnover, measuring the rate of information arrival, is disregarded.

An alternative measure of trading volume is taken from the Bank of Japan, a data set on brokered transactions in Tokyo yen/dollar market, which has been used by Wei (1994) and Hartmann (1999). An obvious drawback of these data sets is the limited representation it provides for the total turnover in the global yen/dollar market.

Another group of studies used the frequency of quote arrival posted by Reuters on its FXFX page as a proxy for trading volume. This approach was used in studies such as the ones of Goodhart and Figliuoli (1991) and Bollerslev and Domovitz (1993). There are many limitations using the frequency of quote arrival as proxy of trading volume. First, of all these quotes are indicative quotes and not actual trades and moreover it is not possible to infer from a quote for which volume it is given. In addition, Reuters tick frequency may be low at times of high trading activity and high at times of low trading activity. This is due to the fact that banks act as data providers to programme an automated data input. When an important event occurs, traders are likely to act and trade actively rather than entering data for Reuters.

A data set that is free from the above limitations is the one for actual transactions in the OTC market. Lyons (1995) and Goodhart et al (1996) used such data (transactions in a week in 1992 and one day in 1993 respectively) but the limitation here is that these data sets cover only a limited segment of the foreign exchange markets and span a very short time period.

A recent paper by Galati (2000) uses a data set with high-frequency data on trading volumes for seven currencies from emerging market countries that are representative of foreign exchange market. As I mentioned above there is relatively little work on trading volume and spreads in foreign exchange markets due to the difficulty of obtaining data. Empirical research shows that trading volumes are highly autocorrelated, implying that volumes can be forecasted to a substantial degree. Therefore, trading volumes can have a different impact on spreads depending on whether they are expected or unexpected. There should be a negative relationship between spreads and expected trading volume (forecastable trading volume), because with higher expected trading volume, spreads should narrow to reflect economies of scale in market making (due to order processing costs) and higher competition among market-makers [Cornell (1978)]. Easley and O'Hara (1992) developed a model that implies spreads decrease with forecastable trading volume. By contrast, unexpected trading volumes (unforecastable trading volume) should have a positive impact on spreads to reflect the arrival of news (risk due to information asymmetry). In his study, Glassaman (1987) shows that the proxy of trading volume does not have the expected relationship with spreads. Jorion (1996) confirms the positive and significant correlation between volatility, volume and spread using currency futures data from the CME and option implied standard deviation (ISD) as a proxy of volatility.

An important study by Bessembinder (1994) showed that the unpredictable component of volatility is measured by ARIMA model. Bessembinder (1994) examines the relationship between trading volumes and spreads. Coefficient estimates on the expected and unexpected components of futures trading volume (as a proxy for trading volume in the interbank foreign exchange market) support the proposition that expected and unexpected trading volumes have heterogeneous effects on bid-ask spreads. His data set consists of daily spot and six-month forward quotations (BP, SF, DM, JY against USD) as of the close of London trading, from January 1979 to December 1992. Hartmann (1999) applies a data set of brokered transactions in Tokyo of daily spot FX volumes for the period from December 1986 to January 1995 for the USD/JY exchange rate to examine the relationship between trading volume and bid-ask spreads. His results confirm those found by Bessembinder (1994). Predictable Dollar/Jen spot volume is negatively linked to spot spreads, while unpredictable volume is positively linked to spreads. However, his results are much more significant than Bessembinder's at the 5% level.

Goodhart and Payne (1996) in their paper *Microstructural dynamics in a foreign exchange electronic broking system* examine the determinants of quote revisions and spreads and find that trades are a major factor in determining quotes and spreads. When transaction volume is high and the possibility of informed trading exists, the spread in the market widens when a deal occurs and this widening persists through time. They also incorporate in their analysis of spread determinants another variable: the lagged spread. The rational is that, after a removal or exhaustive transaction, an uncompetitively large spread will lead to more competitive quotes and hence spread reduction. They use data from Reuters D2000-2 electronic broking system taken from a record in June 1993. Their theoretical motivation comes from inventory trading models of Ho and Stoll (1983) and asymmetric information models of Glosten and Milgrom (1985)

Galati (2000) examines the volume-spread relationship in the foreign exchange markets in emerging market countries. His results are in contrast to the predictions of the theory and previous empirical research, showing that in most cases spreads and trading volumes are negatively correlated. Results show that coefficients on unexpected volumes are negative and insignificant. The explanation that the author gives is that “the sample period may be too short to allow for changes in these foreign exchange markets that lead to more efficient trade processing and higher competition among market-makers”. In another study, Kouki (2003) found no evidence that volume has an information content on spread by using data from Tunisian dealers. In particular, both the euro and dollar transaction volume (when decomposed in unexpected and expected) have no significant effect in spread.

Section 4.5.3: The effect of dealer competition on bid-ask spread

While seasonal patterns in the spread FX data are present, a question remains as to their cause. To address this question one can consider the effect of dealer competition on spread. There is a relatively small number of empirical studies on the effect of dealer competition in the FX market. These studies are by Glassman (1987), Booth (1988), Bollerslev and Melvin (1994), Bessembinder (1994) and Huang and Masulis (1999). In contrast, the importance of dealer competition has received a great deal of attention in the equity market [e.g. Stoll (1978b), Laux (1995)]. While the microstructure models of equity markets don’t capture the conditions present in the FX market, the fact that all these models strongly suggest that dealer competition is an important determinant of bid-ask spreads gives space for empirical analysis of the FX market.

Aggregate dealer activity is important because it impacts on expected inventory costs of individual dealers. Increase in the number of active dealers should decrease spreads because a dealer will have an improved ability to lay off undesired inventory. The degree of competition is measured by the number of active dealers in the market. In general empirical results suggest that spreads have a negative relationship with the number of dealers.

Huang and Masulis (1999) study spot FX rates for the DM/$ exchange rate using quote data for the period from October 1992 to September 1993.They regress bid-ask spreads on the number of dealers and exchange rate volatility. They find that bid-ask spreads fall with the rise in the number of dealers. The dealer competition variable maintains its significant impact on bid-ask spread even after controlling for the changes in FX volatility. Together, the number of dealers and exchange rate volatility in the regression explained about 17% of the variability in bid-ask spreads.

Section 4.5.4: The effect of central bank intervention on bid-ask spread

In their study, Naranjo and Nimalendran (2000) after controlling for inventory and order processing costs, find that bid-ask spreads increase with U.S dollar and German deutsche mark foreign exchange rate intervention during the period 1976-94. When the intervention is decomposed into expected and unexpected components, they find a statistically and economically significant increase in spreads with the variance of unexpected intervention, while expected intervention has no significant impact on spreads.

Section 4.5.5: The effect of trading activity on bid-ask spread

The theoretical models that describe the relationship between trading activity and bid-ask spreads provide different predictions of that relationship. Other models (Admati and Pfleiderer, 1988) suggest the spread should decrease when trading activity increases where other models (Subrahmanyam, 1989) suggest the opposite.

Bollerslev and Domovitz (1993) studied the link between bid-ask spread and trading activity by examining the bid-ask quotes for deutsche mark-dollar exchange rate over a period of three months approximately in 1989. The results show that trading activity has a strong positive effect on the conditional variance of the spread process. In other words, as market activity increases, the transaction costs become more uncertain. Moreover, by using an alternative measure of trading activity, the duration between trades they find that duration has a negative effect on the conditional mean of the spread process and a positive effect on conditional volatility. The meaning of that is as orders increase in frequency the spread decreases. This is in line with empirical research by Biais, Hillion, and Spatt (1995). They also examine the relationship between the spread and trading activity at aggregate level, and results reveal a sharp peak in the spread as the level of quote arrivals goes virtually to zero during the Far Eastern lunch break. Overall though, it is not clear if there is any systematic relationship between spread and trading activity at the aggregate level.

Since the relationship between trading activity and spread is not clear at the aggregate level, more clear relationship may be evident when looking at trading activity and spread of individual banks. The actual comparison is between the above relationship with large banks and small banks. When looking at the average spread offered by Deutsche Bank, one cannot identify a systematic relationship between the two variables. However, when the smaller bank (Danske bank) is examined a U-shaped pattern is observed. The explanation is that smaller banks are more sensitive to inventory adjustments than larger banks, and therefore will increase their quoted spread at the end of their regional trading day. Moreover, smaller banks have less information based on order flow at the beginning of their regional trading day than large banks, therefore the adverse selection component of the spread is expected to be higher for small banks at their opening. This is a very important result because we can parallel the behaviour of these small banks with that of risk-averse stock market traders modelled in the theoretical literature.

Section 4.5.6: Seasonality effects (weekend and holiday) on bid-ask spreads

Another important determinant of spreads is seasonality. When we refer to seasonality we mean the effect of weekends and Holidays (non trading time intervals) on the bid-ask spread. Rational thinking suggests that spreads prior to weekends and holidays will increase due to decreased liquidity. Dealers generally try to reduce their net FX exposure to zero near the end of each trading day and especially at the end of the business week. A number of researchers have examined this issue, among them Glassman (1987), Bessembinder (1994), Bossaerts and Hilton (1991), Huang and Masulis (1999) and Osterberg (1992).

Bessembinder (1994) examined this relationship using data on bid-ask quotes for the British pound, Swiss franc, German mark and Japanese Yen against the U.S dollar from January 1979 to December 1992. His results are consistent with the rational assertion that spreads increase before weekends and holidays because of increased risk and decreased liquidity. In particular, he finds that spreads increase by over 50% (averaged across four currencies) before London and New York holidays and more than double before holidays observed in London, New York and Tokyo (main financial centres). In general, he finds that spreads increase significantly before holidays observed in all financial centres and do not increase significantly before single country holidays. As far as the weekend effect is concerned, spreads in his sample are significantly higher on Fridays than other days. It is worth mentioning that increases in spreads before holidays are considerably larger than increases before weekends. In addition, Bessembinder investigates the reason that spreads widen during weekends and holidays. He shows that spreads widen with proxies for inventory carrying costs a result which contrasts with the studies of equity markets where the evidence of inventory costs before weekend and holidays are weak.

In another paper, Huang and Masulis (1999) study the spot FX rates of DM/$ exchange rate for the period October 1992 to September 1993 and focus again on FX seasonality effects. They studied carefully the seasonality patterns in the quote data and emphasize the importance of these regularities. They examine FX seasonality effects by ordinary least squares using various seasonal indicators such as time of day, weekends, month ends, daylight saving time, and holidays in major trading centres. Empirical results indicate that mean spread exhibits substantial variability across the seasonal indicators used. The mean spreads peak around the Tokyo lunch hour and stay relatively high through most of the Asian trading period. Spreads are lowest in the overlap of the Asian and European trading period.

Bossaerts and Hillion (1991) use daily observations for spot and one-month forward rates to examine the intraweek patterns of the bid-ask spread. The use data for the British pound, the Canadian dollar, the Danish krone, the Dutch guilder, the French franc, the Italian lira, the Japanese yen, the Swiss franc, and the Deutsche mark for the period June 1, 1973 through June 13, 1988. They find that bid-ask spreads in both the forward and the spot foreign exchange markets are significantly larger on Fridays for all currencies considered.

Section 4.5.7: The intra-day behaviour of bid-ask spreads

Bollerslev and Domowitz (1993) examine the international patterns of intraday trading activity and the time series properties of returns and bid-ask spreads for the DM-Dollar exchange rate. They show how trading activity, measured by the number of quotes, changes with bid-ask spreads during the day across different countries. What makes this paper distinct from previous studies is that they don’t use bid and ask quotes as the transaction price for the empirical analysis. This is because the screen quotes available for analysis may not be representative of true transaction prices since dealers may negotiate these prices and the actual trade may occur inside the bid-ask quote.

The data set consists of bid-ask quotes for the DM-dollar rate from Sunday, April 9 to Friday, June 30, 1989, obtained from Reuters' network screens. Over that period, quotes appeared from 125 participating banks in the market. The data set is used to capture the average quote arrival during Monday and during Friday and the average quote arrival during the day for three of the largest centers (Hong Kong, London, New York).

The number of quote arrivals peaks after midnight as the Tokyo and Sydney markets open with subsequent activity in Singapore and Hong Kong. Trading activity remains strong in the afternoon Far Eastern trading session, and continues as Hong Kong and Singapore close and London and Frankfurt open. A decline is observed after that until the New York market opens. After the New York opening the trading activity starts to build up and declines gradually after the New York close until the Far Eastern markets open again. Trading activity in Hong Kong decreases sharply during lunchtime. In London the decrease is much more gradual. New York activity peaks at lunch hour because lunchtime coincides roughly with the high activity in London and Frankfurt.

In a theoretical paper, Chakrabarti (2000) studied the marginal impact of the parameters used in spread, spread volatility and return volatility in the morning and the afternoon. To this end, regression coefficients were estimated of the different measures of the pattern in spread, spread volatility and return volatility on the parameters varied in the simulation. The regression results revealed that spread, spread volatility and return volatility all seem to be affected by the two parameters that represent the risk aversion of traders for holding inventory overnight and during the day. Moreover, R^2 suggests that there is more unexplained variation in the afternoon variables than on the morning ones.

Section 4.6: Summary and conclusions

In this chapter I review the structure of the FX market and focus on the determinants of the bid-ask spread. The determinants of bid-ask spreads are inventory-based and information-based. There are three components of inventory carrying costs discussed in the FX literature: the cost of holding a liquid currency inventory (related to interest rates), market risk, and trading activity. Asymmetric information is another plausible determinant for the spread. A number of papers examine the effect of scheduled macroeconomic announcements on FX prices and find increased return volatility on days of macroeconomic announcements (Andersen, Bollerslev, Diebold and Vega 2003, Andersen and Bollerslev 1998, Harvey and Huang 1991, Ederington and Lee 1993). I examine the effect of macroeconomic news announcements on the spread in chapter 7 together with other explanatory variables.

From the literature review of this section we can see that up to date there is very limited research on the FX market wide liquidity and its characteristics. A reason why FX market microstructure attracted researchers' attention only in the last few years was the lack of available data. Most of the work in the FX market is fragmented focusing on individual market characteristics. With my work in the following chapters I fill a significant gap in the literature by examining market-wide commonality in liquidity using many variables at the same time and over a long period of time. In chapter 6, I look at the intraday liquidity in the FX market by examining the intraday behaviour of bid-ask spreads. The literature review discussed in this chapter was the starting point to understand the determinants of the bid-ask spread in the FX market and therefore decide which explanatory variables I will use in my empirical work (Chapter 7). The decision was based on theoretical motivations (inventory-based and information-based models) and previous empirical work (which variables have proved significant in past studies, which variables provided mixed results etc). Finally, this literature review points out the lack of a comprehensive investigation on the interaction between spreads and trading activity, exchange rate volatility and inventory holding costs. I examine this with the implementation of vector autoregression analysis on both quoted and relative spreads (Chapter 8).

Chapter 5: Data and Summary Statistics

Section 5.1: Introduction and overview

This chapter presents the data and summery statistics. I consider spread and trading activity information for three currency pairs: the US dollar/Japanese yen (JP/US), the British pound/US dollar (GB/US) and the Euro/US dollar (EU/US). I use these four currencies because they are the most traded ones in the FX market. According to the most recent research results published by the Bank of International Settlements (2007 survey), the most traded currency in all past BIS surveys was the US dollar, being on one side of at least 80% of transactions during the years. In 2007, the actual percentage was 86.3%. The euro remained the second most traded currency (37%) followed by the yen (16.5%) and the pound sterling (15%). I first explain the source of my data and the rational for the use of the sample and sub-samples and I continue with a discussion of major spread trends over the ten year period of my sample. The rest of the chapter presents results from summary statistics for daily spreads and trading activity and an intraday analysis for spread, spread variance and the number of quote revisions.

Section 5.2: The Olsen FX data

Olsen and Associates is a provider of e-finance technology and services, including high-frequency market data. Olsen provides access to a database of tick-by-tick price moves in the foreign exchange, interest rate and other markets. Olsen Data collect raw high frequency financial data from a number of sources, filter it in real time, and store it.

The Olsen database represents a major sample of worldwide market activity and is considered one of the largest collections of high quality, filtered data. Olsen collects live data from one or more real time data feeds and consolidates and filters the information to create the data sets. The filtering process is done through the Olsen data filter algorithm. Any research analysis of high frequency data is strongly influenced by bad data. As Olsen mentions, bad data can be a result of human input errors as well as automated quoting algorithms running on computers at the site of market makers. Details of the complex filtering system are beyond the scope of this thesis, but can be found in Muller (1999). I can simply say that when every received tick is stored, it is marked with a degree of credibility, which can subsequently be used as a selection criterion when extracting data from the databases.

Olsen has a well recognised database. Many published papers have used the Olsen dataset in the past. For example, a number of authors have analysed realized variance measures of foreign exchange returns computed from the Olsen data sets. These data sets were made available for use in three conferences on the statistical analysis of high frequency data sponsored by Olsen and Associates. The Olsen HFDF-2000 data is the most commonly used data set. Andersen, T., and T. Bollerslev (1998a, 1998b), Andersen, T., T. Bollerslev, F.X. Diebold, P. Labys (2001, 2003) and Maheu et. Al (2002) are only a few of the authors who used the Olsen data sets.

The data set I received from Olsen consists of the last bid-ask quotes at 5-minute intervals and the number of quote revisions in the 5-minute interval. This is a bilateral quote but not necessarily the best prices on both sides of the market. All quotes are time stamped and are based on GMT time. The trading day begins at 00:00am and ends at 23:55pm GMT time with the first 5 minute interval covering 00:00am to 00:05am and stamped as 00:05 on 01.01.1995 and the last 23:55pm to 00:00am on 31.01.2005.

Section 5.3: Creating the data sets

Since the FX market is in operation 24 hours and trading moves over the course of the 24-hour day, I segregate the data into three time zones. This is done to capture the trading activity caused by individual market places when the financial markets are open in Europe (London), United States (New York) and Asia (Japan). Therefore, I create a UK, a US (Eastern) and Asia time zone to capture the trading activity in the most active markets according to BIS 2007 survey (see Chapter 4, Table 4.1). In each time zone the trading day begins at 8:00am and ends at 5:00pm. This segmentation of the data allows the exclusion of hours when trading activity is very low. Based on the same rationale, I do not consider trading during weekends. Therefore, I leave out hours when trading activity is very low or almost non-existent, so that unrepresentative trades do not bias the results.

Table 5.1: US, UK and ASIA Time Zones

The shaded boxes indicated the selected hours used in my samples in order to capture the active hours of trading in each time zone. The table also shows how the three different time zones overlap. Each day trading starts with the opening of the Australasia area, followed by Europe and then North America. As one region's markets close another opens, or has already opened, and continues to trade in the FX market. Often these markets will overlap (as shown in this table) for some hours providing some of the most active trading.

Time zones		
ASIA	UK	US
08:00	23:00 (-1 day)	18:00 (-1 day)
09:00	00:00	19:00
10:00	01:00	20:00
11:00	02:00	21:00
12:00	03:00	22:00
13:00	04:00	23:00
14:00	05:00	00:00
15:00	06:00	01:00
16:00	07:00	02:00
17:00	08:00	03:00
18:00	09:00	04:00
19:00	10:00	05:00
20:00	11:00	06:00
21:00	12:00	07:00
22:00	13:00	08:00
23:00	14:00	09:00
00:00	15:00	10:00
01:00	16:00	11:00
02:00	17:00	12:00

03:00	18:00	13:00
04:00	19:00	14:00
05:00	20:00	15:00
06:00	21:00	16:00
07:00	22:00	17:00
08:00		18:00

I consider an aggregate sample that extends from 01.01.1995 to 31.01.2005 (full sample) and three other sub-samples in order to capture changes over my long sample. These are:

Period 1: 01.01.1995 – 31.05.1997 (period before Asian crisis)
Period 2: 01.06.1997 – 31.12.1998 (Asian crisis period)
Period 3: 01.01.1999 – 31.01.2005 (Period after Asian crisis)

Daylight saving time (DST) is the portion of the year in which a region's local time is advanced by (usually) one hour from its official standard time. Therefore, an adjustment is required in order to align the GMT hours with the trading hour. For example, during winter in the UK from October to March, GMT is the official UK time. But between March and October UK time is one hour ahead of GMT. So, if I was not considering daylight savings, the 8:00 to 17:00 GMT period during the summer would capture trading activity between 9:00 to 18:00 UK time and not 8:00 to 17:00 UK time. Daylight savings do not apply in Japan. Therefore, no daylight saving adjustment is required. In the table below, I present the dates on which daylight savings took place during my data set.

Table 5.2: Daylight Savings

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Example of obtaining the relevant dataset from the Olsen raw data.

The data below is an example of a part of a trading day (06.01.2003) with the observations at 5-minute intervals. For each currency combination the data provided from Olsen includes:

-the best bid-ask quotes in the 5-minute interval. (Recorded as High Bid & Low Ask)
-the last bid-ask quotes at 5-minute intervals. This is a bilateral quote but not necessarily the best prices on both sides of the market. (Recorded as Close Bid and Close Ask)
-the number of quote revisions in the 5-minute interval. (Recorded as Number of Ticks)

DATE	USD_JPY_HL_DailySpread	USD_JPY_CL_DailySpread	USD_JPY_DailyTicks	USD_JPY_Total_Ticks
02.01.1995	0.049524	0.079048	2	216
03.01.1995	0.017037	0.060278	12.25	1323
04.01.1995	0.005607	0.06271	16.77778	1812
05.01.1995	0.004537	0.061111	15.44444	1668
06.01.1995	0.014766	0.05972	12.55556	1356

Section 5.4: Liquidity and trading activity measures

After the three separate datasets are created, the information in each is used to calculate two measures of liquidity and one measure of trading activity.

Daily Liquidity Measures

From the quoted bid and ask information sampled at 5 minute intervals, I obtain a spread measure for each day by taking the average of this spread using each 5 minute interval.

$$S_{it} = \sum_{t=1}^{N} (a_i - b_i)/N \qquad \text{Eq. 5.1}$$

$N = 96$

Although quoted spread is used in many studies in the FX market, it has limitations. Goodhart (1995) reports that the quoted spread does not exactly reflect the real spread. Moreover as Olsen et al., (2001, p.45) mention, "the nominal spread ($p_{ask} - p_{bid}$) is in units of the underlying price" therefore, spreads from different markets cannot be compared to each other. A suitable variable that overcomes this difficulty is the relative spread which is dimensionless. The relative spread can be calculated as follows:

$$\text{Relative Spread} = \log_{ask} - \log_{bid} \qquad \text{Eq. 5.2}$$

Olsen mentions another advantage of the relative spread: the relative spread of JP/US is the relative spread of US/JP. As he notes "other spread definitions do not have this perfect symmetry".

Daily Trading Activity Measure

Due to the lack of good data on foreign exchange trading volumes at high frequencies, few studies have been focusing on the FX market. For example a number of studies (Grammatikos and Saunders (1986), Batten and Bhar (1993), Bessembinder (1994) and Jorion (1996)) used data on futures contracts as a proxy for interbank trading volumes.

I use the average number of quote revisions in the 5-minute intervals as a measure of trading activity. Despite its limitations a number of studies, such as Goodhart and Figliuoli (1991) and Bollerslev and Domovitz (1993), use the frequency of quote arrival as a proxy of trading activity. The limitations of this are: first, all these quotes are indicative and not actual trades; and second it is not possible to infer from a quote the volume for which it is given. In addition, Reuters tick frequency may be low at times of high trading activity and high at times of low trading activity. This is due to the fact that banks act as data providers to programme an automated data input. When an important event occurs, traders are likely to act and trade actively rather than entering data for Reuters. For a review of the studies that examine the measures of trading volume in the FX market see Chapter 4 (section 4.5.2).

Section 5.5: Full sample summary statistics for daily spreads and number of quote revisions

In this part of the thesis, I provide summary statistics for the daily mean quoted and relative spread (full sample), and for the daily mean number of quote revisions of JP/US, GB/US and EU/US exchange rates for different time zones. For the JP/US and the GB/US the full sample extends from 01.01.1995 to 31.01.2005. For the EU/US exchange rate the sample is from 01.01.2001 to 31.01 2005. The results are based on 2630 daily mean spreads for JP/US and GB/US and 1066 daily mean spreads for the EU/US. The daily mean quoted spreads were calculated based on the last bid-ask quotes recorded at 5-minute intervals, between 8:00am and 5:00pm local time, obtained from Olsen. The daily mean relative spreads were calculated based on the difference of the logarithm of the ask price and the logarithm of the bid price. The logarithmic bid and ask values are based on the last bid-ask quotes recorded at 5-minute intervals, between 8:00am and 5:00pm local time, obtained from Olsen. The daily mean number of quote revisions were calculated based on the number of quote revisions recorded in 5-minute intervals, between 8:00am and 5:00pm local time, obtained from Olsen.

Section 5.5.1: Spread trends between January 1995 and January 2005

Looking at Graphs 5.1, 5.2 and 5.3, we can see that during the period of the full sample, ***the spread of JP/US*** exchange rate declined considerably but also fluctuated significantly. Looking at 1995, the first year of the sample, we can see a considerable increase in the spread in all time zones. During this period the dollar declined (throughout most of 1995) especially against the Japanese yen.

The dollar started the year just above 100 yen per dollar. In February, however, the dollar plunged, hitting in late April a post-World War II low of 79.85 against the yen. The dollar remained low until August and then climbed to stand again at 100 yen per dollar. The Federal Reserve raised interest rates for the last time (after a series of increases in 1994) on February 1st, pushing up the federal funds rate by half a percentage point to six percent. With the economy slowing and the inflation outlook, in July the Fed cut the federal funds rate by a quarter percentage point to 5.75 percent. In 1996 the spread declined and by end of the year returned to the levels of the first quarter of 1995. During the first half of 1996 the US economy grew somewhat faster and unemployment was lower in the first half of this year than was forecast.

From the second quarter of 1996 until almost the end of 1998, there was an upward trend in all time zones. The spread increased during the Asian crisis. The Asian currency and financial crisis triggered by the crash of the Thai baht on July 2, 1997 (20% devaluation) subsequently spread to such countries as Indonesia and the Republic of Korea, with a negative impact on the world economy as a whole. The Asian currencies depreciated due to the lack of confidence of investors and the inability of central banks to stabilise the local currencies. Values of Southeast Asian currencies declined, and speculators responded by withdrawing more of their funds from these countries, which led to further weakness. Currency and financial markets latter settled down due to efforts by the Asian countries and support from various countries, with Japan playing the central role, as well as international institutions such as the IMF and the World Bank. The Asian crisis seemed to stabilise by 1999 and the JP/US spread in the UK time zone experienced a constant declining trend until the end of the sample with some sudden spread increases like the one due to the September 11, 2001 terrorist attacks. In the US and ASIA time zones, though, this declining trend began after the early 2001. For the period until the early 2001 in these time zones the spread fluctuated at a bit lower levels than during the Asian crisis period.

The spread of GB/US exchange rate (Graphs 5.4, 5.5, 5.6) had a similar trend to the spread of the JP/US during the Asian crisis only in the Asia time zone. In the UK time zone the upward trend lasted only until the end of 1996 and the spread remained at this high level until the second quarter of 1998 and started declining after this period until the end of our sample. In the US time zone, the upward trend is observed to begin in the last months of 1996 and last until the second quarter of 1998.

As far as ***the spread of EUR/US*** exchange rate (Graphs 5.7, 5.8, 5.9) is concerned, we can see a clear declining trend from January 2001 until January 2005 in all time zones. However, between January 2001 and January 2005 there were short periods were the spread increased. In the UK and US time zones there was an upward trend between February 2001 and end of April 2001, between the end of May 2004 and end of June 2004 and in December 2001, 2002, 2003 and 2004. The Asia time zone experienced two periods of significant upward trend, December 2002 and first week of May to first week of June 2002. In all the above cases, the declining trend of the spreads after the end of Asian crisis corresponds to the considerable increase in the number of ticks during that period (Graphs 5.13, 5.14, 5.15).

Section 5.5.2: Quoted daily spread summary statistics

The mean spread is almost the same for each exchange rate when different time zones are considered. For example, as Table 5.3 shows, the mean value for the JP/US is 0.0582 in the UK time zone, 0.0580 in US time zone and 0.0594 in Asia time zone. In section 5.7, I provide correlation results that show high correlation between the daily spreads across different time zones.

The standard deviation (SD) for the spread of the JP/US rate ranges between 0.014 and 0.017 in the three time zones. For the GB/US it ranges between 0.00013 and 0.00018 and for EU/US between 0.0000597 and 0.0000737. These results show that although the S.D of EU/US mean spread moves in a wider range it is less volatile than the other two rates. The Kurtosis statistics show that the EU/US mean spread (in all time zones) is leptokurtic (kurtosis is greater than 3). This means that the probability density functions are more peaked and have fat tails. In contrast, the mean spread for the JP/US and GB/US are platykurtic (in all time zones) indicating less peaked distribution with thinner tails. The skewness statistics reveal that the EU/US mean spread has positive skewness in all time zones indicating that most of the observed values are less than the mean. The same variable for JP/US and GB/US has negative skewness but very close to zero.

I also check if the quoted spread series is characterised by a unit root or not using the Dickey and Fuller test. The null hypothesis of a unit root is rejected in favour of the stationary alternative in each case as the test statistic (Tables 5.5) is more negative than the critical value (-1.95).

Section 5.5.3: Relative daily spread

The relative spread is dimensionless (doesn't depend on the value of the underlying currency) therefore allows the direct comparison of spreads in different exchange rates. As we can see in Table 5.4 the highest spread in all time zones is for the JP/US and the lowest for the EU/US. However, the appropriate direct comparison for the 10-year period should be for the JP/US and GBP/US exchange rates since only their data span the same period. The trading of EU/US started after 01.01.2001 and therefore we should compare it with the other two exchange rates only for the period after the introduction of euro until the end of our sample.

Looking at Graphs 5.10, 5.11 and 5.12 we can see that in all three time zones the JP/US spread was always higher than the GB/US spread with only one exception: from the 3rd quarter of 2001 until the 2nd quarter or 2002 (and until the end of 2002 for the Asia time zone). The difference in the spread was the widest from the 1st quarter of 1995 until the 1st quarter of 1996. A possible reason for that might be the considerably higher volatility (in all time zones) of the JP/US exchange rate during that period as we can see from the ICSS algorithm results [Chapter 6]. Over the full period of the sample, the JP/US spread in UK time zone is larger (22.3%) than the GB/US spread, with this difference a bit smaller in the US time zone (19.35%) than in the Asia time zone (around 20 percent). This implies that trading on the JP/US exchange rate over the 10-year period of our sample was more expensive that trading on the GB/US.

The EU/US spread (in all three time zones) was higher on average than GB/US until the last quarter of 2004 with the exception of the period between the 1st quarter of 2003 and the end of 2003. This difference in the spread was wider in the six-month period after the introduction of the euro reflecting the uncertainty in the market about the new currency.

Finally, I check if our relative spread series is stationary using the Dickey and Fuller test. The null hypothesis of a unit root is rejected in favour of the stationary alternative in each case as the test statistic (Tables 5.5) is more negative than the critical value (-1.95).

Section 5.5.4: Daily number of quote revisions summary statistics

Table 5.6 shows that the highest trading activity, as measured by the number of quote revisions, is observed for the EU/US exchange rate in the UK time zone with a mean value 164.7 per 5-minute interval and is considerably higher than the other currencies in all three time zones. In most cases the EU/US number of quote revisions in all time zones is more than double the number of quote revisions of GB/US and JP/US.[9] This result is expected since according the BIS

[9] However, the time period that data is available for the EU/US spread is different (after 01.01.2001) therefore, a more relevant comparison can be found in the sub sample analysis were

survey, in 2007 the EU/US rate had the highest share (27%) in daily FX market turnover. The number of quote revisions is higher in the UK time zone, followed by the US time zone and Asia time zone. This is also expected since according to the same survey, the UK is the major trading centre. The lowest tick number of quote revisions is observed for the GB/US exchange rate in the Asia time zone with a mean value 26.7 per 5-minute interval.

The mean value of the number of quote revisions for JP/US and GB/US is almost the same in the UK and US time zones. For example, the mean value for the JP/US rate in the UK time zone is 73.04 and the mean value for the GB/US rate in the same time zone is 73.58. For the other samples the mean values are reasonably similar.

The SD for the number of quote revisions variable for all three exchange rates is higher in the UK time zone, while the number of quote revisions is less volatile in Asia time zone (Table 5.6). The Kurtosis statistics show that in all cases but one (GB/US, ASIA time zone), the number of quote revisions is platykurtic (kurtosis less than 3) indicating less peaked distributions with thinner tails. The skewness statistics reveal that the number of quote revisions for the three exchange rates has positive skewness in all time zones, indicating that most of the observed values are less than the mean.

Overall, I summarise the results from the full sample as follows:

- in all three time zones the JP/US relative spread was always higher than the GB/US one. The difference in the spread was the widest from the 1st quarter of 1995 until the 1st quarter of 1996.

JP/US and GB/US spread data span from 01.01.1999 to 31.05.2005. The results for the third sub period show again that tick activity is considerably higher for the EU/US spread.

- the highest trading activity, as measured by the number of quote revisions, is observed for the EU/US exchange rate in the UK time zone.

- the mean value of the number of quote revisions for JP/US and GB/US is almost the same in the UK and US time zones.

- JP/US, GB/US and EU/US spreads are wider as dealers enter the market (captured by the first 5 15-minutes intervals) in the UK, US and Asia time zones. Spreads are also wider as dealers exit as we can see from the last quarter-hour intervals (30-36) in the UK and US time zones. This result is in line with Hung and Masulis (1999) and Hsieh and Kleidon (1996).

- the seasonal patterns throughout the 24-hour day (as captured in my three time zones) supports the U-shaped pattern of trades reported in other studies, such as Ding (1999), where U-shaped patterns are reported for the DM/US and JP/US currency pairs.

Table 5.3: Summary Statistics for Quoted Spread, Full Sample

Summary statistics for the daily mean quoted spread (full sample) of JP/US, GB/US and EU/US exchange rates for different time zones. For the JP/US and the GB/US the full sample extends from 01.01.1995 to 31.01.2005. For the EU/US exchange rate the sample is from 01.01.2001 to 31.01 2005. The results are based on 2630 daily mean spreads for JP/US and GB/US and 1066 daily mean spreads for the EU/US. The daily mean spreads were calculated based on the last bid-ask quotes recorded at 5-minute intervals, between 8:00am and 5:00pm local time, obtained from Olsen.

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Table 5.4: Summary Statistics for Relative Spread, Full Sample

Summary statistics for the daily mean relative spread (full sample) of JP/US, GB/US and EU/US exchange rates for different time zones. For the JP/US and the GB/US the full sample extends from 01.01.1995 to 31.01.2005. For the EU/US exchange rate the sample is from 01.01.2001 to 31.01 2005. The results are based on 2630 daily mean spreads for JP/US and GB/US and 1066 daily mean spreads for the EU/US. The daily mean relative spreads were calculated based on the difference of the logarithm of the ask price and the logarithm of the bid price. The logarithmic bid and ask values are based on the last bid-ask quotes recorded at 5-minute intervals, between 8:00am and 5:00pm local time, obtained from Olsen.

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Table 5.5: Dickey-Fuller (DF) test statistics

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Table 5.6: Summary Statistics for Daily Number of Quote Revisions, Full Sample

Summary statistics for the daily mean number of quote revisions (full sample) of JP/US, GB/US and EU/US exchange rates for different time zones. For the JP/US and the GB/US the full sample extends from 01.01.1995 to 31.01.2005. For the EU/US exchange rate the sample is from 01.01.2001 to 31.01 2005. The results are based on 2630 daily mean number of quote revisions for JP/US and GB/US and 1066 daily mean number of quote revisions for the EU/US. The daily mean number of quote revisions were calculated based on the number of quote revisions recorded in 5-minute intervals, between 8:00am and 5:00pm local time, obtained from Olsen.

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Graph 5.1: JP/US Quoted Spread, Full Sample, UK Time Zone

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Graph 5.2: JP/US Quoted Spread, Full Sample, US Time Zone

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Graph 5.3: JP/US Quoted Spread: Full Sample, ASIA Time Zone

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Quoted spread for JP/US rate between 01.01.95 and 31.01.2005. Over that period 2630 daily mean spreads were calculated (Weekends are not included). The daily mean spreads were calculated based on the last recorded bid and ask quotes at 5-minute intervals, between 8:00am and 5pm local time, obtained from Olsen.

Graph 5.4: GB/US Quoted Spread, Full Sample, UK Time Zone

Graph 5.5: GB/US Quoted Spread, Full Sample, US Time Zone

Graph 5.6: GB/US Quoted Spread, Full Sample, ASIA Time Zone

Quoted spread for GB/US rate between 01.01.95 and 31.01.2005. Over that period 2630 daily mean spreads were calculated (Weekends are not included). The daily mean spreads were calculated based on the last recorded bid and ask quotes at 5-minute intervals, between 8:00am and 5pm local time, obtained from Olsen.

Graph 5.7: EU/US Quoted Spread, Full Sample, UK Time Zone

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Graph 5.8: EU/US Quoted Spread, Full Sample, US Time Zone

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Graph 5.9: EU/US Quoted Spread: Full Sample, ASIA Time Zone

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Quoted spread for EU/US rate between 01.01.2001 and 31.01.2005. Over that period 1066 daily mean spreads were calculated (Weekends are not included). The daily mean spreads were calculated based on the last recorded bid and ask quotes at 5-minute intervals, between 8:00am and 5pm local time, obtained from Olsen.

Graph 5.10: JP/US, GB/US and EU/US Relative Spread, Full Sample, UK Time Zone

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Graph 5.11: JP/US, GB/US and EU/US Relative Spread, Full Sample, US Time Zone

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Graph 5.12: JP/US, GB/US and EU/US Relative Spread, Full Sample, ASIA Time Zone

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Relative spread of JP/US, GB/US and EU/US exchange rates. Full sample extends from 01.01.1995 to 31.12.2005 (for the EU/US from 01.01.2001). The results are based on 2630 daily mean spreads (1066 for the EU/US). The daily mean relative spreads were calculated based on the difference of the logarithm of the ask price and the logarithm of the bid price. The logarithmic bid and ask values are based on the last bid-ask quotes recorded at 5-minute intervals, between 8:00am and 5:00pm local time, obtained from Olsen.

Graph 5.13: Number of Quote Revisions, Full Sample, UK Time Zone

Graph 5.14: Number of Quote Revisions, Full Sample, US Time Zone

Graph 5.15: Number of Quote Revisions, Full Sample, ASIA Time Zone

Number of quote revisions (full sample) of JP/US, GB/US and EU/US exchange rates in the UK, US and ASIA time zone. For the JP/US and the GB/US the full sample extends from 01.01.1995 to 31.01.2005. For the EU/US exchange rate the sample is 01.01.2001 to 31.01 2005. The results are based on 2630 daily mean number of quote revisions for US/JP and GB/US and 1066 daily mean number of quote revisions for the EU/US. The daily mean number of quote revisions were calculated based on the number of quote revisions recorded in 5-minute intervals, between 8:00am and 5:00pm local time, obtained from Olsen.

Section 5.5.5: Intraday spreads, spread variance and number of quote revisions

My intraday spread data (quoted and relative spreads) are obtained from the last bid-ask quotes recorded at 5-minute intervals, between 8:00am and 5:00pm local time, obtained from Olsen. For the US/JP and the GB/US exchange rates the full sample extends from 01.01.1995 to 31.01.2005. For the EU/US exchange rate the sample is from 01.01.2001 to 31.01 2005. As in my daily sample, I focus on the business week (Monday to Friday) excluding weekend quotes due to very low trading activity. I aggregate the 5-minute interval data within adjacent 15-minute intervals and describe market conditions, spread, spread variance and the number of quote revisions to capture trading activity behaviour across these intervals. The 15-minute periods have been used by other researchers, like Huang and Masulis (1999)[10], who show that time-of-day effects are captured relatively well with the use of these intervals.

As a result, there are 36 quarter-hour periods per day over 2630 (1066 for the EU/US) weekdays in my ten-year sample, yielding 94,680 quarter-hour periods for the JP/US and GB/US exchange rates and 38,376 quarter-hour periods for the EU/US, in each time zone.

Tables 5.7 and 5.8, and Graphs 5.16 to 5.24 present the results for the mean quoted and relative spreads per 15-minute interval for JP/US, GB/US and EU/US currency pairs in UK, US and Asia time zones. Tables 5.9 and 5.10 present the results for the quarter-hour variance for the quoted and relative spreads for the three currency pairs in UK, US and Asia time zones. Market microstructure studies [Goodhart and Demos (1990), Andersen and Bollerslev (1998)] suggest seasonality patterns in the intraday FX data. The aggregation of my intraday sample in 36 15-minute intervals shows that for all three currency pairs, the

[10] Their sample consists of tick-by-tick data of DM/US exchange rates between October 1st 1992 and September 29, 1993, obtained from Olsen.

JP/US, GB/US and EU/US spreads are wider as dealers enter the market (captured by the first 5 15-minutes intervals) in the UK, US and Asia time zones. Spreads are also wider as dealers exit as we can see from the last quarter-hour intervals (30-36) in the UK and US time zones. This result is in line with Hung and Masulis (1999) who report that “spreads initially rise with the influx of new dealers and order flow (new information) but later spreads tend to drop due to increased dealer competition”. In addition, Hsieh and Kleidon (1996), report U-shaped patterns for the DM/US currency pair for London and New York. For the Asia time zone the spread pattern as dealers exit is different, showing no clear increase of the spread (actually the spreads of GB/US and EU/US decrease) which may be explained by the fact that the close of the active working day overlaps with the opening of London, the most active trading centre in the world. Spread variance is higher in the first few 15-minute intervals than the last 15-minute intervals for the JP/US and GB/US spreads in the UK and US time zones. In Asia time zone the result is the opposite. EU/US spread variance is higher when Asian dealers enter, fluctuates at considerably lower levels during trading in the UK and increases again considerably as dealers in North America exit.

Table 5.11 and Graphs 5.25 to 5.27 present the mean number of quote revisions per 15-minute interval for our three currency pairs in UK, US and Asia time zones. The seasonal patterns throughout the 24-hour day (as captured in my three time zones) in the aggregate data are pronounced. Trading activity rises in periods when Asian dealers begin to place FX quotes (intervals 1-10), is maintained at high levels during active trading hours in the UK time zone and gradually starts to drop after interval 15 (around lunch time) in the US time zone to fall to low levels towards the end of the trading day (interval 30-36). This observation further supports the U-shaped pattern of trades reported in other studies, such as Ding (1999), where U-shaped patterns are reported for the DM/US and JP/US currency pairs.

As far as individual time zones are concerned, the mean number of quote revisions per 15-minute period for all currency pairs is high at the beginning of the active trading day and in early afternoon where it reaches a peak (interval 25) with a range of 192.29 (JP/US) to 581.75 (EU/US) in the UK time zone. In the US time zone, for all currency spreads, the number of quote revisions increases in the first four quarter-hour intervals and gradually falls as dealers exit. Finally, in the Asia time zone, the number of quote revisions increases in the first nine 15-minute intervals and after interval 19, to reach a peak at the end of the active trading day, which as I mentioned earlier overlaps with the opening of London trading.

Table 5.7: Intraday Mean Quoted Spread, Full Sample

Intraday quarter-hour mean quoted spread (full sample, mean spreads X 100) of JP/US, GB/US and EU/US exchange rates for different time zones calculated based on the last bid-ask quotes recorded at 5-minute intervals, between 8:00am and 5:00pm local time, obtained from Olsen. For the JP/US and the GB/US the full sample extends from 01.01.1995 to 31.01.2005. For the EU/US exchange rate the sample is from 01.01.2001 to 31.01 2005. Interval 1 covers the trading quarter between 8:00am-8:15am and interval 36 between 4:45pm to 5:00pm.

Table 5.8: Intraday Mean Relative Spread, Full Sample

Intraday quarter-hour mean relative spread (full sample, mean spreads X 10,000) of JP/US, GB/US and EU/US exchange rates for different time zones calculated based on the last bid-ask quotes recorded at 5-minute intervals, between 8:00am and 5:00pm local time, obtained from Olsen. For the JP/US and the GB/US the full sample extends from 01.01.1995 to 31.01.2005. For the EU/US exchange rate the sample is from 01.01.2001 to 31.01 2005. Interval 1 covers the trading quarter between 8:00am-8:15am and interval 36 between 4:45pm to 5:00pm.

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Graph 5.16: JP/US Quoted Spread, Full Sample, UK Time Zone

Graph 5.17: JP/US Quoted Spread, Full Sample, US Time Zone

Graph 5.18: JP/US Quoted Spread, Full Sample, ASIA Time Zone

Intraday quarter-hour mean quoted spread (full sample, mean spreads X 100) of JP/US exchange rate for different time zones calculated based on the last bid-ask quotes recorded at 5-minute intervals, between 8:00am and 5:00pm local time, obtained from Olsen. The full sample extends from 01.01.1995 to 31.01.2005. Interval 1 covers the trading quarter between 8:00am-8:15am and interval 36 between 4:45pm to 5:00pm.

Graph 5.19: GB/US Quoted Spread, Full Sample, UK Time Zone

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Graph 5.20: GB/US Quoted Spread, Full Sample, US Time Zone

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Graph 5.21: GB/US Quoted Spread, Full Sample, ASIA Time Zone

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Intraday quarter-hour mean quoted spread (full sample, mean spreads X 100) of GB/US exchange rate for different time zones calculated based on the last bid-ask quotes recorded at 5-minute intervals, between 8:00am and 5:00pm local time, obtained from Olsen. GB/US the full sample extends from 01.01.1995 to 31.01.2005. Interval 1 covers the trading quarter between 8:00am-8:15am and interval 36 between 4:45pm to 5:00pm.

Graph 5.22: EU/US Quoted Spread, Full Sample, UK Time Zone

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Graph 5.23: EU/US Quoted Spread, Full Sample, US Time Zone

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Graph 5.24: EU/US Quoted Spread, Full Sample, ASIA Time Zone

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Intraday quarter-hour mean quoted spread (full sample, mean spreads X 100) of EU/US exchange rate for different time zones calculated based on the last bid-ask quotes recorded at 5-minute intervals, between 8:00am and 5:00pm local time, obtained from Olsen. For the EU/US exchange rate the sample is from 01.01.2001 to 31.01 2005. Interval 1 covers the trading quarter between 8:00am-8:15am and interval 36 between 4:45pm to 5:00pm

Table 5.9: Intraday Quoted Spread Variance, Full Sample

Intraday quarter-hour variance for quoted spread (full sample, variance X 1,000,000) of JP/US, GB/US and EU/US exchange rates for different time zones calculated based on the last bid-ask quotes recorded at 5-minute intervals, between 8:00am and 5:00pm local time, obtained from Olsen. For the JP/US and the GB/US the full sample extends from 01.01.1995 to 31.01.2005. For the EU/US exchange rate the sample is from 01.01.2001 to 31.01 2005. Interval 1 covers the trading quarter between 8:00am-8:15am and interval 36 covers the trading quarter between 4:45pm-5:00pm.

Table 5.10: Intraday Relative Spread Variance, Full Sample

Intraday quarter-hour variance for relative spread (full sample, variance X 1,000,000) of JP/US, GB/US and EU/US exchange rates for different time zones calculated based on the last bid-ask quotes recorded at 5-minute intervals, between 8:00am and 5:00pm local time, obtained from Olsen. For the JP/US and the GB/US the full sample extends from 01.01.1995 to 31.01.2005. For the EU/US exchange rate the sample is from 01.01.2001 to 31.01 2005. Interval 1 covers the trading quarter between 8:00am-8:15am and interval 36 covers the trading quarter between 4:45pm-5:00pm.

Table 5.11: Intraday Mean Number of Quote Revisions, Full Sample

Intraday quarter-hour mean number of quote revisions (full sample) of JP/US, GB/US and EU/US exchange rates for different time zones calculated based on the number of quote revisions recorded in 5-minute intervals, between 8:00am and 5:00pm local time, obtained from Olsen. For the JP/US and the GB/US the full sample extends from 01.01.1995 to 31.01.2005. For the EU/US exchange rate the sample is from 01.01.2001 to 31.01 2005. Interval 1 covers the trading quarter between 8:00am-8:15am and interval 36 between 4:45pm to 5:00pm.

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Graph 5.25: JP/US Intraday Number of Quote Revisions, Full Sample, UK, US and ASIA Time Zones

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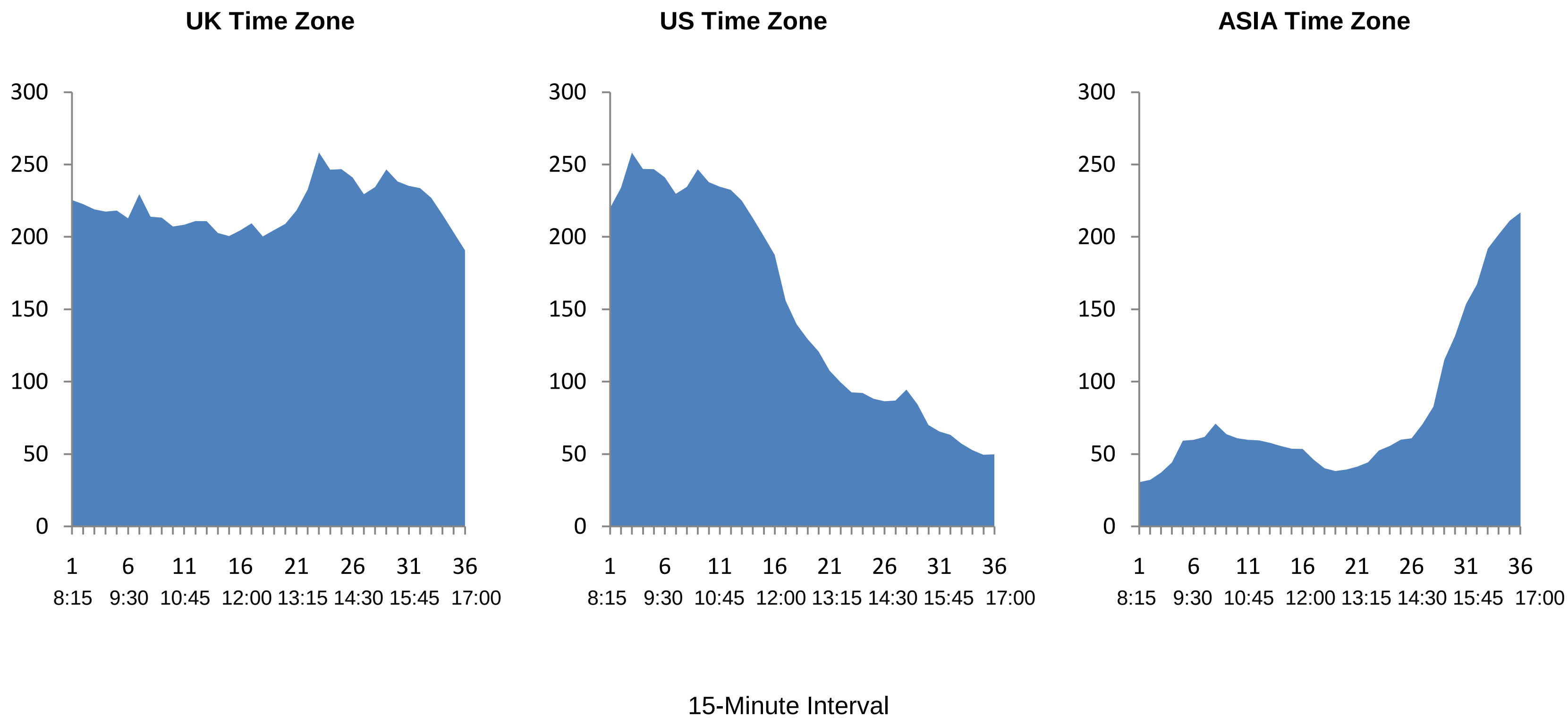
Intraday quarter-hour mean number of quote revisions (full sample) of JP/US exchange rate for different time zones calculated based on the number of quote revisions recorded in 5-minute intervals between 8:00am and 5:00pm local time, obtained from Olsen. The full sample extends from 01.01.1995 to 31.01.2005. Interval 1 covers the trading quarter between 8:00am-8:15am and interval 36 between 4:45pm to 5:00pm.

Graph 5.26: GB/US Intraday Number of Quote Revisions, Full Sample, UK, US and ASIA Time Zones



Intraday quarter-hour mean number of quote revisions (full sample) of GB/US exchange rate for different time zones calculated based on the number of quote revisions recorded in 5-minute intervals between 8:00am and 5:00pm local time, obtained from Olsen. The full sample extends from 01.01.1995 to 31.01.2005. Interval 1 covers the trading quarter between 8:00am-8:15am and interval 36 between 4:45pm to 5:00pm.

Graph 5.27: EU/US Intraday Number of Quote Revisions, Full Sample, UK, US and ASIA Time Zones

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Intraday quarter-hour mean number of quote revisions (full sample) of EU/US exchange rate for different time zones calculated based on the number of quote revisions recorded in 5-minute intervals between 8:00am and 5:00pm local time, obtained from Olsen. The full sample extends from 01.01.2001 to 31.01.2005. Interval 1 covers the trading quarter between 8:00am-8:15am and interval 36 between 4:45pm to 5:00pm.

Section 5.6: Sub periods summary statistics

During the Asian crisis, bid-ask spreads for Asian emerging market currencies increased sharply. Therefore, it is interesting to see the behavior of the spreads for the three exchange rates we examine in this study. Becker and Sy (2005) show that the costs associated with a US$10 million roundtrip transaction before and during the crisis period for the different Asian currencies that they analyze in their paper increased dramatically. They report for example, that “for the Indonesian rupiah, the cost increased from a moderate US$8,000 pre-crisis to a cross-section high of US$215,900 during the crisis”. Such levels and swings in the costs of currency transactions have a significant impact on both micro- and macroeconomic variables.

Section 5.6.1: Quoted daily spread summary statistics

Table A5.1 (appendix 5) shows that for both the JP/US and GB/US exchange rates, the mean spread increased only by a small amount during the Asian crisis (Period 2 sample) for the UK, US and Asia time zones. In particular spreads increased between 5.6% (JP/US, in US time zone) and 17% (GB/US, in Asia time zone) when the three time zones are considered. These results are consistent with Martin (2003) who examined a sample of 21 emerging and developed country currencies to evaluate the impact of the Asian crisis on currency bid-ask spreads. She reports that none of the developed countries show significant changes in spreads. This may have resulted from downward pressure on spreads due to predictable flight to quality volume that offset the upward pressure on spreads due to increased volatility.

For both the JP/US and GB/US exchange rates, the mean spread (UK, US and Asia time zones) in the period after the Asian crisis is lower or slightly lower than in the period before the crisis. Finally, the JP/US and GB/USD exchange rates have their highest and lowest mean quoted spread values in the same sub samples (Period 2 and Period 3 respectively) and in the same time zones (UK time zone for both the highest and the lowest mean spread).

Looking at the standard deviation of the spreads (appendix 5, Table A5.1), we can observe that the period with the highest spread volatility is Period 3 of our sample. In particular, for the JP/US and GB/US spreads in all time zones the volatility in almost all cases is double than in the period after the Asian crisis (Period 3). It is interesting to notice that during Period 2, which is the period that covers the Asian crisis, the spreads have the lowest volatility. Period 3 provides the opportunity to compare more directly the volatility of all spreads since the euro started trading on the January 01, 2001. As with the full sample, the EU/US spread is less volatile than the other two rates in Period 3.

Section 5.6.2: Relative daily spread

Relative spreads allow the direct comparison among the spreads of different exchange rates. Therefore, the most interesting comparison is for the 3rd period of our sample where the spreads of the three exchange rates can be compared. For the ***first period*** of the sample I observe a common pattern in the movement of the spread for the JP/US and the GB/US exchange rates. The JP/US spread was in most cases higher than the GB/US spread with the mean value in all time zones to be around 33 percent higher. The difference was wider for the first year of our sample (1995 –1996) where in many cases the JP/US spread was more than double than GB/US spread. For example on the 22.06.1995 the JP/US spread was 0.0004 and the GB/US spread 0.00014. In the first period for all time zones the spread for JP/US peaked on the 14.04.1995 and for the GBP/US on the 10.04.1995 with the exception of UK time zone where the peak occurred on 17.04.1005 for the GBP/US.

Looking at Graphs 5.10, 5.11 and 5.12 we can see that for the ***second period*** of my sample the difference of the spread between the JP/US and the GB/US was higher in the last quarter of 1998 in all time zones. In particular the JP/US spread increased considerably from 07.10.1998 and for the next few days reaching a pick on the 12.10.1998 in the UK and US time zones. Around these dates occurred many important economic events, such as the Japan's announcement of a $30 billion aid package for Southeast Asia to help the region recover from recession, the IMF and World Bank joint plenary session to debate the global economic crisis and the interest rates cut by the Fed to prevent weak financial markets from tripping the US into a recession.

In the ***third period*** of the sample, we can see that both the spreads and the difference between the US/JP spread and the GB/US spread narrowed in all time zones (Graphs 5.10, 5.11, 5.12). The downward trend for the spreads began in different periods when different time zones are considered. In particular, in the UK time zone spreads were fluctuating around 0.00025 and 0.0003 for the JP/US and around 0.0002 and 0.00025 for the GB/US in 1999. From 2000, there was a consistent downward trend. Although the situation is similar in the US and Asia time zones, with lower spreads for both e/r, though the downward trend began only after early 2001.

The introduction of the euro currency on 01.01.2001 allows the comparison of the spreads of all three exchange rates from the date of introduction to the 31.01.2005. Results show that the EU/US spread was higher (in all time zones) on average than the JP/US and GB/US spreads for more than two years after the introduction of euro. However, after the 1st quarter of 2003 and until the end of our sample the EU/US spread in most cases was lower than the US/JP spread. Moreover, the EU/US spread decreased considerably during the first half of 2001, when it was fluctuating around 0.0002 until the end of 2004, when it was fluctuating around 0.0001. Last but not least, for all currency pairs under consideration and in all time zones, the spreads peaked in most cases on Christmas and New Years Eve (and around these days).

Section 5.6.3: Summary statistics for daily number of quote revisions

Results show considerably higher trading activity, as captured by the number of quote revisions variable, for all exchange rates and all sample periods in the UK time zone (Table A5.3). As I mentioned before this result is expected since the UK is the major trading centre. The mean number of quote revisions for both the JP/US and GB/US in all time zones (UK, US and ASIA) increased by a significant amount (approximately five times for JP/US and four times for GBP/USD) between Period 1 and Period 3 samples. For example, for the JP/US (UK time zone) the average number of quote revisions in a 5 minute interval increased by almost five times between Period 1 (21.7) and Period 3 (104.57). This increase in the number of quote revisions was followed by a considerable reduction in the quoted spreads of the JP/US and GB/US rates in the UK time zone. For the US and Asia time zones the spreads decreased but by a much smaller amount. In section 5.7 I provide analytical results for the correlation between spreads and number of quote revisions in different time zones. Results show negative correlation in all cases.

Finally, the JP/US and GB/US exchange rates have their highest and lowest mean values for the number of quote revisions in the same sub periods (Period 3 and Period 1 respectively) and in the same time zones (UK and Asia time zones respectively).The SD for all three exchange rates in all sub-periods is higher in the UK time zone.

Section 5.6.4: Intraday spreads, spread variance and number of quote revisions

My intraday spread data (quoted and relative spreads) are obtained from the last bid-ask quotes recorded at 5-minute intervals, between 8:00am and 5:00pm local time, obtained from Olsen. As in my daily sample, I focus on the business week (Monday to Friday) excluding the weekend quotes due to very low trading activity. I aggregate the 5-minute interval data within adjacent 15-minute intervals and describe market conditions, spread, variance the number of quote revisions (as a proxy of trading activity) behaviour across these intervals and across my three sub-periods.

Tables A5.4, A5.5, A5.9, A510, A5.14 and A.515 (Appendix 5) present the results for the mean quoted and relative spreads per 15-minute interval in the three sub-period of my sample for JP/US, GB/US and EU/US currency pairs in UK, US and Asia time zones. Tables A5.6, A5.7, A511, A5.12, A5.16, and A5.17 present the results for the quarter-hour variance in the three sub-periods of my sample for the quoted and relative spreads for the three currency pairs in UK, US and Asia time zones. In general, results show differences in the behaviour of the quarter-hour mean spreads of a particular currency in different sub-periods. In particular, the JP/US mean spread (UK and US time zones) is higher in the first 15-minute intervals of the day when compared to the mean spread in the last 15-minute intervals of the active trading day for the first two sub-periods (Period 1 and Period 2). This pattern is reversed in Period 3, where the mean spreads per 15-minute period are higher at the end of the close of the active trading day compared to the opening. A similar pattern is observed for the GB/US in the UK and US time zones.

Tables A5.8, A5.13 and A5.18 (Appendix 5) present the mean number of quote revisions per 15-minute interval in my three sub-periods, for the three currency pairs in UK, US and Asia time zones. The mean number of quote revisions per 15-minute interval in all three sub-period is very similar to the full sample results with seasonal patterns being evident throughout the 24-hour day (as captured in the three time zones) in the aggregate data. Therefore, there is no clear evidence that the general pattern of the intraday number of quote revisions changed during the Asian crisis period (Period 2 of my sample). As with the full sample results, trading activity in all periods rise when Asian dealers begin to place FX quotes (intervals 1-10), is maintained at relatively high levels during active trading hours in the UK time zone (with a U-shaped pattern between the opening and around the 23rd interval), and gradually starts to drop after interval 15 (around lunch time) in the US time zone to fall to low levels towards the end of the trading day (interval 30-36). This observation further supports the U-shaped pattern of trades reported in other studies, such as Ding (1999), where U-shaped patterns are reported for the DM/US and JP/US currency pairs.

Overall, I summarise the results from the sub-period samples as follows:

- the EU/US spread was higher (in all time zones) on average than the JP/US and GB/US spreads for more than two years after the introduction of euro. However, after the 1st quarter of 2003 and until the end of our sample the EU/US spread in most cases was lower than the US/JP spread.

- results show considerably higher trading activity for all exchange rates and all sample periods in the UK time zone This result is expected since the UK is the major trading centre.

- results from the daily number of quote revisions supports the U-shaped pattern of trades reported in other studies, such as Ding (1999), where U-shaped patterns are reported for the DM/US and JP/US currency pairs.

- in general, results show differences in the behaviour of the quarter-hour mean spreads of a particular currency in different sub-periods.

Section 5.7: Correlation between spreads and trading activity (Full Sample)

I consider three types of correlation in this section: the correlation between spreads of the same currencies in different time zones, the correlation between spreads of different currencies in the same time zone, and the correlation between spreads and their number of quote revisions.

Section 5.7.1: Correlation results between spreads of the same currencies in different time zones

For each currency pair, the results presented in Table 5.16 (Panel A) show a high correlation between the spreads in different time zones. The highest correlation (0.86) is observed for the quoted spread of JP/US rate and the quoted spread of GB/US between the UK/US time zones. The least correlated quoted spreads (0.62) are those of the EU/US rate in the UK/Asia time zones.

The correlation between spreads in the UK and US time zones, for all currency pairs, ranges between 0.77 and 0.86. The UK/Asia time zones correlations range between 0.62 and 0.77, while the US/Asia time zone correlations have values between 0.70 and 0.84. Therefore we can see that for any of the exchange rates I consider in this study, spreads are more correlated between UK/US time zones. This is expected probably due to the overlap of time zones. As we can see in Table 5.1, during the course of the day, there are five hours when the UK and US markets operate actively simultaneously. Each trading day, after lunch in the UK, the trading in North America starts when the financial markets open.

Section 5.7.2: Correlation between spreads of different currencies in the same time zone

Table 5.12 (Panel B) shows the correlation results between spreads of different currencies in the same time zone. All spreads are highly and positively correlated with correlation results ranging between 0.70 and 0.92. The most correlated spreads are the ones of the GB/US and JP/US rates. For the UK time zone the correlation is the highest (0.92). This result is expected and is explained by the fact that important economic events in a major financial market have a global impact and the effect spreads immediately to the economies of other countries.

Section 5.7.3: Correlation between spreads and number of quote revisions

All results show negative correlation between spreads and number of quote revisions suggesting that spreads are narrower (wider) when trading activity is higher (lower). I find that this relationship is very strong (around –0.80 in different time zones) for the spreads of GB/US and JP/US rates but less strong for the EU/US rate as shown in Table 5.12 (Panel C). A negative relationship between spreads and number of quote revisions is expected since during hours of higher dealer activity the risks of holding inventory are lower. Of course correlation is not a measure of causality. Many studies examine this causality; the possible effects of higher trading activity on the bid-ask spread in the FX market. Admati and Pfleiderer (1988) provide a theoretical model that suggests spread should decrease when trading activity increases where other models (Subrahmanyam, 1989) suggest the opposite. The empirical findings of Bollerslev and Domovitz (1993) suggest that when orders increase in frequency the spread decreases.

Studies show that this opposite impact on spreads depends on whether the trading activity volumes are expected or unexpected. Expected trading volumes should be negatively correlated with spreads to the extent that they reflect economies of scale and are associated with higher competition among market makers [Cornell (1978)]. By contrast, unexpected trading volumes should have a positive impact on spreads to the extent that they are associated with higher volatility through the mixture of distribution hypothesis. Therefore, the strong negative relationship between the number of ticks and the GB/US and JP/US respectively might be an indication of lower inventory risk and higher competition among market makers.

Table 5.12: Correlation Panel

Panel A presents correlation results between the daily mean quoted spread (full sample) of JP/US, GB/US and EU/US exchange rates in different time zones. Panel B shows the correlation results between different spreads in the same time zone. Panel C shows the correlation results between spreads and number of quote revisions. For the JP/US and the GB/US the full sample extends from 01.01.1995 to 31.01.2005. For the EU/US exchange rate the full sample extends from 01.01.2001 to 31.01 2005. The correlation results are based on 2630 daily mean spreads for US/JP and GB/US and 1066 daily mean spreads for the EU/US. The daily mean spreads were calculated based on the last bid-ask quotes recorded at 5-minute intervals, between 8:00am and 5:00pm local time, obtained from Olsen.

Panel A Correlation Between Spreads of the Same Rate in Different Time Zones			
	GB/US	JP/US	EU/US
UK/US	0.86	0.86	0.77
UK/ASIA	0.77	0,77	0.62
US/ASIA	0.77	0.85	0.70
Panel B Correlation Between Different Spreads in the Same Time Zones			
	GB/US and JP/US	GB/US and EU/US	JP/US and EU/US
UK	0.92	0.77	0.77
US	0.86	0.75	0.77
ASIA	0.74	0.70	0.79
Panel C Correlation Between Spreads and Number of Quote Revisions			
	GB/US	JP/US	EU/US
UK	-0.74	-0.82	-0.27
US	-0.80	-0.80	-0.47
ASIA	-0.76	-0.78	-0.58

Section 5.8: Summary and conclusion

In this chapter I provide summary statistic results for daily spread and trading activity and describe the intraday spread, spread variance and the number of quote revisions. In general, my results support the findings from previous studies, such as those of Ding (1999), Hung and Masulis (1999) and Hsieh and Kleidon (1996), that report strong seasonality patterns in bid-ask spreads and trading activity in the FX market.

In the next chapter I apply the ICSS algorithm to search for structural breaks in the exchange rate variance and the bid-ask spread variance and compare results from the two time series. This methodology will also allow me to relate the results from the structural breaks to the ones from the sub-periods of my sample described in this chapter and find if there are any significant changes in the behaviour of the variables during the Asian crisis.

Chapter 6: Exchange rate volatility and spread volatility

Section 6.1: Introduction and overview

In this chapter I use the Inclan and Tiao (1994) Iterated Cumulative Sum of Squares (ICSS) algorithm to identify sudden changes to the unconditional volatility of the exchange rates and spread series of JP/US, GB/US and EU/US for three time zones (UK, US and Asia) in order to identify the number of variance shifts (changes to volatility) and the dates on which these shifts took place. An advantage of this methodology is that I can define to the day (time) when unconditional volatility shifted, allowing me to distinguish between periods of high and low volatility.

This provides the opportunity to examine the variance shifts of exchange rates and spreads using the three sub-periods described in the previous chapter and test the hypothesis that exchange rate volatility and spread volatility were higher during the Asian crisis. In addition, I examine whether spread volatility coincides with exchange rate volatility. The ICSS methodology will also allow me to distinguish between periods of high and low volatility at different times of day using my intra-day sample. According to information-based models and the available empirical evidence reviewed in previous chapters I expect to find intraday patterns in the volatility of liquidity. Identifying such patterns can be helpful as traders can choose the most advantageous time of the day (e.g times with high liquidity and lower costs), financial market supervisors can become aware of consistent patterns in behaviour, which may have regulatory implications and we can test market microstructure theories and compare results to previous studies. I expect spreads to be higher as the three major FX markets open and close. Finally, this work is important because the variance of the spread is the key characteristic of the spread in GARCH modelling discussed in the next chapter.

Section 6.2: Detecting variance shifts

The Inclan and Tiao (1994) ICSS test is designed to identify sudden changes to the unconditional volatility of series. Thus a series is assumed to be stationary over some segment of the data until a sudden change in volatility takes place. After this point the variance is assumed to be stationary once again until another sudden change in variance occurs. To estimate the number of changes to the unconditional variance and the point at which each variance shift occurs, Inclan and Tiao (1994) suggest a three step algorithm. In the first instance, using the full data set, the maximum absolute value of the Dk series is calculated as:

$$D_k = \frac{C_k}{C_T} - \frac{k}{T} \qquad k = 1,...,T \qquad \text{Eq. 7.1}$$

where C_k and C_T are the mean centred cumulative sum of squares calculated using k and T observations, respectively. If there are no variance changes over the sample period, the series Dk oscillates around zero but drifts up or down from zero when a variance shift occurs. If $\max|Dk|\sqrt{(n/2)}$ is greater than the critical value[11], then a possible variance change point has been found. The critical value at 5% level is 1,358.

Once a possible change point cp_i has been identified after m observations, the data should be partitioned into two groups spanning $(t_1,....,t_{m-1}):(t_{m+1},...,T)$. The $\max|Dk|\sqrt{(n/2)}$ statistic is then calculated for each of the two new samples. In each of these two samples an additional change point could potentially be identified. This would require a further sub-division of the data until all the data has been examined in intervals t_1 to each change point until T is reached and no further change points can be found.

In the third step all N change points should be recorded in order $cp_1, cp_2,..., cp_N$. Assuming the two extreme values are cp_0 where $t=0$ and cp_{N+1} where $t=T$. Each

[11] n is the number of observations used to calculate Dk.

possible change point should be re-checked by calculating $|Dk|\sqrt{(n/2)}$ for data observations spanning alternative change points (cp_i:cp_{i+2}) until the change points (cp_{N-2}):(cp_N) are reached. If $\max|Dk|\sqrt{(n/2)}$ no longer reaches the critical value, the possible change point should be eliminated. This step should be repeated until the number of change points found in each pass of the data does not change and change points found are "close" to those of the previous pass.

This procedure has been adopted successfully by Aggarwal et al. (1999) to identify the volatility changes in the stock return indexes of developed and emerging markets, by Chelley-Steeley (2005) to capture the effect of microstructure changes to the volatility in equity markets and by Ewing and Malik (2005) to study the source of the volatility spillovers between firms of different market capitalization. Applications have also been made to the study of volatility changes in interest rates (Fernandez (2004)) and exchange rates, [Malik (2003), Chelley-Steeley and Tsorakidis (2009)].

The ICSS algorithm tends to overstate the number of actual sudden shifts in variance as is pointed out by Bacmann and Dubois (2002). In particular, the behavior of the ICSS algorithm is questionable under the presence of conditional heteroskedasticity. Bacmann and Dubois show that one way to circumvent this problem is by filtering the return series by a GARCH (1,1) model, and applying the ICSS algorithm to the standardized residuals. They conclude that sudden shifts in unconditional variance are less frequent than was shown previously. I follow this methodology in the application of the ICSS to the exchange rate and spread series.

An alternative to using the ICSS algorithm not explored here is to apply wavelet analysis which can identify all the variances in a wavelet table. A detailed discussion of wavelet analysis and its application to indentifying variance shifts is provided by Percival and Walden (2004). While applications of wavelet analysis to the examination of cross country volatility spillovers can be found in Lee (2001, 2004).

Section 6.3: Exchange rate variance changes, Daily Sample

I apply the ICSS algorithm of Inclan and Tiao (1994) to each exchange rate series (standard errors were used in the estimation process obtained from a GARCH[1,1] model) and I find evidence of some but not too many volatility shifts associated with each exchange rate.

Tables 6.1(a,b,c), 6.2(a,b,c), 6.3(a,b,c) provide a list of the dates on which volatility changes were found to have occurred. The changing unconditional volatility of each exchange rate can be viewed in Graphs 6.1(a,b,c), 6.2(a,b,c), 6.3(a,b,c).

The greatest number of change points (ten) occurs for the JP/US exchange rate in all three time zones. The lowest number of change points, only one, occurs for the EU/US exchange rate in the UK time zone, but we need to consider that the EU/US exchange rate was in place for only four years in my sample. The year which overall has the most variance change points considering the exchange rates of all currencies under consideration is 1998. Therefore, as expected I find some evidence that during the Asian crisis exchange rate volatility increased. Overall, the most change points are found in the Asia time zone (one more change point in total than the US time zone). It is worth mentioning that when we look at each exchange rate separately, most of its volatility change points occur on the same or around the same dates in different time zones. This provides some preliminary evidence of the commonality of liquidity in the FX market. I look further in this issue in the following chapters. A period with high volatility for the exchange rate of JP/US was June 13th 1998 to June 19th 1998 (ASIA time zone) as the standard deviation rose by 295%. The GB/US exchange rate was noticeably more volatile from December 25th 2003 until the end of the sample, as standard deviation rose by 230%. When looking at the EU/US currency pair we see that the period with the highest volatility was June 19th 2002 to August 13st 2002 in the US time zone. For the JP/US exchange rate the period after early June 2000 stands out as the period of low volatility in all three time zones. For the GB/US exchange rate a period of low volatility occurs between June 1995 and October 1996 in both the UK and Asia time zones. For the EU/US the volatility in all time zones is similar, with a lower value in the period between August 2002 and March 2003 in the US time zone.

Section 6.4: Spread variance changes, Daily Sample

I find several volatility shifts in the variance of the quoted and relative spreads. Since spread is a measure of liquidity, the higher the number of volatility shifts for a particular spread, the higher the volatility of liquidity of the currency pair associated with that spread.

Tables 6.4(a,b,c) to 6.9(a,b,c) provide a list of the dates on which volatility changes were found to have occurred. The changing unconditional volatility of each spread can be viewed on Graphs 6.4(a,b,c) to 6.9(a,b,c).

The greatest number of change points occurs for the GB/US spread in the UK time zone (24 for the quoted spread and 20 for the relative spread). But there are quite large numbers of change points for other spreads: eighteen for the quoted GB/US spread in US time zone, seventeen for the relative GB/US spread in the Asia time zone, sixteen for the quoted JP/US spread in the UK time zone and fifteen for the relative JP/US spread in the UK time zone. Ten change points were found for the quoted EU/US spread in the Asia time zone but we need to consider that the EU/US exchange rate was in place for only four years in the sample. The year which overall has the most variance change points, considering spreads of all exchange rates, in all time zones, is 2003 for both the quoted and relative spread. Therefore, spreads were not more volatile during the Asian crisis. This is in contrast to my findings from the exchange rate volatility where most variance shifts were found during that period. For the quoted and relative spread, the most change points were found in the UK time zone, forty-nine and forty-two respectively.

I should mention that the periods with the highest volatility are short periods surrounding holidays where volatility increased dramatically. These included: December 26th 1996 to January 3rd 1997 for the GB/US quoted and relative spread (US time zone) and December 26th 2003 to January 7th 2004 for the EU/US quoted and relative spread (US time zone). For all spreads (quoted and relative) under consideration year 2004 stands out as being the year with the most periods of low volatility. Finally, it is important to mention that I don't find enough evidence to conclude that exchange rate volatility coincides with spread volatility.

Table 6.1(a): Change Points Against the Japanese Yen, (US Time Zone)

In this table change point indicates the date of a volatility shift, Interval is the date points between which the variance of exchange rate changes was stationary. Standard deviation is the standard deviation of exchange rate changes for the appropriate interval. The % change is the percentage increase or decrease in the standard deviation relative to the previous interval. The critical value of at a 95% level is 1.358.

Change Point	Interval	σx100	% Change
January 13 1995	January 2 1995 – January 13 1995	0.327	
March 02 1995	January 14 1995 – March 02 1995	0.148	-54.74
October 06 1995	March 03 1995 – October 06 1995	0.419	183.11
May 06 1997	October 07 1995 – May 06 1997	0.198	-52.74
June 17 1997	May 07 1997 – June 17 1997	0.47	137.37
June 11 1998	June 18 1997 – June 11 1998	0.291	-38.09
September 01 1998	June 12 1998 – September 01 1998	0.486	67.01
October 21 1998	September 02 1998 – October 21 1998	0.829	70.58
April 02 1999	October 22 1998 – April 02 1999	0.396	-52.23
June 07 2000	April 03 1999 – June 07 2000	0.305	-22.98
	June 08 2000 – January 31 2005	0.235	-22.95

Table 6.1(b): Change Points Against the British Pound, (US Time Zone)

In this table change point indicates the date of a volatility shift, Interval is the date points between which the variance of exchange rate changes was stationary. Standard deviation is the standard deviation of exchange rate changes for the appropriate interval. The % change is the percentage increase or decrease in the standard deviation relative to the previous interval. The critical value of at a 95% level is 1.358.

Change Point	Interval	σx100	% Change
December 30 2003	January 2 1995 – December 30 2003	0.182	
May 25 2004	December 31 2003 – May 25 2004	0.311	70.88
	May 26 2004 – January 31 2005	0.204	-34.41

Table 6.1(c): Change Points Against the Euro, (US Time Zone)

In this table change point indicates the date of a volatility shift, Interval is the date points between which the variance of exchange rate changes was stationary. Standard deviation is the standard deviation of exchange rate changes for the appropriate interval. The % change is the percentage increase or decrease in the standard deviation relative to the previous interval. The critical value of at a 95% level is 1.358.

Change Point	Interval	σx100	% Change
September 24 2001	January 01 2001 – September 24 2001	0.285	
June 18 2002	September 25 2001 – June 18 2002	0.204	-28.42
August 13 2002	June 19 2002 – August 13 2002	0.331	62.25
March 13 2003	August 14 2002 – March 13 2003	0.182	-45.02
May 28 2004	March 14 2003 – May 28 2004	0.269	47.80
	May 29 2004 – January 31 2005	0.216	-19.70

Table 6.2(a): Change Points Against the Japanese Yen, (UK Time Zone)

In this table change point indicates the date of a volatility shift, Interval is the date points between which the variance of exchange rate changes was stationary. Standard deviation is the standard deviation of exchange rate changes for the appropriate interval. The % change is the percentage increase or decrease in the standard deviation relative to the previous interval. The critical value of at a 95% level is 1.358.

Change Point	Interval	σx100	% Change
March 03 1995	January 2 1995 – March 03 1995	0.188	
October 03 1995	March 04 1995 – October 03 1995	0.403	114.3617
May 06 1997	October 04 1995 – May 06 1997	0.196	-51.3648
June 13 1997	May 07 1997 – June 13 1997	0.538	174.4898
June 16 1998	June 14 1997 – June 16 1998	0.298	-44.6097
July 03 1998	June 17 1998 - July 03 1998	0.7	134.8993

September 01 1998	July 04 1998 – September 01 1998	0.316	-54.8571
October 09 1998	September 02 1998 – October 09 1998	0.887	180.6962
March 16 1999	October 10 1998 – March 16 1999	0.435	-50.9583
June 12 2000	March 17 1999 – June 12 2000	0.287	-34.023
	June 13 2000 - January 31 2005	0.222	-22.6481

Table 6.2(b): Change Points Against the British Pound, (UK Time Zone)

In this table change point indicates the date of a volatility shift, Interval is the date points between which the variance of exchange rate changes was stationary. Standard deviation is the standard deviation of exchange rate changes for the appropriate interval. The % change is the percentage increase or decrease in the standard deviation relative to the previous interval. The critical value of at a 95% level is 1.358.

Change Point	Interval	σx100	% Change
June 06 1995	January 2 1995 – June 06 1995	0.226	
October 28 1996	June 07 1995 – October 28 1996	0.123	-45.5752
June 21 2002	October 29 1996 – June 21 2002	0.184	49.5935
January 31 2005	June 22 2002 – January 31 2005	0.213	15.76087

Table 6.2(c): Change Points Against the Euro, (UK Time Zone)

In this table change point indicates the date of a volatility shift, Interval is the date points between which the variance of exchange rate changes was stationary. Standard deviation is the standard deviation of exchange rate changes for the appropriate interval. The % change is the percentage increase or decrease in the standard deviation relative to the previous interval. The critical value of at a 95% level is 1.358.

Change Point	Interval	σx100	% Change
May 21 2004	January 01 2001 – May 21 2004	0.251	
	May 22 2004 – January 31 2005	0.191	-23.9044

Table 6.3(a): Change Points Against the Japanese Yen, (ASIA Time Zone)

In this table change point indicates the date of a volatility shift, Interval is the date points between which the variance of exchange rate changes was stationary. Standard deviation is the standard deviation of exchange rate changes for the appropriate interval. The % change is the percentage increase or decrease in the standard deviation relative to the previous interval. The critical value of at a 95% level is 1.358.

Change Point	Interval	σx100	% Change
March 03 1995	January 02 1995 - March 03 1995	0.208	
October 06 1995	March 04 1995 – October 06 1995	0.453	117.79

May 09 1997	October 07 1995 – May 09 1997	0.193	-57.40
June 16 1997	May 10 1997 – June 16 1997	0.499	158.55
June 12 1998	June 17 1997 – June 12 1998	0.28	-43.89
June 19 1998	June 13 1998 – June 19 1998	1.107	295.36
October 07 1998	June 20 1998 – October 07 1998	0.392	-64.59
October 20 1998	October 08 1998 – October 20 1998	1.106	182.14
April 05 1999	October 21 1998 – April 05 1999	0.374	-66.18
June 05 2000	April 06 – 1999 – June 05 2000	0.288	-22.99
	June 06 2000 – January 31 2005	0.233	-19.10

Table 6.3(b): Change Points Against the British Pound, (ASIA Time Zone)

In this table change point indicates the date of a volatility shift, Interval is the date points between which the variance of exchange rate changes was stationary. Standard deviation is the standard deviation of exchange rate changes for the appropriate interval. The % change is the percentage increase or decrease in the standard deviation relative to the previous interval. The critical value of at a 95% level is 1.358.

Change Point	Interval	σx100	% Change
March 03 1995	January 02 1995 – March 03 1995	0.257	
March 15 1995	March 04 1995 – March 15 1995	0.848	229.96
September 27 1995	March 16 1995 – September 27 1995	0.279	-67.10
December 04 1996	September 28 1995 – December 04 1996	0.206	-26.16
December 24 2003	December 05 1996 – December 24 2003	0.293	42.23
	December 25 2003 – January 31 2005	0.969	230.72

Table 6.3(c): Change Points Against the Euro, (ASIA Time Zone)

In this table change point indicates the date of a volatility shift, Interval is the date points between which the variance of exchange rate changes was stationary. Standard deviation is the standard deviation of exchange rate changes for the appropriate interval. The % change is the percentage increase or decrease in the standard deviation relative to the previous interval. The critical value of at a 95% level is 1.358.

Change Point	Interval	σx100	% Change
September 18 2001	January 01 2001 – September 18 2001	0.335	
March 13 2003	September 19 2001 – March 13 2003	0.233	-30.45
May 11 2004	March 14 2003 – May 11 2004	0.321	37.77
	May 12 2004 – January 31 2005	0.238	-25.86

Table 6.4(a): Change Points Quoted Spread JP/US, (US Time Zone)

In this table change point indicates the date of a volatility shift, Interval is the date points between which the variance of exchange rate changes was stationary. Standard deviation is the standard deviation of exchange rate changes for the appropriate interval. The % change is the percentage increase or decrease in the standard deviation relative to the previous interval. The critical value of at a 95% level is 1.358.

Change Point	Interval	σx10,000	% Change
April 26 1996	January 02 1995 – April 26 1996	76.4	
January 09 2002	April 27 1996 – January 09 2002	65.5	-14.27
	January 10 2002 – January 31 2005	53.1	-18.93

Table 6.4(b): Change Points Quoted Spread GB/US, (US Time Zone)

In this table change point indicates the date of a volatility shift, Interval is the date points between which the variance of exchange rate changes was stationary. Standard deviation is the standard deviation of exchange rate changes for the appropriate interval. The % change is the percentage increase or decrease in the standard deviation relative to the previous interval. The critical value of at a 95% level is 1.358.

Change Point	Interval	σx10,000	% Change
April 03 1995	January 02 1995 – April 03 1995	0.567	
July 06 1995	April 04 1995 – July 06 1995	0.855	50.65
December 25 1995	July 07 1995 – December 25 1995	0.514	-39.86
January 08 1996	December 26 1995 – January 08 1996	1.689	228.55
December 25 1996	January 09 1996 – December 25 1996	0.471	-72.11
January 03 1997	December 26 1996 – January 03 1997	5.033	968.23
September 25 1997	January 04 1997 – September 25 1997	0.703	-86.03
January 21 1998	September 26 1997 – January 21 1998	1.066	51.56
November 23 1998	January 22 1998 – November 23 1998	0.649	-39.11
May 18 2000	November 24 1998 – May 18 2000	0.982	51.30
December 24 2001	May 19 2000 – December 24 2001	0.716	-27.06
January 08 2002	December 25 2001 – January 08 2002	2.079	190.29
December 22 2003	January 09 2002 – December 22 2003	0.541	-73.99
January 06 2004	December 23 2003 – January 06 2004	2.029	275.26
August 17 2004	January 07 2004 – August 17 2004	0.376	-81.46
	August 18 2004 – January 31 2005	0.256	-32.01

Table 6.4(c): Change Points Quoted Spread EU/US, (US Time Zone)

In this table change point indicates the date of a volatility shift, Interval is the date points between which the variance of exchange rate changes was stationary. Standard deviation is the standard deviation of exchange rate changes for the appropriate interval. The % change is the percentage increase or decrease in the standard deviation relative to the previous interval. The critical value of at a 95% level is 1.358.

Change Point	Interval	σx10,000	% Change
September 06 2001	January 01 2001 – September 06 2001	0.351	
January 08 2002	September 07 2001 – January 08 2002	0.633	80.27
December 20 2002	January 09 2002 – December 20 2002	0.450	-28.93
January 07 2003	December 21 2002 – January 07 2003	1.180	162.56
April 23 2003	January 08 2003 – April 23 2003	0.570	-51.72
September 23 2003	April 24 2003 – September 23 2003	0.378	-33.75
December 25 2003	September 24 2003 – December 25 2003	0.260	-31.15
January 07 2004	December 26 2003 – January 07 2004	3.544	1263.25
December 24 2004	January 08 2004 – December 24 2004	0.310	-91.25
	December 25 2004 – January 31 2005	0.517	66.69

Table 6.5(a): Change Points Quoted Spread JP/US, (UK Time Zone)

In this table change point indicates the date of a volatility shift, Interval is the date points between which the variance of exchange rate changes was stationary. Standard deviation is the standard deviation of exchange rate changes for the appropriate interval. The % change is the percentage increase or decrease in the standard deviation relative to the previous interval. The critical value of at a 95% level is 1.358.

Change Point	Interval	σx10,000	% Change
May 28 1998	January 02 1995 – May 28 1998	65.70	
December 23 1998	May 29 1998 – December 23 1998	47.70	-27.40
January 04 1999	December 24 1998 – January 04 1999	255.70	436.06
April 07 1999	January 05 1999 – April 07 1999	71.10	-72.19
March 03 2000	April 08 1999 – March 03 2000	53.60	-24.61
May 08 2000	March 04 2000 – May 08 2000	101.90	90.11
December 06 2000	May 09 2000 – December 06 2000	62.40	-38.76
January 03 2001	December 07 2000 – January 03 2001	181.50	190.87
June 21 2001	January 04 2001 – June 21 2001	67.80	-62.64
December 24 2001	June 22 2001 – December 24 2001	47.40	-30.09
January 03 2002	December 25 2001 – January 03 2002	218.30	360.55
December 25 2002	January 04 2002 – December 25 2002	57.40	-73.71
January 09 2003	December 26 2002 – January 09 2003	205.90	258.71
December 25 2003	January 10 2003 – December 25 2003	54.60	-73.48
January 05 2004	December 26 2003 – January 05 2004	186.80	242.12

July 06 2004	January 06 2004 – July 06 2004	32.90	-82.39
	July 07 2004 – January.31.2005	20.50	-37.69

Table 6.5(b): Change Points Quoted Spread GB/US, (UK Time Zone)

In this table change point indicates the date of a volatility shift, Interval is the date points between which the variance of exchange rate changes was stationary. Standard deviation is the standard deviation of exchange rate changes for the appropriate interval. The % change is the percentage increase or decrease in the standard deviation relative to the previous interval. The critical value of at a 95% level is 1.358.

Change Point	Interval	σx10,000	% Change
April 17 1995	January 02 1995 – April 17 1995	0.518	
July 11 1995	April 18 1995 – July 11 1995	0.985	90.15
August 28 1995	July 12 1995 – August 28 1995	0.370	-62.44
September 22 1995	August 29 1995 – September 22 1995	0.671	81.35
December 25 1995	September 23 1995 – December 25 1995	0.304	-54.69
May 20 1996	December 26 1995 – May 20 1996	0.631	107.70
December 24 1997	May 21 1996 – December 24 1997	0.436	-30.91
January 05 1998	December 25 1997 – January 05 1998	2.293	425.69
May 21 1998	January 06 1998 – May 21 1998	0.421	-81.62
June 05 1998	May 22 1998 – June 05 1998	1.068	153.44
December 11 1998	June 06 1998 – December 11 1998	0.351	-67.11
December 29 1998	December 12 1998 – December 29 1998	1.930	449.44
July 19 1999	December 30 1998 – July 19 1999	0.760	-60.62
May 28 2001	July 20 1999 – May 28 2001	0.991	30.42
December 24 2001	May 29 2001 – December 24 2001	0.573	-42.22
January 03 2002	December 25 2001 – January 03 2002	3.115	443.92
March 12 2002	January 04 2002 – March 12 2002	0.455	-85.39
May 22 2002	March 13 2002 – May 22 2002	0.882	93.75
December 25 2002	May 23 2002 – December 25 2002	0.517	-41.38
December 30 2002	December 26 2002 – December 30 2002	6.240	1106.91
December 25 2003	December 31 2002 – December 25 2003	0.469	-92.48
December 30 2003	December 26 2003 – December 30 2003	4.923	949.56
July 19 2004	December 30 2003 – July 19 2004	0.282	-94.27
December 13 2004	July 19 2004 – December 13 2004	0.170	-39.62
	December 14 2004 – January 31 2005	0.319	87.35

Table 6.5(c): Change Points Quoted Spread EU/US, (UK Time Zone)

In this table change point indicates the date of a volatility shift, Interval is the date points between which the variance of exchange rate changes was stationary. Standard deviation is the standard deviation of exchange rate changes for the appropriate interval. The % change is the percentage increase or decrease in the standard deviation relative to the previous interval. The critical value of at a 95% level is 1.358.

Change Point	Interval	σx10,000	% Change
April 04 2002	January 01 2001 – April 04 2002	0.472	
December 24 2002	April 05 2002 – December 24 2002	0.363	-23.06
December 30 2002	December 25 2002 – December 30 2002	2.202	506.4828
February 19 2003	December 31 2002 – February 19 2003	0.501	-77.2313
April 18 2003	February 20 2003 – April 18 2003	0.272	-45.7995
April 23 2003	April 19 2003 – April 23 2003	1.965	623.1175
December 25 2003	April 24 2003 – December 25 2003	0.297	-84.8846
January 05 2004	December 26 2003 – January 05 2004	2.469	731.1725
December 23 2004	January 06 2004 – December 23 2004	0.250	-89.8603
	December 24 2004 – January 31 2005	0.434	73.52463

Table 6.6(a): Change Points Quoted Spread JP/US, (ASIA Time Zone)

In this table change point indicates the date of a volatility shift, Interval is the date points between which the variance of exchange rate changes was stationary. Standard deviation is the standard deviation of exchange rate changes for the appropriate interval. The % change is the percentage increase or decrease in the standard deviation relative to the previous interval. The critical value of at a 95% level is 1.358.

Change Point	Interval	σx10,000	% Change
October 03 1995	January 02 1995 – October 03 1995	0.629	
November 04 1996	October 04 1995 – November 04 1996	0.518	-17.65
September 25 1997	November 05 1996 – September 25 1997	0.955	84.23
January 27 2000	September 26 1997 – January 27 2000	0.810	-15.21
May 30 2001	January 28 2000 – May 30 2001	0.820	1.28
August 17 2001	May 31 2001 – August 17 2001	0.632	-22.93
May 02 2002	August 18 2001 – May 02 2002	0.680	7.63
January 17 2003	May 03 2002 – January 17 2003	0.504	-25.97
October 27 2003	January 18 2003 – October 27 2003	0.520	3.31
	October 28 2003 – January 31 2005	0.590	13.32

Table 6.6(b): Change Points Quoted Spread GB/US, (ASIA Time Zone)

In this table change point indicates the date of a volatility shift, Interval is the date points between which the variance of exchange rate changes was stationary. Standard deviation is the standard deviation of exchange rate changes for the appropriate interval. The % change is the percentage increase or decrease in the standard deviation relative to the previous interval. The critical value of at a 95% level is 1.358.

Change Point	Interval	σx10,000	% Change
January 17 1995	January 02 1995 – January 17 1995	0.344	
March 03 1995	January 18 1995 – March 03 1995	0.188	-45.16
April 21 1995	March 04 1995 – April 21 1995	0.543	188.24
January 12 1996	April 22 1995 – January 12 1996	0.283	-47.93
January 22 1998	January 13 1996 – January 22 1998	0.242	-14.58
October 07 1998	January 23 1998 – October 07 1998	0.181	-24.92
June 08 1999	October 08 1998 – June 08 1999	0.285	57.33
August 10 1999	June 09 1999 – August 10 1999	0.425	48.82
December 10 1999	August 11 1999 – December 10 1999	0.211	-50.32
May 29 2000	December 11 1999 – May 29 2000	0.418	98.17
March 01 2001	May 30 2000 – March 01 2001	0.314	-25.01
December 24 2001	March 02 2001 – December 24 2001	0.248	-20.88
January 03 2002	December 25 2001 – January 03 2002	0.876	253.34
December 23 2002	January 04 2002 – December 23 2002	0.179	-79.54
April 29 2003	December 24 2002 – April 29 2003	0.306	70.85
February 19 2004	April 30 2003 – February 19 2004	0.228	-25.60
December 06 2004	February 20 2004 – December 06 2004	0.125	-45.11
	December 07 2004 – January 31 2005	0.197	57.90

Table 6.6(c): Change Points Quoted Spread EU/US, (ASIA Time Zone)

In this table change point indicates the date of a volatility shift, Interval is the date points between which the variance of exchange rate changes was stationary. Standard deviation is the standard deviation of exchange rate changes for the appropriate interval. The % change is the percentage increase or decrease in the standard deviation relative to the previous interval. The critical value of at a 95% level is 1.358.

Change Point	Interval	σx10,000	% Change
September 06 2001	January 01 2001 – September 06 2001	0.351	
January 08 2002	September 07 2001 – January 08 2002	0.633	80.27
December 20 2002	January 09 2002 – December 20 2002	0.450	-28.93
January 07 2003	December 21 2002 – January 07 2003	1.180	162.56
April 23 2003	January 08 2003 – April 23 2003	0.570	-51.72
September 23 2003	April 24 2003 – September 23 2003	0.378	-33.75
December 25 2003	September 24 2003 – December 25 2003	0.260	-31.15

January 07 2004	December 26 2003 – January 07 2004	3.544	1263.25
December 24 2004	January 08 2004 – December 24 2004	0.310	-91.25
	December 25 2004 – January 31 2005	0.517	66.69

Table 6.7(a): Change Points Relative Spread JP/US, (US Time Zone)

In this table change point indicates the date of a volatility shift, Interval is the date points between which the variance of exchange rate changes was stationary. Standard deviation is the standard deviation of exchange rate changes for the appropriate interval. The % change is the percentage increase or decrease in the standard deviation relative to the previous interval. The critical value of at a 95% level is 1.358.

Change Point	Interval	σx10,000	% Change
June 06 1995	January 02 1995 – June 06 1995	0.408	
April 26 1996	June 07 1995 – April 26 1996	0.318	-22.07
November 11 1998	April 27 1996 – November 11 1998	0.219	-31.07
January 06 1999	November 12 1998 – January 06 1999	0.428	95.17
December 21 1999	January 07 1999 – December 21 1999	0.229	-46.57
May 18 2000	December 22 1999 – May 18 2000	0.350	52.89
January 09 2002	May 19 2000 – January 09 2002	0.240	-31.30
June 30 2003	January 10 2002 – June 30 2003	0.192	-20.19
January 05 2004	July 01 2003 – January 05 2004	0.293	52.89
April 27 2004	January 06 2004 – April 27 2004	0.188	-35.78
	April 28 2004 – January 31 2005	0.132	-30.10

Table 6.7(b): Change Points Relative Spread GB/US, (US Time Zone)

In this table change point indicates the date of a volatility shift, Interval is the date points between which the variance of exchange rate changes was stationary. Standard deviation is the standard deviation of exchange rate changes for the appropriate interval. The % change is the percentage increase or decrease in the standard deviation relative to the previous interval. The critical value of at a 95% level is 1.358.

Change Point	Interval	σx10,000	% Change
April 03 1995	January 02 1995 - April 03 1995	0.159	
July 06 1995	April 04 1995 – July 06 1995	0.235	47.82
December 25 1995	July 07 1995 – December 25 1995	0.143	-39.30
January 08 1996	December 26 1995 – January 08 1996	0.476	234.07
December 25 1996	January 09 1996 – December 25 1996	0.132	-72.29
January 03 1997	December 26 1996 - January 03 1997	1.300	884.59
September 25 1997	January 04 1997 – September 25 1997	0.188	-85.55
January 211998	September 26 1997 – January 21 1998	0.280	48.88
August 07 1998	January 22 1998 – August 07 1998	0.153	-45.20
March 22 1999	August 08 1998 – March 22 1999	0.220	43.58

January 11 2000	March 23 1999 – January 11 2000	0.289	31.55
December 24 2001	January 12 2000 – December 24 2001	0.218	-24.52
January 08 2002	December 25 2001 – January 08 2002	0.628	187.46
December 23 2003	January 09 2002 – December 23 2003	0.152	-75.86
January 06 2004	December 24 2003 – January 06 2004	0.522	244.25
August 17 2004	January 07 2004 – August 17 2004	0.090	-82.67
	August 18 2004 – January 31 2005	0.060	-33.37

Table 6.7(c): Change Points Relative Spread EU/US, (US Time Zone)

In this table change point indicates the date of a volatility shift, Interval is the date points between which the variance of exchange rate changes was stationary. Standard deviation is the standard deviation of exchange rate changes for the appropriate interval. The % change is the percentage increase or decrease in the standard deviation relative to the previous interval. The critical value of at a 95% level is 1.358.

Change Point	Interval	σx10,000	% Change
August 02 2001	January 01 2001 – August 02 2001	0.170	
September 13 2001	August 03 2001 – September 13 2001	0.383	125.04
December 21 2001	September 14 2001 – December 21 2001	0.177	-53.85
January 08 2002	December 22 2001 – January 08 2002	0.622	252.12
December 20 2002	January 09 2002 – December 20 2002	0.220	-64.62
January 07 2003	December 21 2002 – January 07 2003	0.528	139.85
April 23 2003	January 08 2003 – April 23 2003	0.246	-53.40
September 23 2003	April 24 2003 – September 23 2003	0.154	-37.56
December 25 2003	September 24 2003 – December 25 2003	0.099	-35.33
January 07 2004	December 26 2003 – January 07 2004	1.314	1222.98
	January 08 2004 – January 31 2005	0.123	-90.64

Table 6.8(a): Change Points Relative Spread JP/US, (UK Time Zone)

In this table change point indicates the date of a volatility shift, Interval is the date points between which the variance of exchange rate changes was stationary. Standard deviation is the standard deviation of exchange rate changes for the appropriate interval. The % change is the percentage increase or decrease in the standard deviation relative to the previous interval. The critical value of at a 95% level is 1.358.

Change Point	Interval	σx10,000	% Change
August 04 1995	January 02 1995 - August 04 1995	0.359	
April 14 1998	August 05 1995 – April 14 1998	0.244	-31.84
December 23 1998	April 15 1998 – December 23 1998	0.172	-29.51
January 22 1999	December 24 1998 – January 22 1999	0.611	254.94
March 03 2000	January 23 1999 – March 03 2000	0.222	-63.62
May 08 2000	March 04 2000 – May 08 2000	0.419	88.33

December 06 2000	May 09 2000 – December 06 2000	0.252	-39.86
February 27 2001	December 07 2000 – February 27 2001	0.458	81.95
December 25 2002	February 28 2001 – December 25 2002	0.214	-53.28
January 09 2003	December 26 2002 – January 09 2003	0.744	247.60
December 11 2003	January 10 2003 – December 11 2003	0.204	-72.60
January 06 2004	December 12 2003 – January 06 2004	0.693	239.84
July 06 2004	January 07 2004 – July 06 2004	0.135	-80.59
December 24 2004	July 07 2004 - December 24 2004	0.071	-47.08
	December 25 2004 – January 31 2005	0.126	77.35

Table 6.8(b): Change Points Relative Spread GB/US, (UK Time Zone)

In this table change point indicates the date of a volatility shift, Interval is the date points between which the variance of exchange rate changes was stationary. Standard deviation is the standard deviation of exchange rate changes for the appropriate interval. The % change is the percentage increase or decrease in the standard deviation relative to the previous interval. The critical value of at a 95% level is 1.358.

Change Point	Interval	σx10,000	% Change
April 17 1995	January 02 1995 – April 17 1995	0.142	
July 11 1995	April 18 1995 – July 11 1995	0.269	90.31
August 28 1995	July 12 1995 – August 28 1995	0.103	-61.91
September 22 1995	August 29 1995 – September 22 1995	0.184	79.14
December 25 1995	September 23 1995 – December 25 1995	0.085	-53.84
January 03 1996	December 26 1996 – January 03 1996	0.446	425.28
September 03 1996	January 04 1996 – September 03 1996	0.141	-68.24
December 24 1997	September 04 1996 – December 24 1997	0.114	-19.66
January 05 1998	December 25 1997 – January 05 1998	0.605	432.59
December 25 1998	January 06 1998 – December 25 1998	0.119	-80.39
June 04 2001	December 26 1998 – June 04 2001	0.272	129.08
December 24 2001	June 05 2001 - December 24 2001	0.170	-37.67
January 04 2001	December 25 2001 – January 04 2001	0.889	424.27
December 25 2002	January 05 2001 – December 25 2002	0.174	-80.46
December 30 2002	December 26 2002 – December 30 2002	1.700	879.23
April 25 2003	December 31 2002 – April 25 2003	0.149	-91.23
December 25 2003	April 26 2003 – December 25 2003	0.113	-24.01
December 30 2003	December 26 2003 – December 30 2003	1.205	962.89
July 17 2004	December 31 2003 – July 17 2004	0.069	-94.28
December 13 2004	July 18 2004 – December 13 2004	0.041	-40.37
	December 14 2004 – January 31 2005	0.072	75.52

Table 6.8(c): Change Points Relative Spread EU/US, (UK Time Zone)

In this table change point indicates the date of a volatility shift, Interval is the date points between which the variance of exchange rate changes was stationary. Standard deviation is the standard deviation of exchange rate changes for the appropriate interval. The % change is the percentage increase or decrease in the standard deviation relative to the previous interval. The critical value of at a 95% level is 1.358.

Change Point	Interval	σx10,000	% Change
April 04 2002	January 01 2001 – April 04 2002	0.246	
December 24 2002	April 05 2002 – December 24 2002	0.175	-29.12
December 30 2002	December 25 2002 – December 30 2002	0.996	469.94
February 19 2003	December 31 2002 – February 19 2003	0.217	-78.17
April 18 2003	February 20 2003 – April 18 2003	0.118	-45.56
April 23 2003	April 19 2003 – April 23 2003	0.836	606.30
December 25 2003	April 24 2003 – December 25 2003	0.118	-85.84
January 06 2004	December 26 2003 – January 06 2004	0.843	612.86
	January 07 2004 – 31 January 2005	0.099	-88.22

Table 6.9(a): Change Points Relative Spread JP/US, (ASIA Time Zone)

In this table change point indicates the date of a volatility shift, Interval is the date points between which the variance of exchange rate changes was stationary. Standard deviation is the standard deviation of exchange rate changes for the appropriate interval. The % change is the percentage increase or decrease in the standard deviation relative to the previous interval. The critical value of at a 95% level is 1.358.

Change Point	Interval	σx10,000	% Change
April 18 1995	January 02 1995 – April 18 1995	0.836	
October 28 1997	April 19 1995 – October 28 1997	0.206	-75.32
July 13 1998	October 29 – July 13 1998	0.291	40.87
April 07 2000	July 14 1998 – April 07 2000	0.221	-23.95
January 30 2001	April 08 2000 – January 30 2001	0.146	-34.04
September 12 2001	January 31 2001 – September 12 2001	0.258	77.22
September 26 2001	September 13 2001 – September 26 2001	0.830	221.08
December 24 2001	September 27 2001 – December 24 2001	0.158	-80.90
January 03 2002	December 25 2001 – January 03 2002	0.602	280.02
March 29 2002	January 04 2002 – March 29 2002	0.182	-69.72
May 23 2002	March 30 2002 – May 23 2002	0.306	68.04
January 06 2004	May 24 2002 – January 06 2004	0.167	-45.35
	January 07 2004 – 31 January 2005	0.064	-61.67

Table 6.9(b): Change Points Relative Spread GB/US, (ASIA Time Zone)

In this table change point indicates the date of a volatility shift, Interval is the date points between which the variance of exchange rate changes was stationary. Standard deviation is the standard deviation of exchange rate changes for the appropriate interval. The % change is the percentage increase or decrease in the standard deviation relative to the previous interval. The critical value of at a 95% level is 1.358.

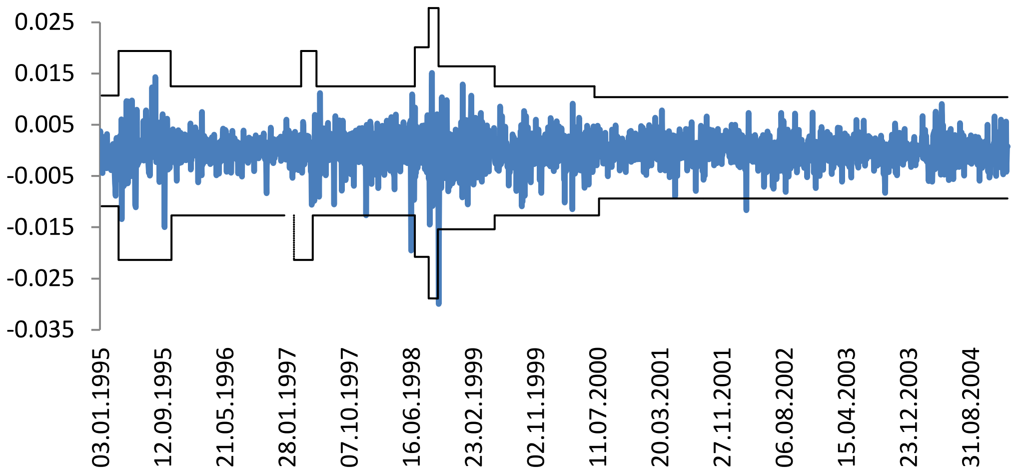
Change Point	Interval	σx10,000	% Change
December 24 1998	January 02 1995 – December 24 1998	2043.6	
December 25 2000	December 25 1998 – December 25 2000	2390	16.95
	December 26 2000 – January 31 2005	2429.2	1.64

Table 6.9(c): Change Points Relative Spread EU/US, (ASIA Time Zone)

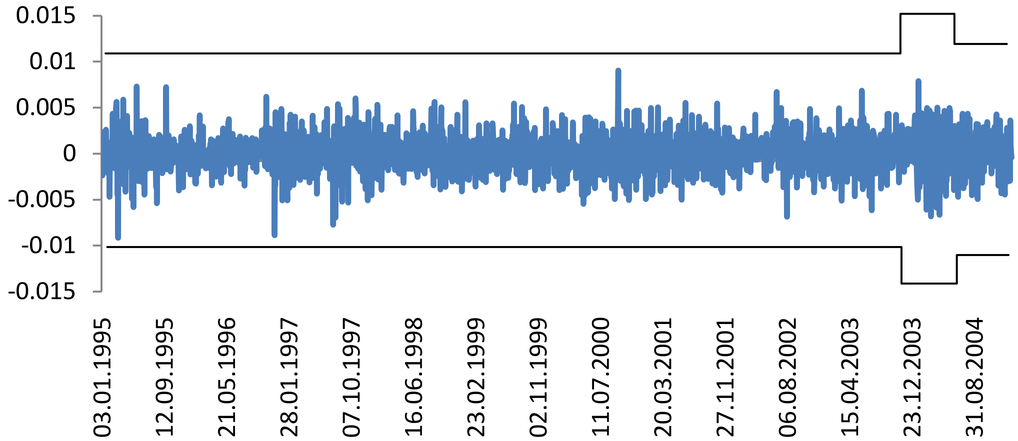
In this table change point indicates the date of a volatility shift, Interval is the date points between which the variance of exchange rate changes was stationary. Standard deviation is the standard deviation of exchange rate changes for the appropriate interval. The % change is the percentage increase or decrease in the standard deviation relative to the previous interval. The critical value of at a 95% level is 1.358.

Change Point	Interval	σx10,000	% Change
August 03 2001	January 01 2001 – August 03 2001	0.171	
March 26 2003	August 04 2001 – March 26 2003	0.301	76.04
December 29 2003	March 27 2003 – December 29 2003	0.178	-40.75
January 08 2004	December 30 2003 – January 08 2004	1.188	566.90
	January 09 2004 – January 31 2005	0.111	-90.64

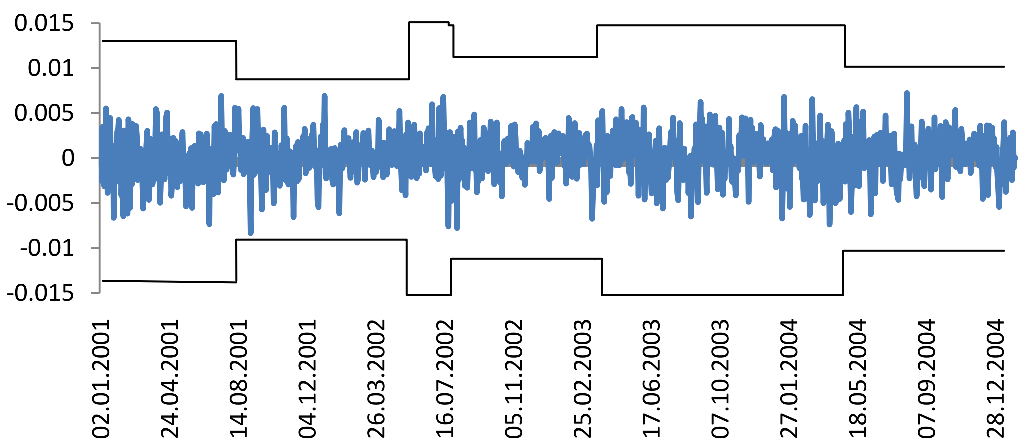
Graph 6.1(a): Change Points Against the Japanese Yen, (US Time Zone)



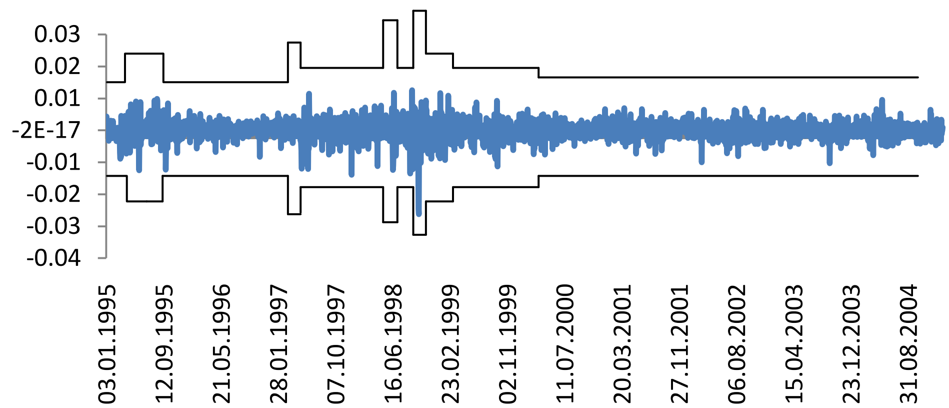
Graph 6.1(b): Change Points Against the British Pound, (US Time Zone)



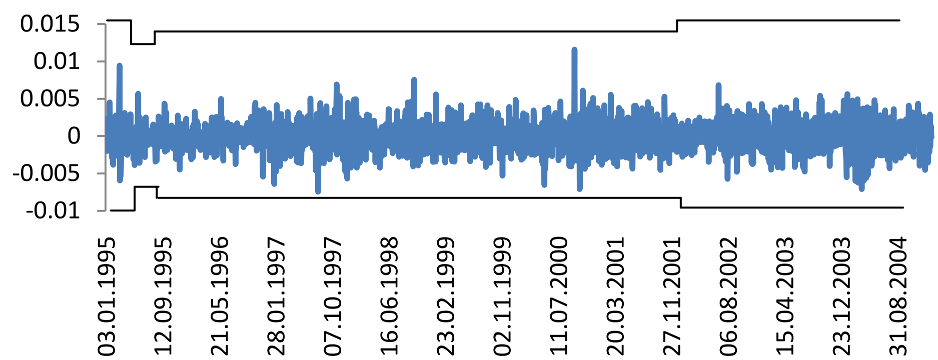
Graph 6.1(c): Change Points Against the Euro, (US Time Zone)



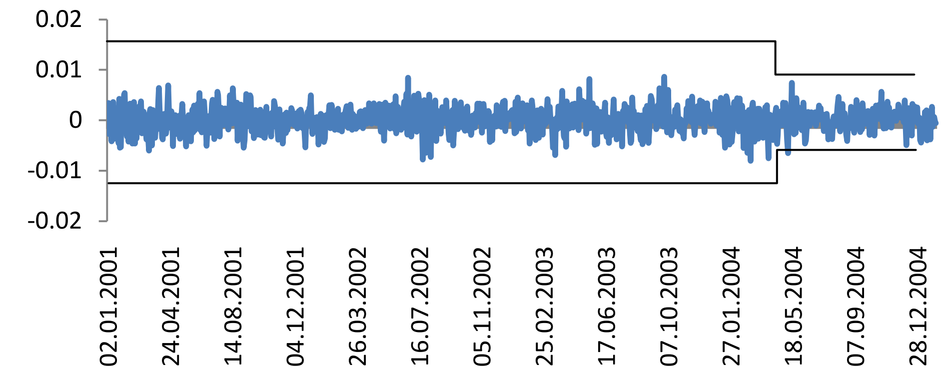
Graph 6.2(a): Change Points Against the Japanese Yen, (UK Time Zone)



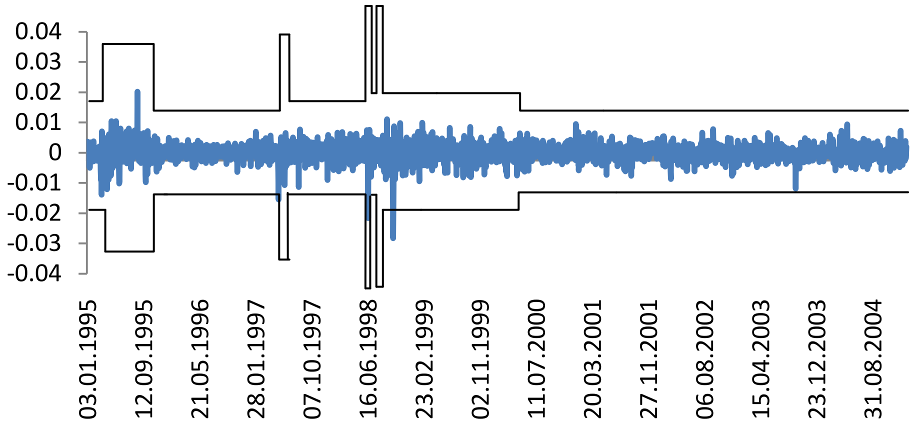
Graph 6.2(b): Change Points Against the British Pound, (UK Time Zone)



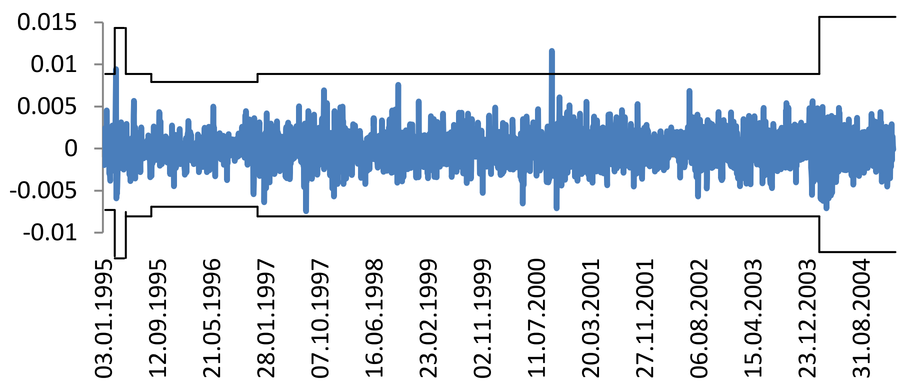
Graph 6.2(c): Change Points Against the Euro, (UK Time Zone)



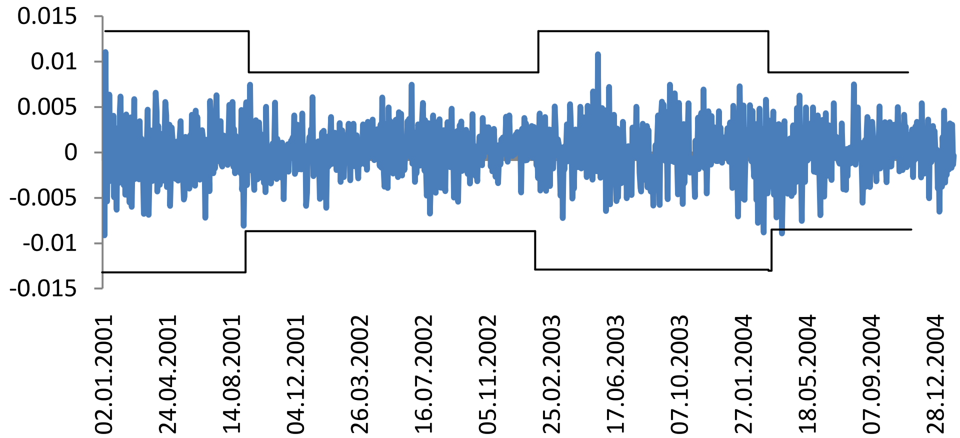
Graph 6.3(a): Change Points Against the Japanese Yen, (ASIA Time Zone)



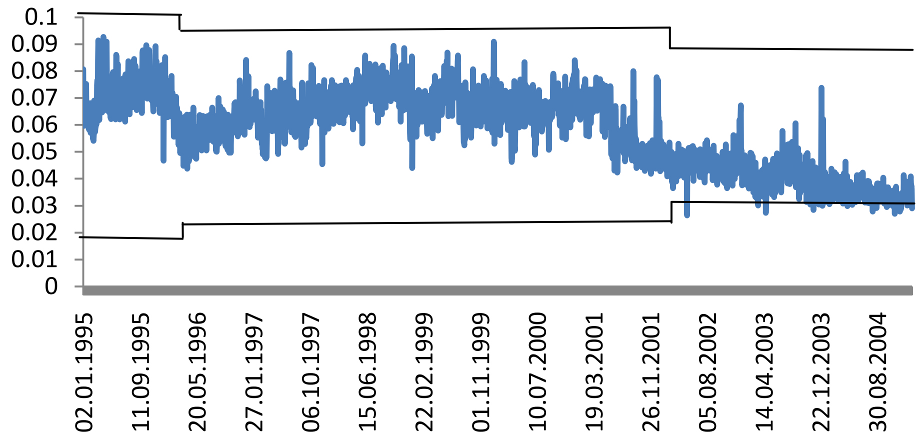
Graph 6.3(b): Change Points Against the British Pound, (ASIA Time Zone)



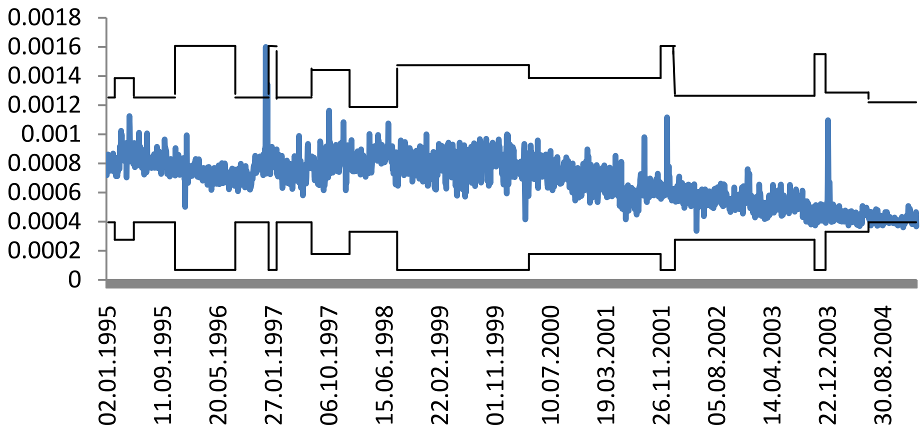
Graph 6.3(c): Change Points Against the Euro, (ASIA Time Zone)



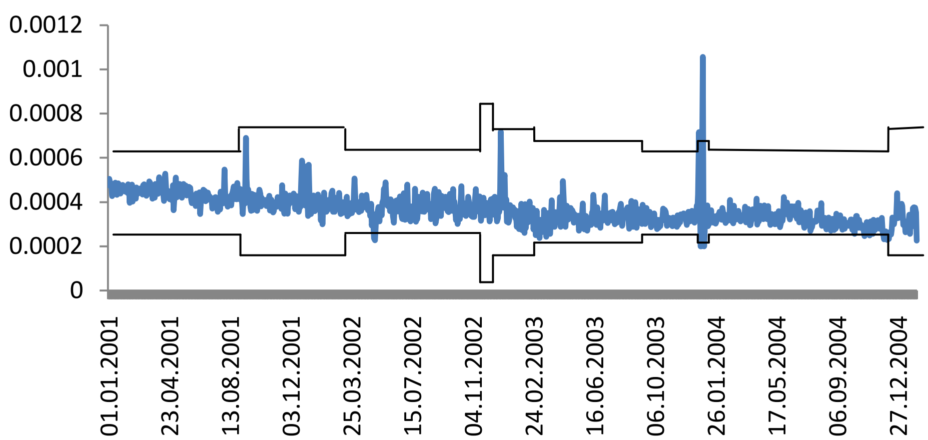
Graph 6.4(a): Change Points Quoted Spread JP/US, (US Time Zone)



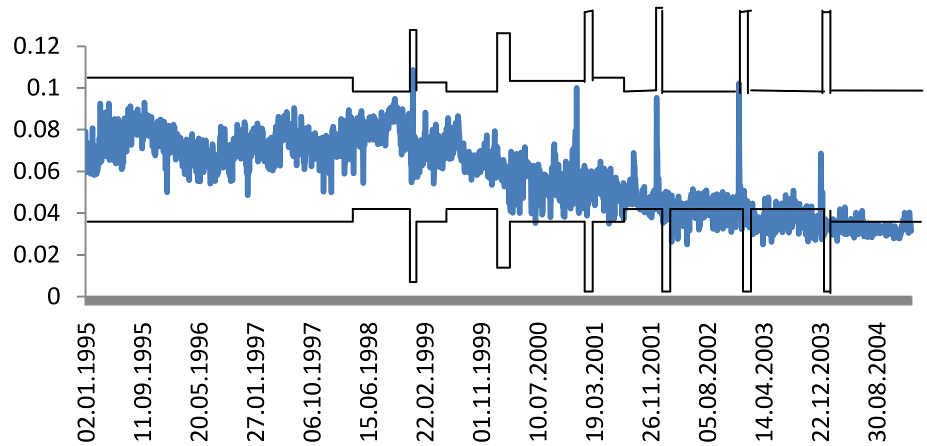
Graph 6.4(b): Change Points Quoted Spread GB/US, (US Time Zone)



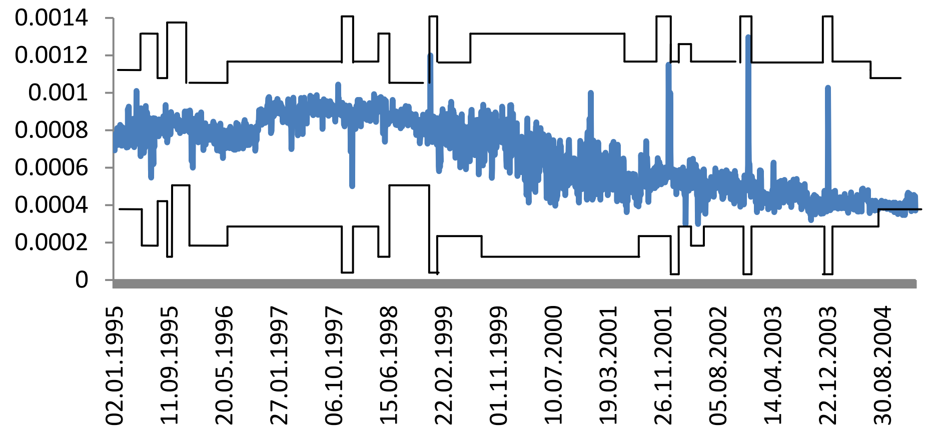
Graph 6.4(c): Change Points Quoted Spread EU/US, (US Time Zone)



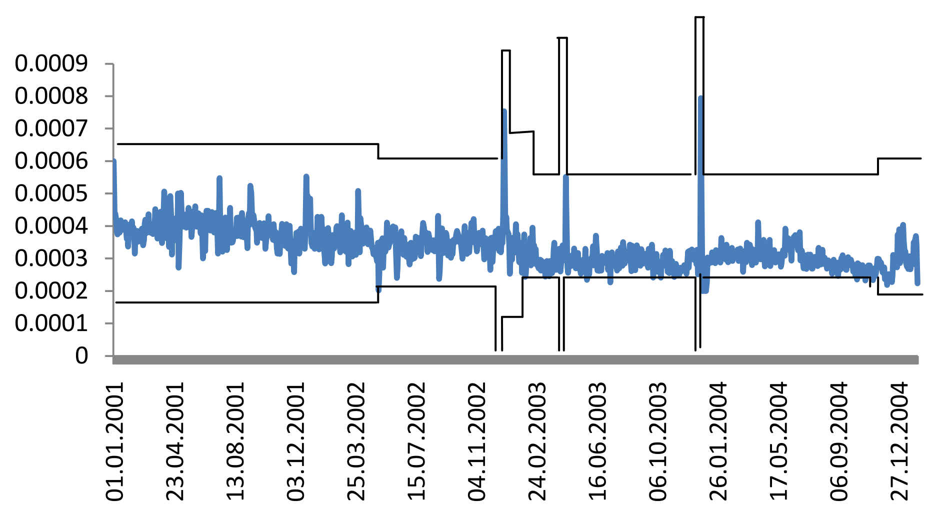
Graph 6.5(a): Change Points Quoted Spread JP/US, (UK Time Zone)



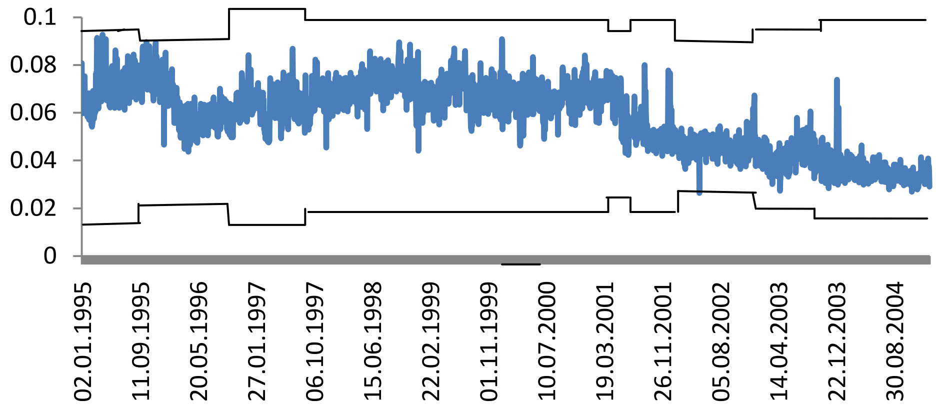
Graph 6.5(b): Change Points Quoted Spread GB/US, (UK Time Zone)



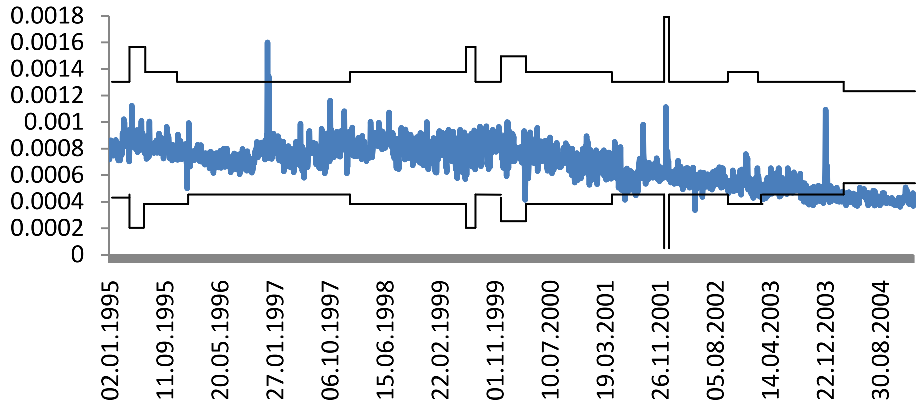
Graph 6.5(c): Change Points Quoted Spread EU/US, (UK Time Zone)



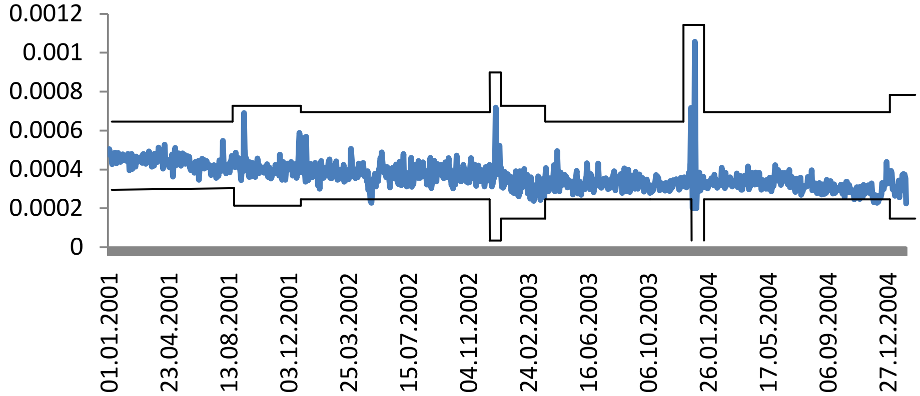
Graph 6.6(a): Change Points Quoted Spread JP/US, (ASIA Time Zone)



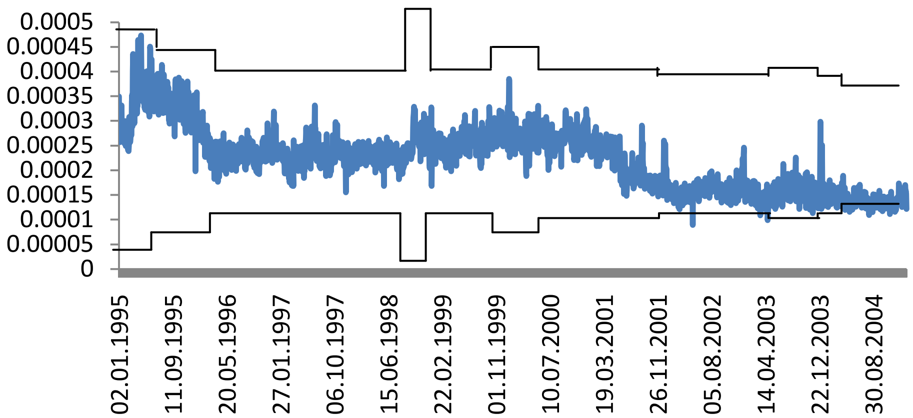
Graph 6.6(b): Change Points Quoted Spread GB/US, (ASIA Time Zone)



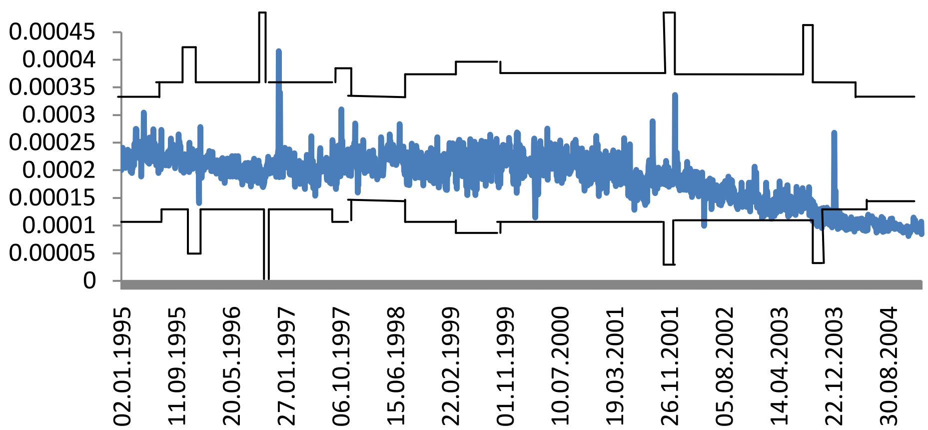
Graph 6.6(c): Change Points Quoted Spread EU/US, (ASIA Time Zone)



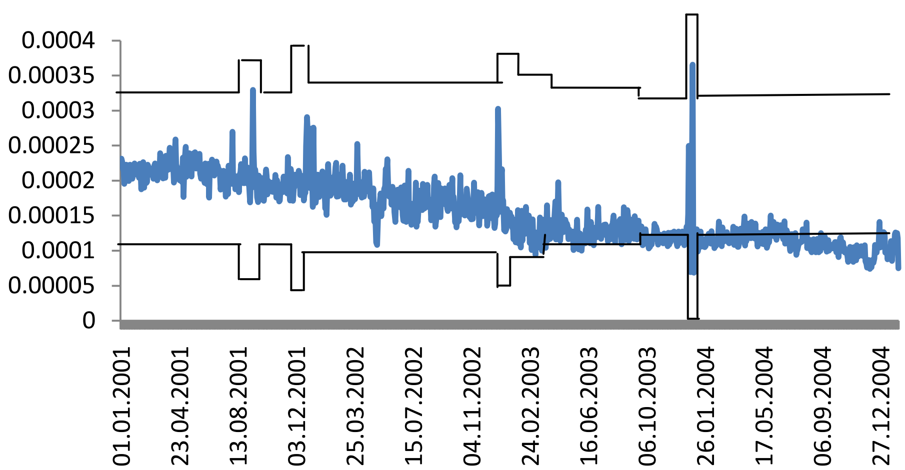
Graph 6.7(a): Change Points Relative Spread JP/US, (US Time Zone)



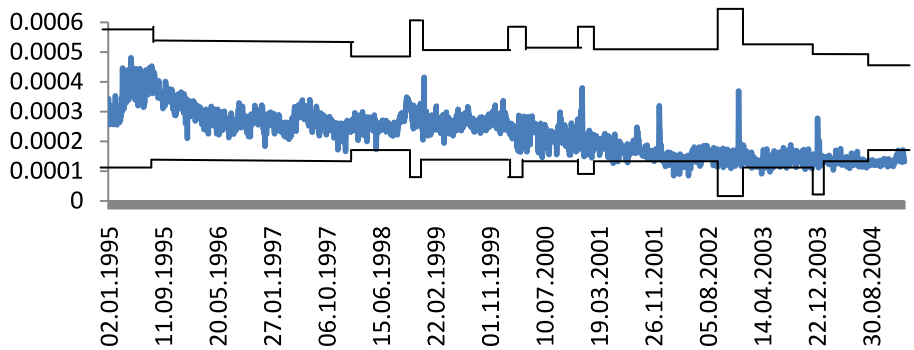
Graph 6.7(b): Change Points Relative Spread GB/US, (US Time Zone)



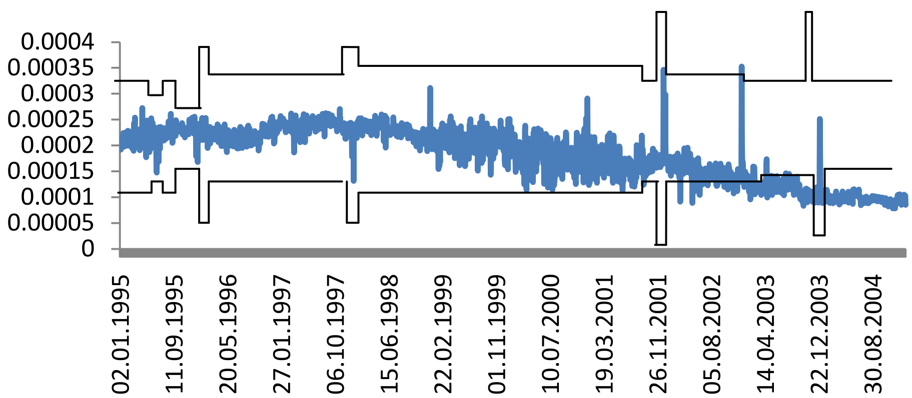
Graph 6.7(c): Change Points Relative Spread EU/US, (US Time Zone)



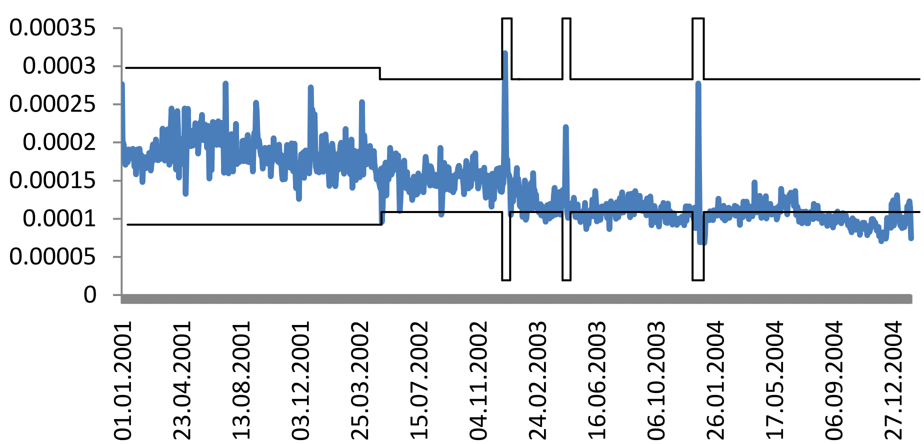
Graph 6.8(a): Change Points Relative Spread JP/US, (UK Time Zone)



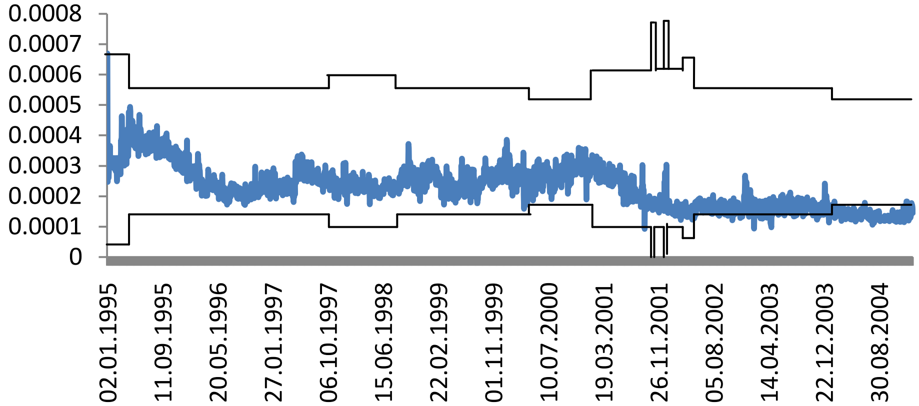
Graph 6.8(b): Change Points Relative Spread GB/US, (UK Time Zone)



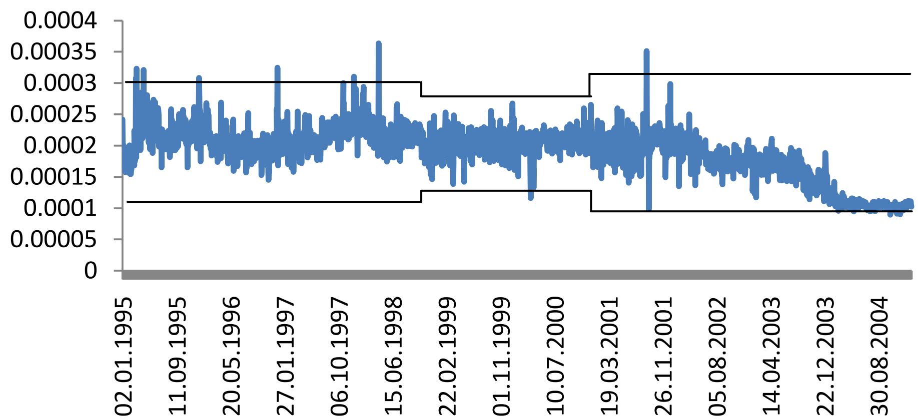
Graph 6.8(c): Change Points Relative Spread EU/US, (UK Time Zone)



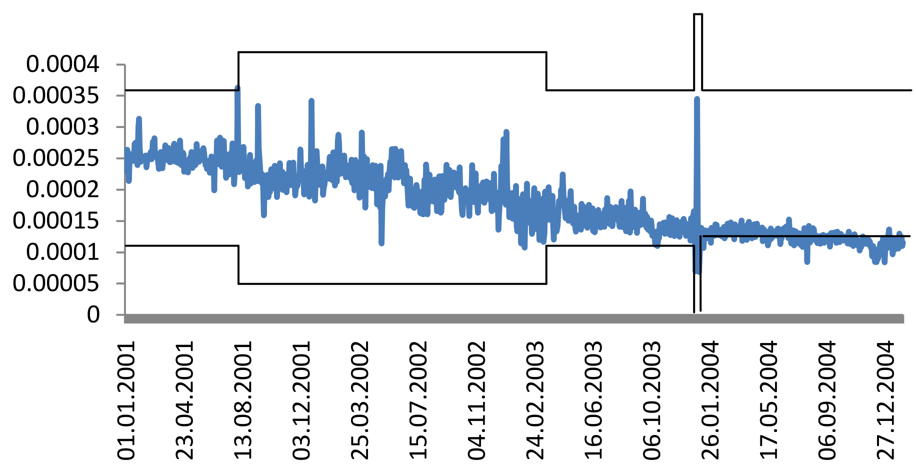
Graph 6.9(a): Change Points Relative Spread JP/US, (ASIA Time Zone)



Graph 6.9(b): Change Points Relative Spread GB/US, (ASIA Time Zone)



Graph 6.9(c): Change Points Relative Spread EU/US, (ASIA Time Zone)



Section 6.5: Exchange rates variance changes, Intraday Sample

Empirical studies of equity markets show that there are U-shaped patterns for returns, trading volume and volatility within each day. The patterns are much less clear for the FX market because it is a 24-hour market, although there is evidence of daily waves of activity as the three major FX markets open and close and trading activity moves from one geographical area to the other. I apply the ICSS algorithm of Inclan and Tiao (1994) to each exchange rate series (standard errors were used in the estimation process obtained from a GARCH[1,1] model) and as expected I find evidence of a very large number of volatility shifts associated with each exchange rate.

Table 6.10 provides the number of volatility shifts for JP/US, GB/US and EU//US exchange rates in US, UK and ASIA time zones for the full intraday sample. The greatest numbers of change points occurs for the GB/US exchange rate, in all three time zones. The highest is observed in the UK time zone, where the GB/US exchange rate reached 1447 volatility shifts from 01.01.1995 to 31.01.2005. The lowest number of change points, occurs for the EU/US exchange rate in the Asia time zone but we need to consider that the EU/US exchange rate was in place only for four years in the sample. Graphs 6.10(a,b,c), 6.11(a,b,c) and 6.12(a,b,c) show the number of volatility shifts during different times of the day as captured by the 36 15-minute intervals during my active trading day. Graphs 6.13(a,b,c), 6.13(a,b,c) and 6.15(a,b,c) show how many times volatility increased/decreased during a particular quarter-hour interval allowing to identify periods where volatility tends to increase or decrease during the day. In all graphs, Interval 1, refers to 8:00-8:15am and interval 36 to 4:45-5:00pm during weekdays. Overall, for all three currency pairs and in all time zones we can see a similar general pattern regarding the relationship between the time of day and the number of volatility change points. The number of change points is considerably higher as dealers enter and exit the market (higher uncertainty of the "true" price due to asymmetric information). In particular, the highest change points occur in the first and last three 15-minute intervals. Of course in all cases, interval 1 has the most volatility shifts as this captures the close (5pm) and opening (8am) of my active trading day and the first 45 minutes of the day. My findings further support previous studies of Baillie and Bollerslev (1990), Hsieh and Kleidon (1996) and Goodhart and Giugale (1993) who report that FX volatility increases as markets open and close. Apart from this general pattern, we can observe another commonality in the pattern of the number of volatility shifts for the GB/US and the EU/US in the US, where the number of volatility shifts are high between interval 9 and 21. Moreover, when we look at the UK time zone, we see a steady increase of the change points from the middle of the day towards the end for the GB/US and the EU/US exchange rates.

Regarding increases/decreases of volatility during the day, we can see that there are considerably more volatility increases than decreases in the first interval for all currency pairs, in the US time zone (for example, volatility increased 360 times and decreases 150 times, approximately, for the JP/US). For the rest of the day and till around period 30 (3.30pm), volatility decreases. The number of volatility decreases per interval is higher than the number of volatility increases (in most cases). This is in line with Dockling, Kawaller and Koch (1999) who find that volatility declines during the day. Volatility tends to increase again as dealers exit the market and especially during the last few periods (4.15-5.00pm); this may reflect necessary dealer inventory adjustments and supports further the U-shaped volatility pattern. In contrast to the US time zone, volatility decreases are more than volatility increases in the UK time zone in the first interval. The general pattern is that more volatility decreases occur during the first half of the day, followed by more volatility increases during the second half of the day and in most cases reach a peak in the last few intervals. The pattern in the Asia time zone is similar to the UK time zone.

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Table 6.10: Number of Volatility Shifts, Exchange Rates

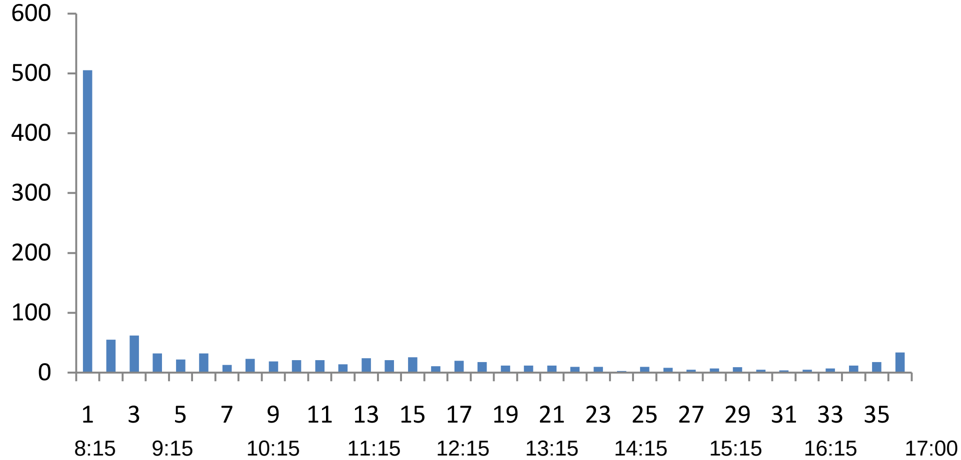
This table indicates the number of change points for yen/dollar, pound/dollar and euro/dollar exchange rates in different time zones (US, UK, ASIA). The full intraday sample extends from 01.01.1995 to 31.01.2005 (for the EU/US from 01.01.2001 to 31.01.2005). The critical value at a 95% level is 1.358.

US			UK			ASIA		
JP/US	GB/US	EU/US	JP/US	GB/US	EU/US	JP/US	GB/US	EU/US
1108	1233	463	1318	1447	521	877	1006	242

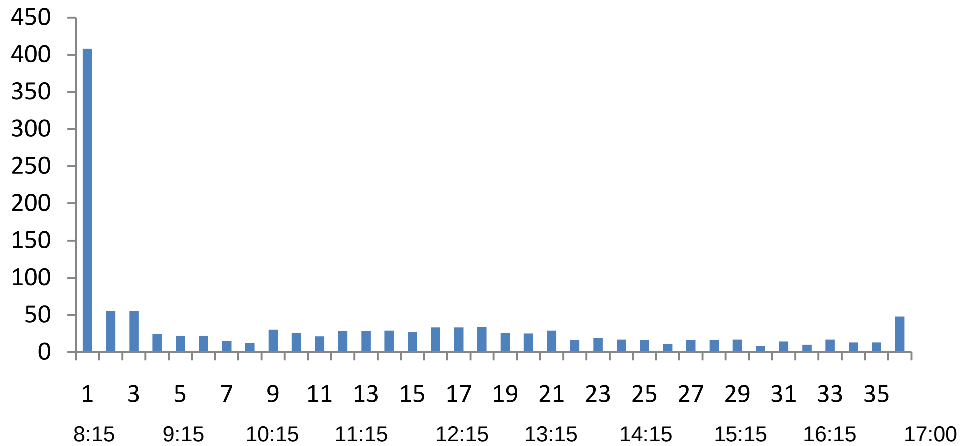
Graphs 6.10 (a,b,c) to 6.12 (a,b,c)

Intraday quarter-hour intervals were calculated based on the last bid-ask quotes recorded at 5-minute intervals, between 8:00am and 5:00pm local time, obtained from Olsen. For the JP/US and the GB/US the full sample extends from 01.01.1995 to 31.01.2005. For the EU/US exchange rate the sample is from 01.01.2001 to 31.01 2005. Interval 1 covers the trading quarter between 8:00am-8:15am and interval 36 4:45pm to 5:00pm

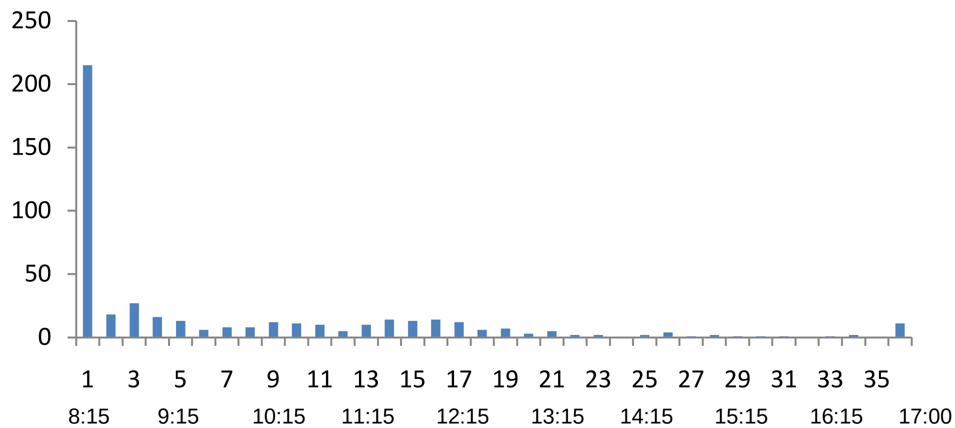
Graph 6.10(a): Number of Volatility Shifts per 15-minite interval (1-36), JP/US Exchange Rate, US Time zone



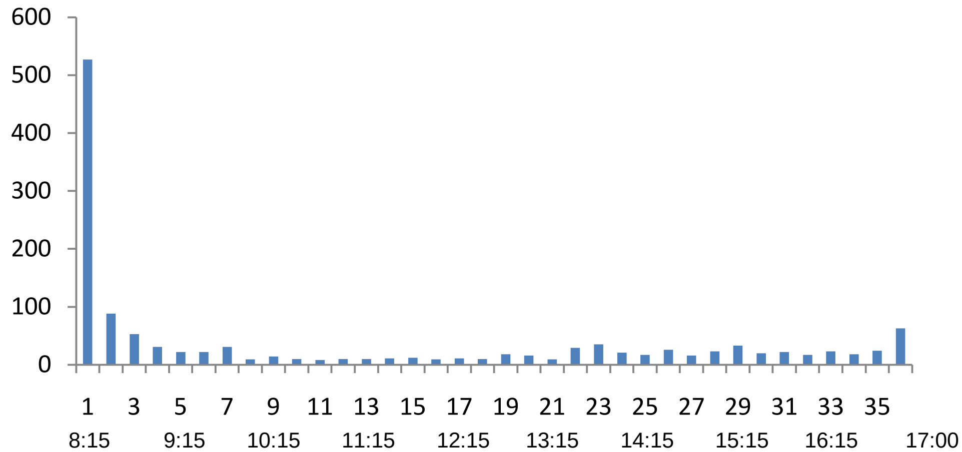
Graph 6.10(b): Number of Volatility Shifts per 15-minite interval (1-36), GB/US Exchange Rate, US Time zone



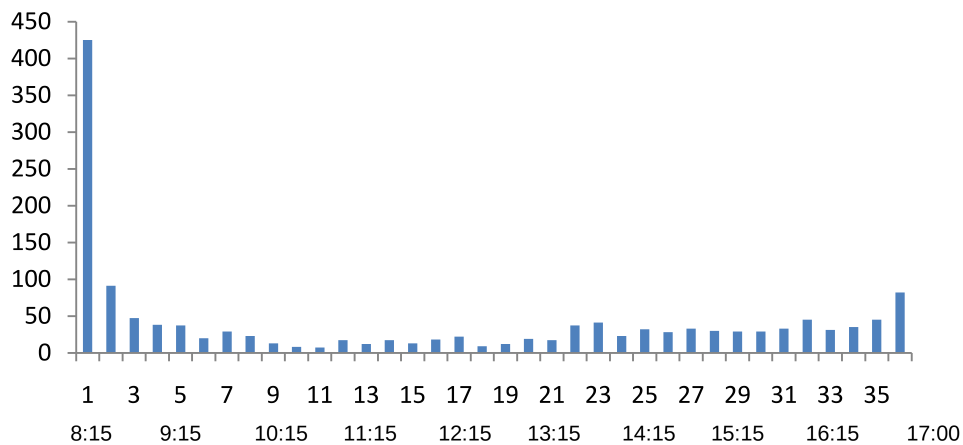
Graph 6.10(c): Number of Volatility Shifts per 15-minite interval (1-36), EU/US Exchange Rate, US Time zone



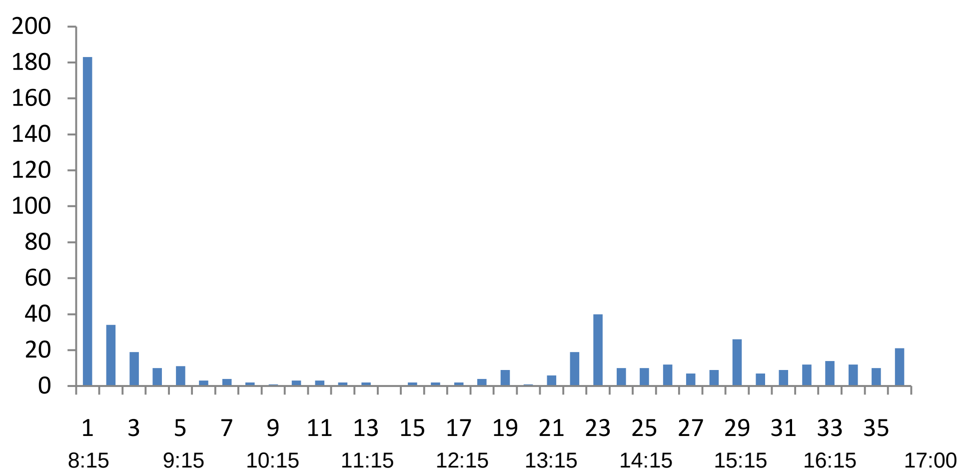
Graph 6.11(a): Number of Volatility Shifts per 15-minite interval (1-36), JP/US Exchange Rate, UK Time zone



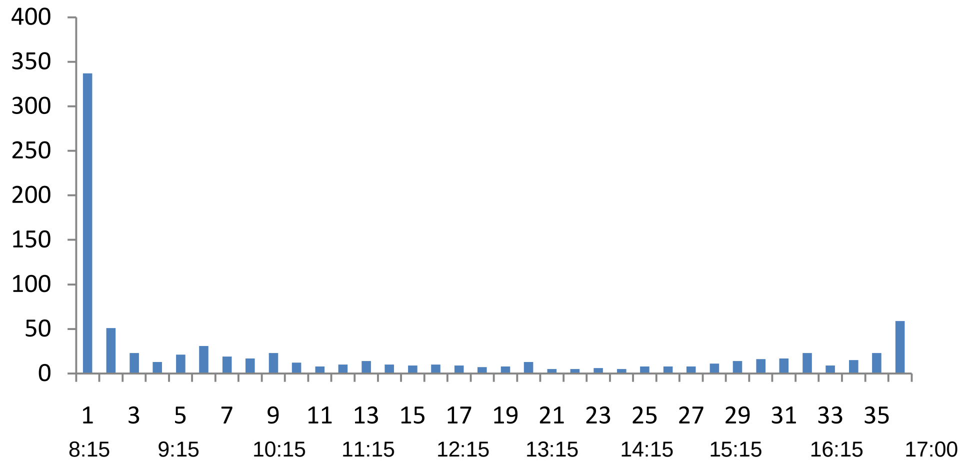
Graph 6.11(b): Number of Volatility Shifts per 15-minite interval (1-36), GB/US Exchange Rate, UK Time zone



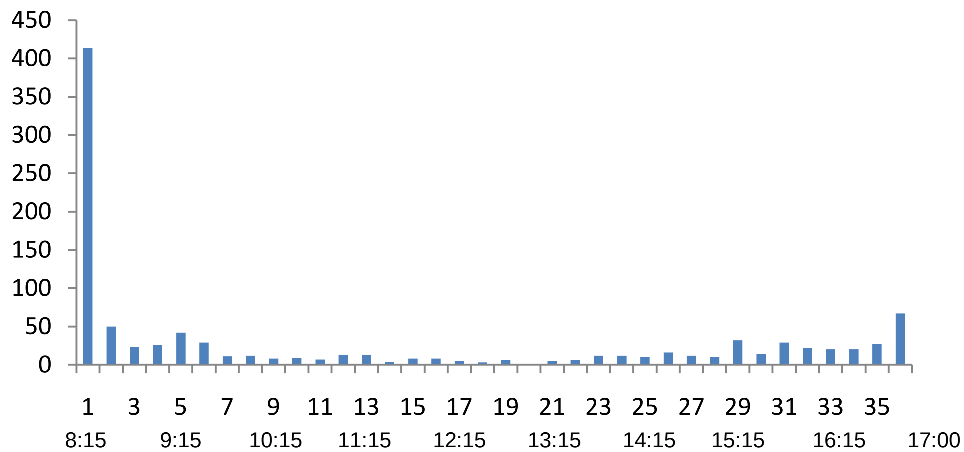
Graph 6.11(c): Number of Volatility Shifts per 15-minite interval (1-36), EU/US Exchange Rate, UK Time zone



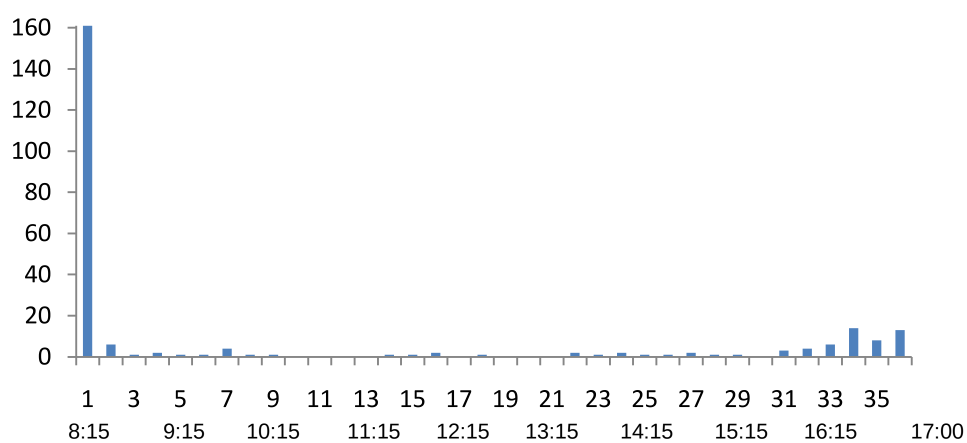
Graph 6.12(a): Number of Volatility Shifts per 15-minite interval (1-36), JP/US Exchange Rate, ASIA Time zone



Graph 6.12(b): Number of Volatility Shifts per 15-minite interval (1-36), GB/US Exchange Rate, ASIA Time zone



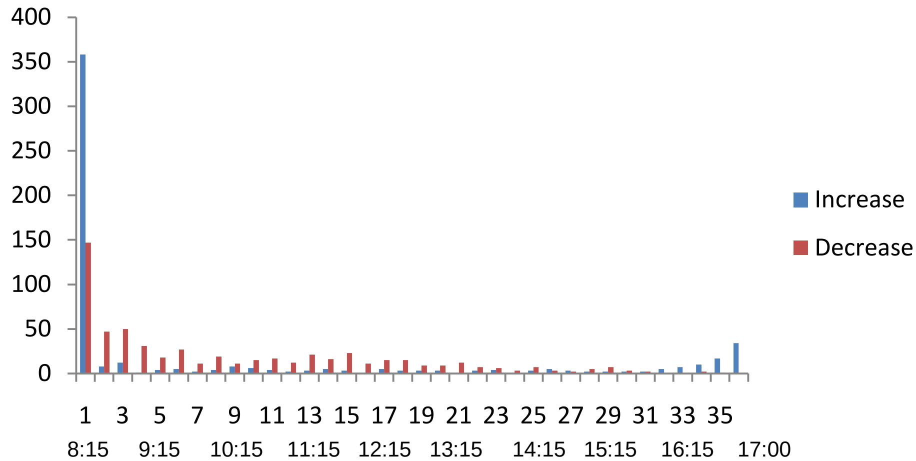
Graph 6.12(c): Number of Volatility Shifts per 15-minite interval (1-36), EU/US Exchange Rate, ASIA Time zone



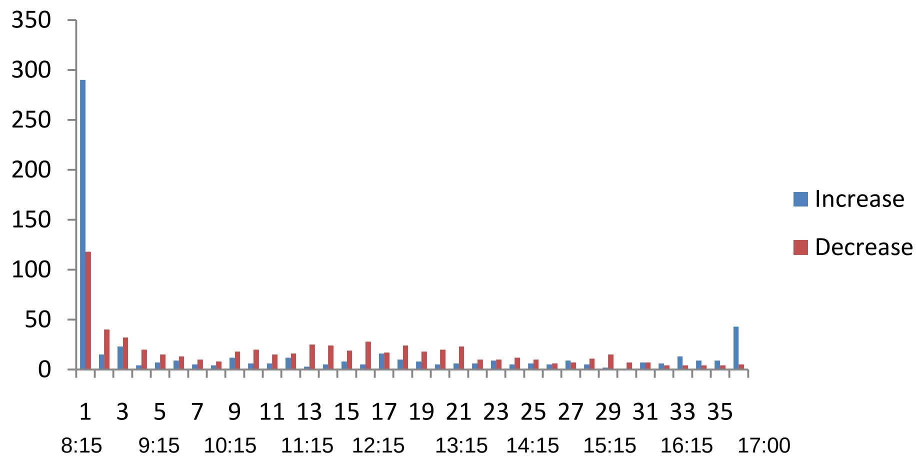
Graphs 6.13(a,b,c) to 6.15(a,b,c)

Intraday quarter-hour intervals were calculated based on the last bid-ask quotes recorded at 5-minute intervals, between 8:00am and 5:00pm local time, obtained from Olsen. For the JP/US and the GB/US the full sample extends from 01.01.1995 to 31.01.2005. For the EU/US exchange rate the sample is from 01.01.2001 to 31.01 2005. Interval 1 covers the trading quarter between 8:00am-8:15am and interval 36 4:45pm to 5:00pm

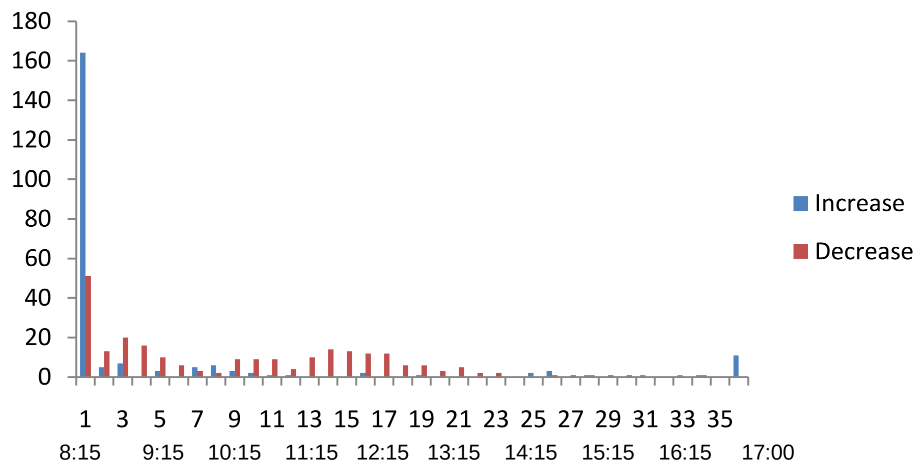
Graph 6.13(a): Volatility Increases/Decreases per 15-minite interval (1-36), JP/US Exchange Rate, US Time zone



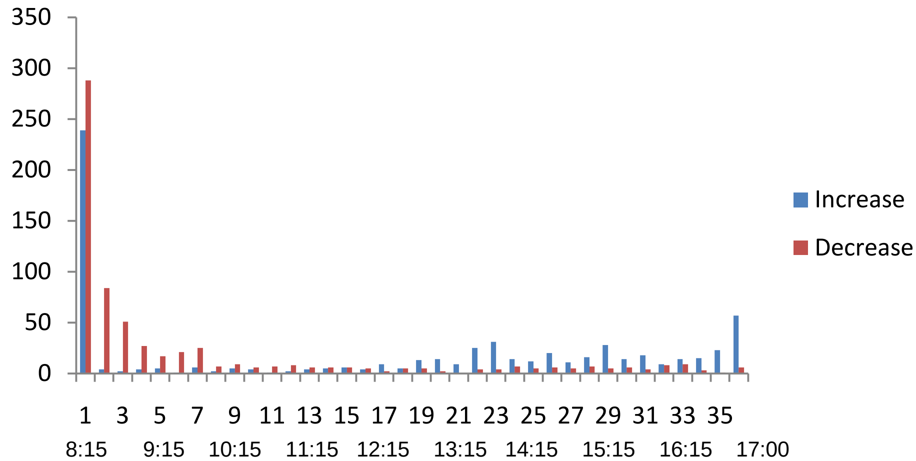
Graph 6.13(b): Volatility Increases/Decreases per 15-minite interval (1-36), GB/US Exchange Rate, US Time zone



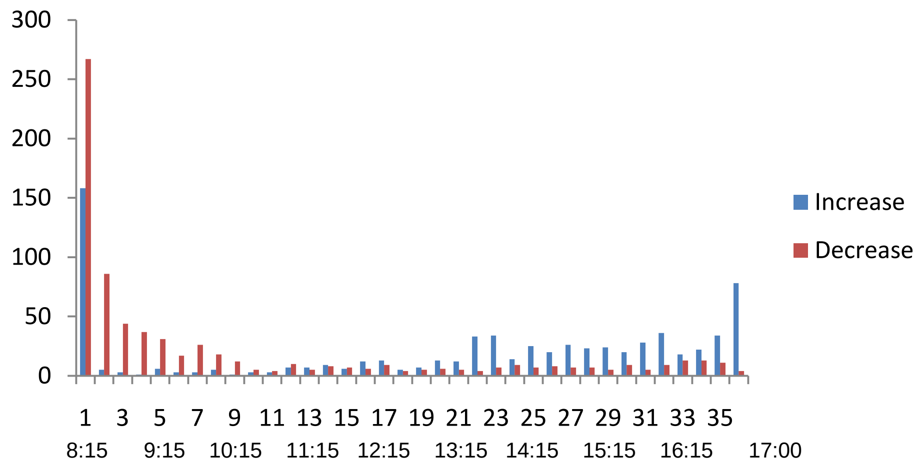
Graph 6.13(c): Volatility Increases/Decreases per 15-minite interval (1-36), EU/US Exchange Rate, US Time zone



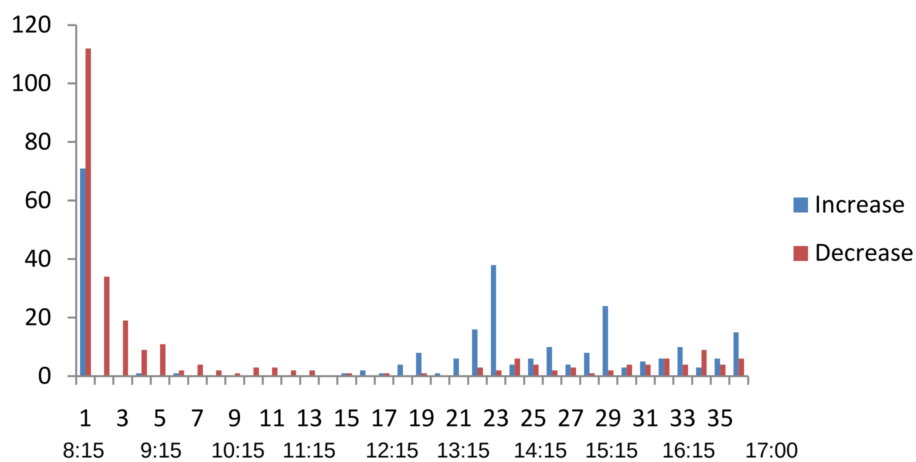
Graph 6.14(a): Volatility Increases/Decreases per 15-minite interval, JP/US Exchange Rate, UK Time zone



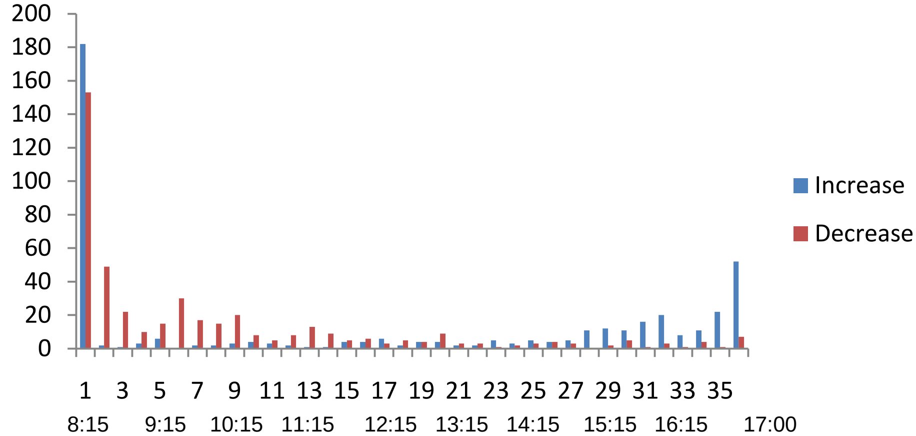
Graph 6.14(b): Volatility Increases/Decreases per 15-minite interval, GB/US Exchange Rate, UK Time zone



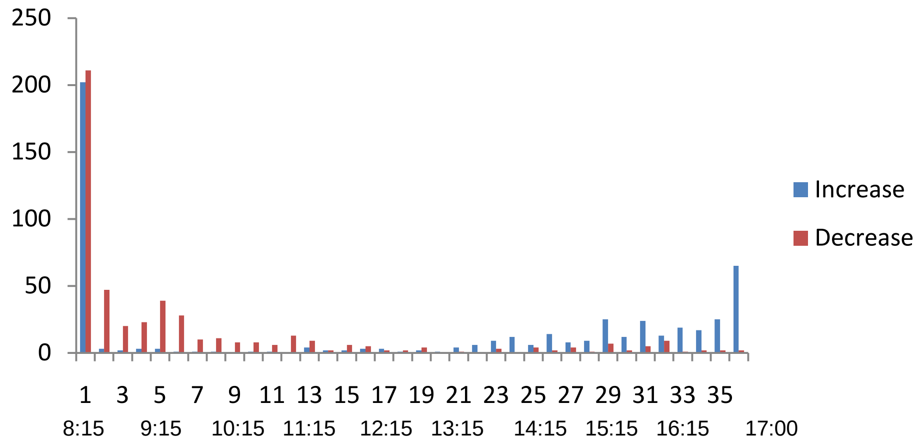
Graph 6.14(c): Volatility Increases/Decreases per 15-minite interval, EU/US Exchange Rate, UK Time zone



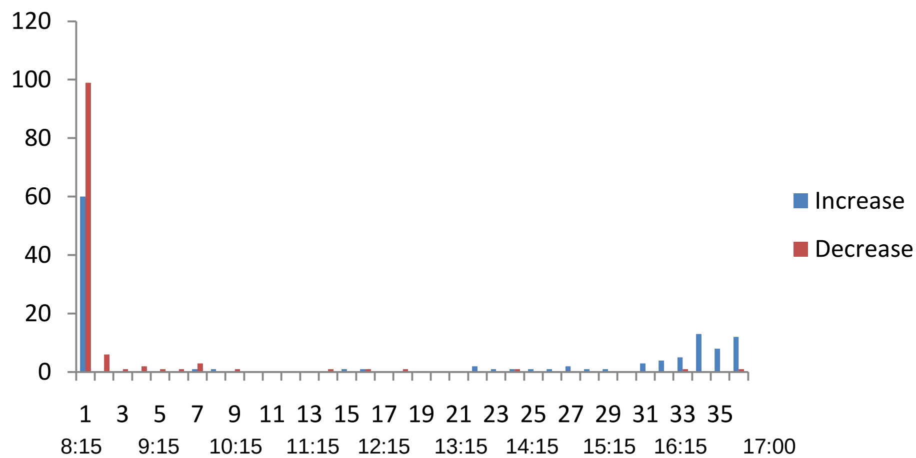
Graph 6.15(a): Volatility Increases/Decreases per 15-minite interval (1-36), JP/US Exchange Rate, ASIA Time zone



Graph 6.15(b): Volatility Increases/Decreases per 15-minite interval (1-36), GB/US Exchange Rate, ASIA Time zone



Graph 6.15(c): Volatility Increases/Decreases per 15-minite interval (1-36), EU/US Exchange Rate, ASIA Time zone



Section 6.6: Spread variance changes, Intraday Sample

Results show many variance shifts associated with each spread but the total number is considerably lower than the one found for the exchange rates.

Table 6.11 provides the number of volatility shifts for JP/US, GB/US and EU//US spreads (quoted and relative) in US, UK and ASIA time zones for the full intraday sample. The greatest number of change points occurs for the GB/US exchange rate in all three time zones. The highest is observed in the Asia time zone where the GB/US exchange rate reached 368 volatility shifts between 01.01.2001 and 31.01.2005. The lowest number of change points, occurs for the EU/US quoted spread in US time zone but we need to consider that the EU/US spread was in place for only four years in my sample. A low number of change points is also observed for the JP/US quoted and relative spread in the US and UK time zones. Graphs 6.16(a,b,c) to 6.21(a,b,c) show the number of volatility shifts during different times of the day as captured by the 36 15-minute intervals during my active trading day. Graphs 6.22 to 6.27(a,b,c) show how many times volatility increased/decreased during a particular quarter-hour interval allowing us to identify periods where volatility tends to increase or decrease during the day. In all graphs Interval 1, refers to 8:00-8:15am and interval 36 to 4:45-5:00pm during weekdays.

In contrast to the pattern observed in the exchange rate sample, we can’t see a clear day pattern in the number of volatility shifts for the spread, although on several occasions the first interval has the most change points. The numbers of volatility shifts are spread during the 36 15-minute intervals (all spreads, all time zones). Of course, there are unique patterns for individual spread series. For example, for the JP/US quoted spread (Asia time zone) there is a sharp increase in the number of volatility shifts as the Asia dealers exit (from period 30 to the end of the active trading day), and in the US time zone a steady drop as North American dealers enter (in the first ten intervals). A different pattern, where change points are more smoothly spread during the day, is observed for the quoted JP/US (UK time zone), quoted and relative GB/US (US time zone) spreads, and relative EU/US (Asia and UK time zones).

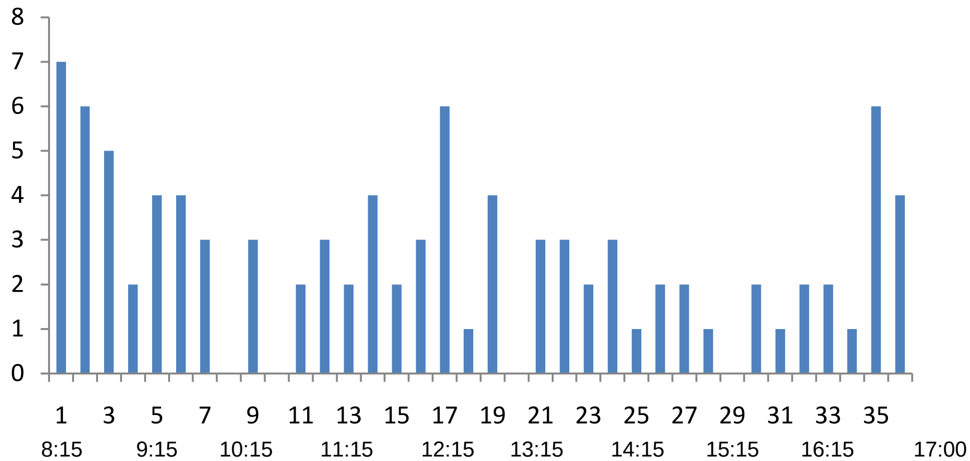
Regarding increases/decreases of spread volatility during the day, we can see that volatility tends to increase as North American dealers enter (in the first five 15-minute intervals, 8.00-9.15am) for the JP/US and GB/US spreads (US time zone). Huang and Masulis (1999) find that spreads gradually rise as North American dealers enter; therefore, that provides further evidence of the effect of increased volatility on the spread. Moreover, Hsieh and Kleidon (1996) find U-shaped FX spread pattern in London and New York markets. There is no clear pattern for the spread of the EU/US currency pair. The spread volatility results are mixed during the rest of the day. Volatility decreases are more than volatility increases at the end of the day for the JP/US and EU/US spreads but not for the GB/US spread. For the GB/US spread there are more volatility decreases in the first half of the day, while for the EU/US volatility increases are more between intervals 23 to 33. In the UK and Asia time zones there are similarities and differences compared to the US time zone. For example, in the UK time zone for the JP/US and GB/US spreads, volatility increases are more that volatility decreases in the first and last 15-minute intervals. For the EU/US spread in the Asia time zone, the number of volatility decreases is higher than the number of volatility increases in the first and last 15-minute intervals. We can see more of these pattern differences in Graphs 6.22 (a,b,c) to 6.27(a,b,c). In the next chapter, I try to explain the reasons for these patterns, such as the higher or lower volatility during different times of the day. To this end, I use a GARCH modelling approach to identify the determinants of spreads by employing various explanatory variables as proxies of inventory holding costs and asymmetric information costs.

Table 6.11: Number of Volatility Shifts, Spreads

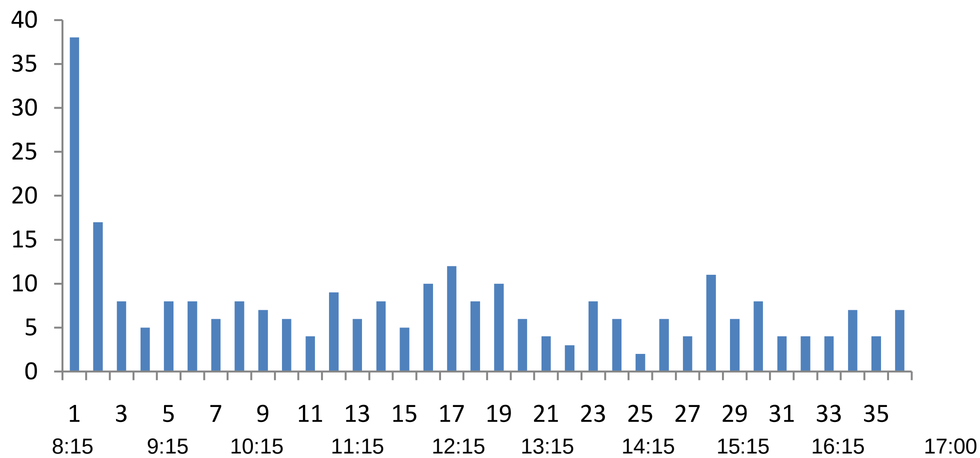
This table indicates the number of change points for the quoted and relative spreads of yen/dollar, pound/dollar and euro/dollar exchange rates in different time zones (US,UK, ASIA). The full intraday sample extends from 01.01.1995 to 31.01.2005 (for the euro/dollar from 01.01.2001 to 31.01.2005). The critical value at a 95% level is 1.358.

Quoted Spread								
US			UK			ASIA		
JP/US	GB/US	EU/US	JP/US	GB/US	EU/US	JP/US	GB/US	EU/US
96	277	92	97	156	136	127	313	120
Relative Spread								
US			UK			ASIA		
JP/US	GB/US	EU/US	JP/US	GB/US	EU/US	JP/US	GB/US	EU/US
120	247	143	99	198	127	119	368	147

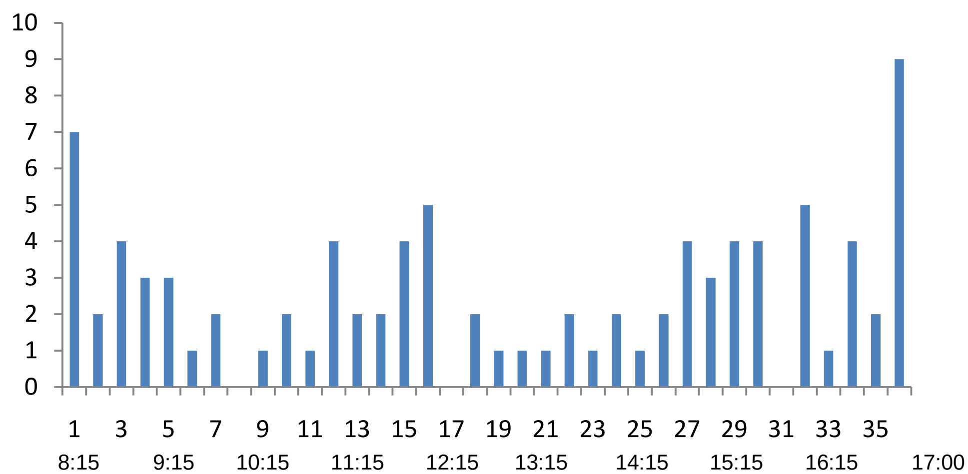
Graph 6.16(a): Number of Volatility Shifts per 15-minite interval (1-36), JP/US Quoted Spread, US Time zone



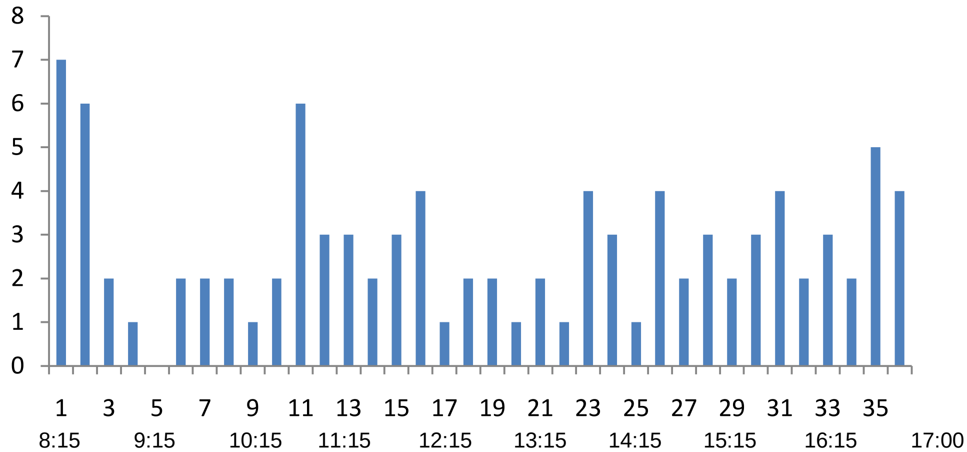
Graph 6.16(b): Number of Volatility Shifts per 15-minite interval (1-36), GB/US Quoted Spread, US Time zone



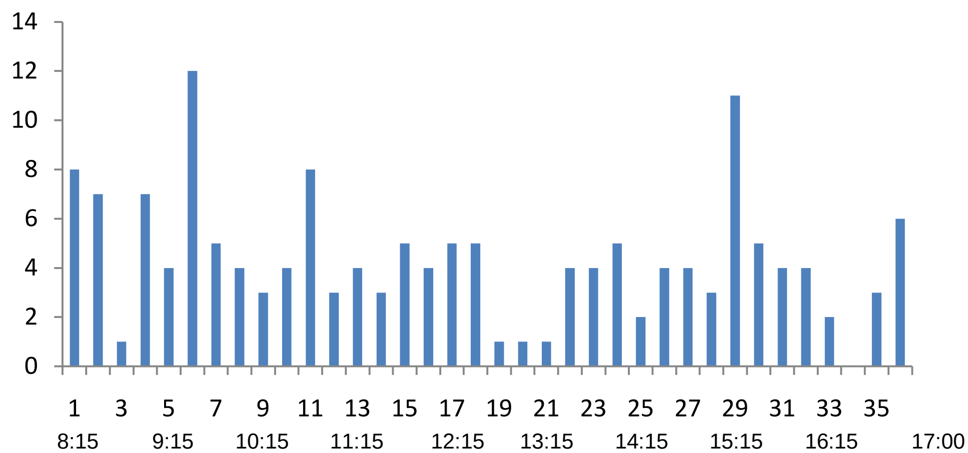
Graph 6.16(c): Number of Volatility Shifts per 15-minite interval (1-36), EU/US Quoted Spread, US Time zone



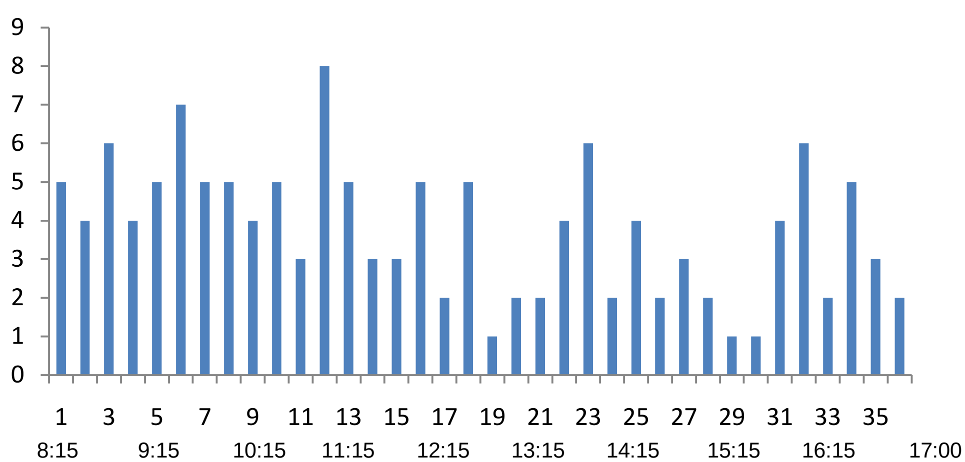
Graph 6.17(a): Number of Volatility Shifts per 15-minite interval (1-36), JP/US Quoted Spread, UK Time zone



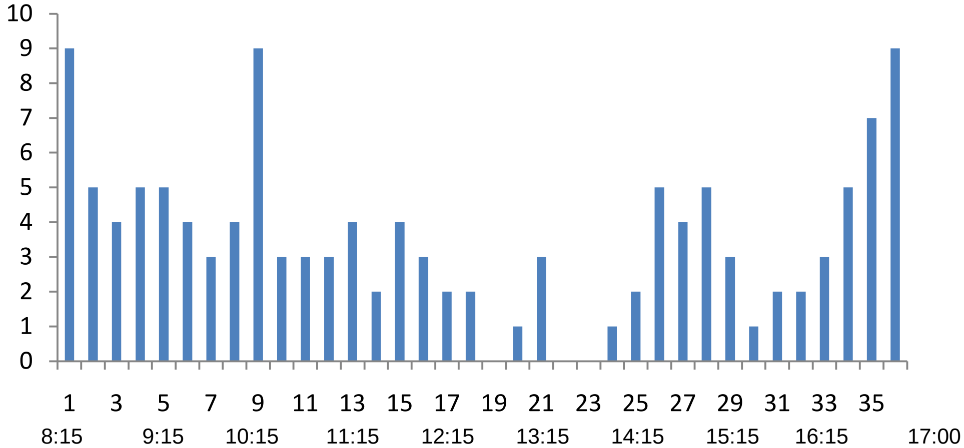
Graph 6.17(b): Number of Volatility Shifts per 15-minite interval (1-36), GB/US Quoted Spread, UK Time zone



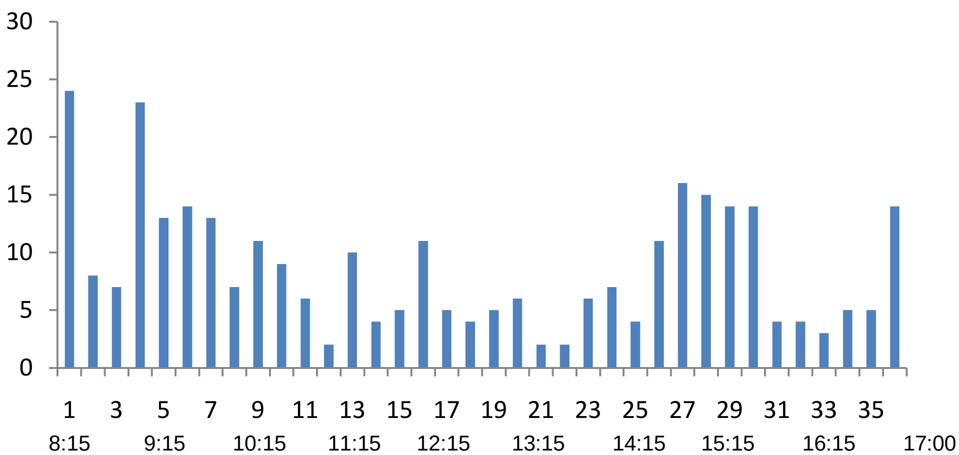
Graph 6.17(c): Number of Volatility Shifts per 15-minite interval (1-36), EU/US Quoted Spread, UK Time zone



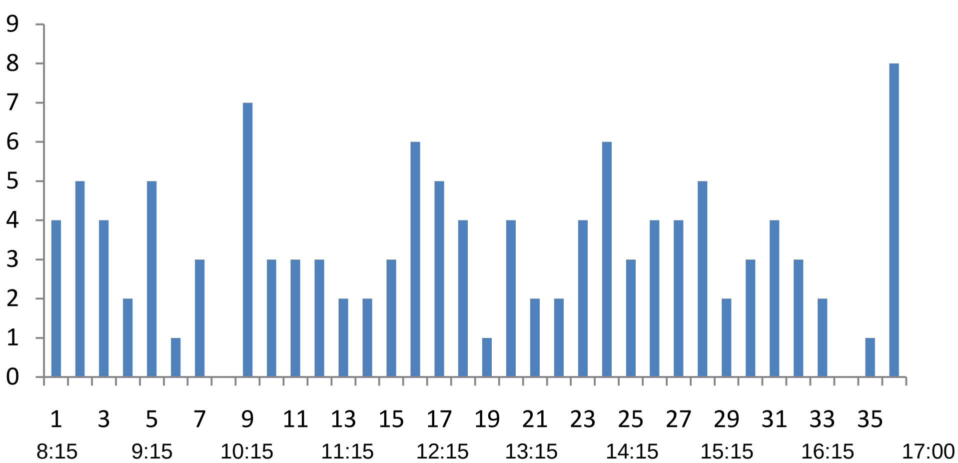
Graph 6.18(a): Number of Volatility Shifts per 15-minite interval (1-36), JP/US Quoted Spread, ASIA Time zone



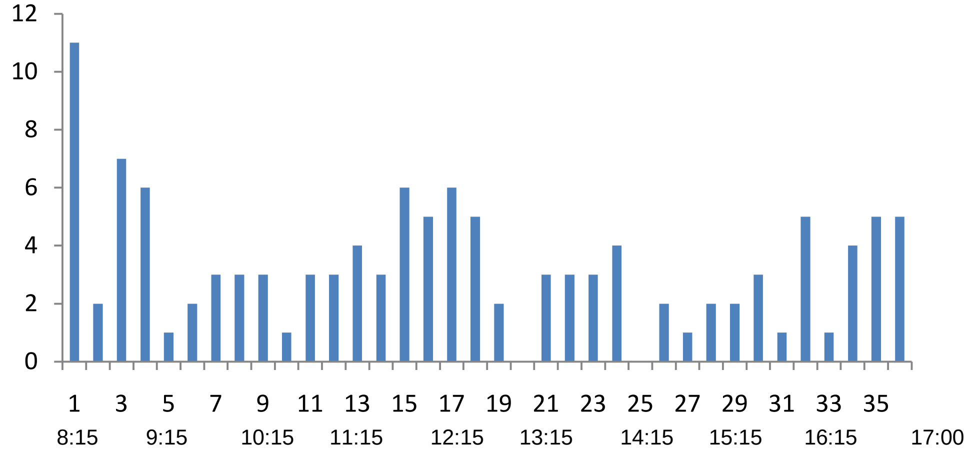
Graph 6.18(b): Number of Volatility Shifts per 15-minite interval (1-36), GB/US Quoted Spread, ASIA Time zone



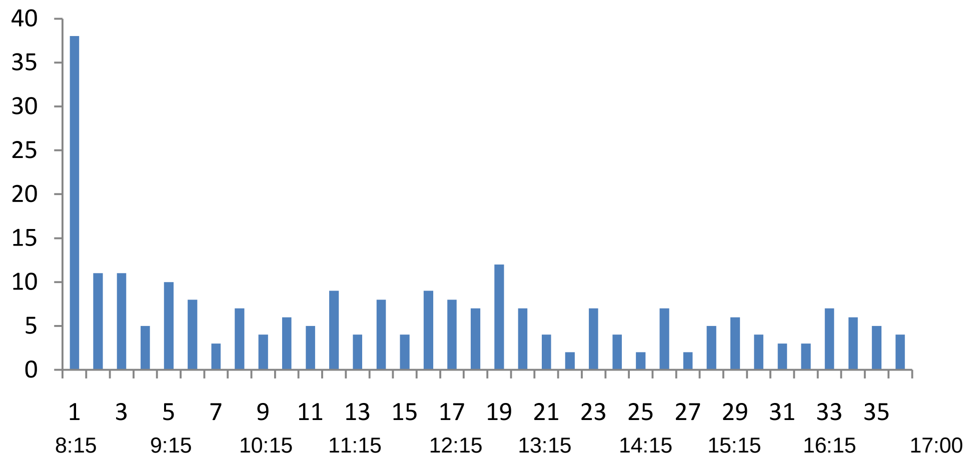
Graph 6.18(c): Number of Volatility Shifts per 15-minite interval (1-36), EU/US Quoted Spread, ASIA Time zone



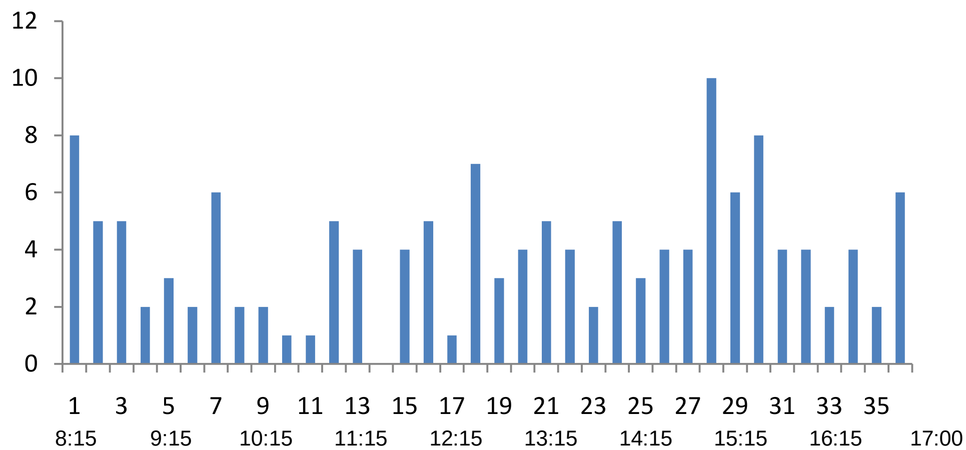
Graph 6.19(a): Number of Volatility Shifts per 15-minite interval (1-36), JP/US Relative Spread, US Time zone



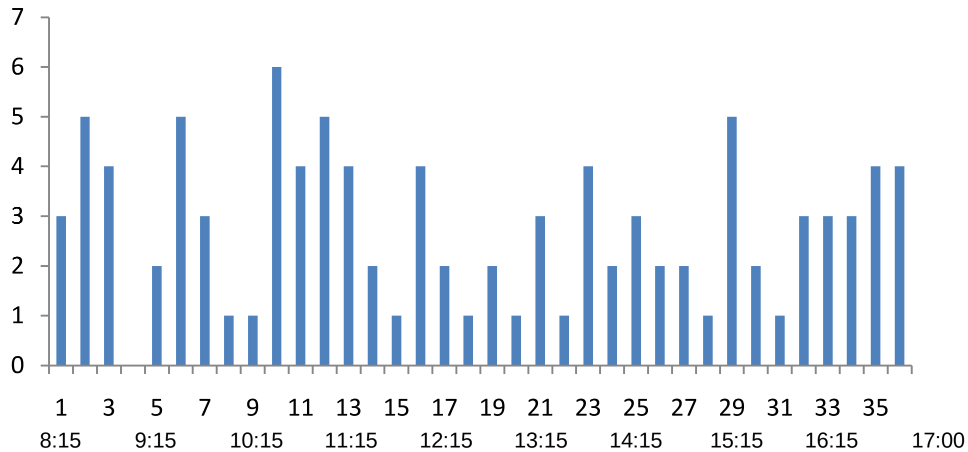
Graph 6.19(b): Number of Volatility Shifts per 15-minite interval (1-36), GB/US Relative Spread, US Time zone



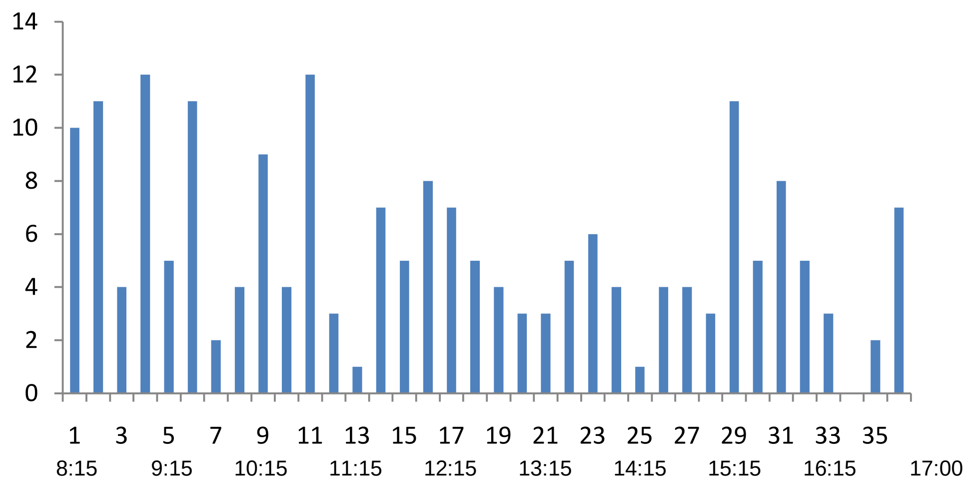
Graph 6.19(c): Number of Volatility Shifts per 15-minite interval (1-36), EU/US Relative Spread, US Time zone



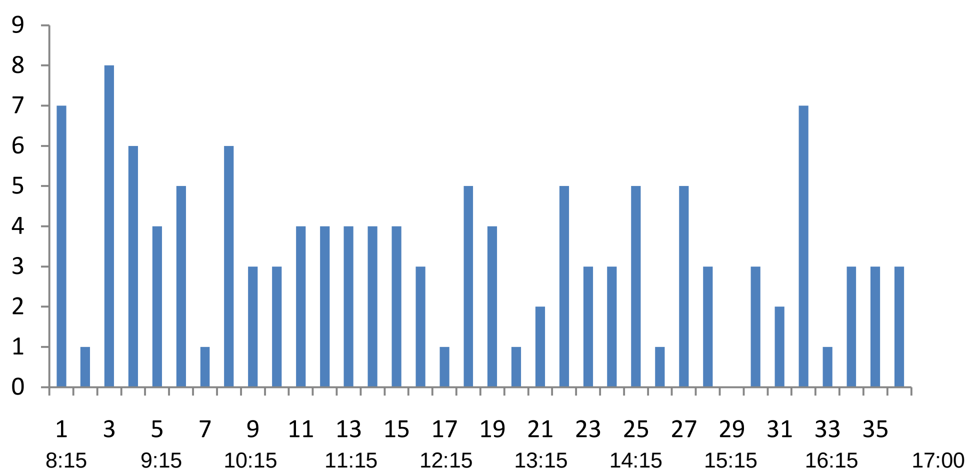
Graph 6.20(a): Number of Volatility Shifts per 15-minite interval (1-36), JP/US Relative Spread, UK Time zone



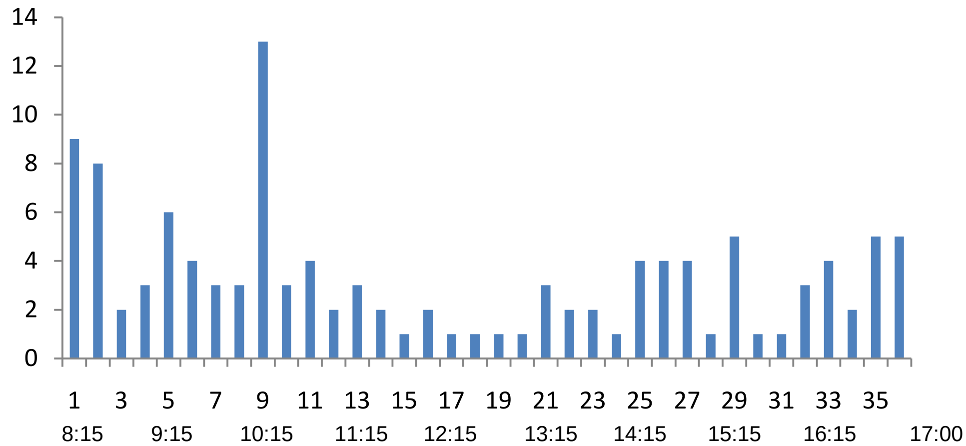
Graph 6.20(b) Number of Volatility Shifts per 15-minite interval (1-36), GB/US Relative Spread, UK Time zone



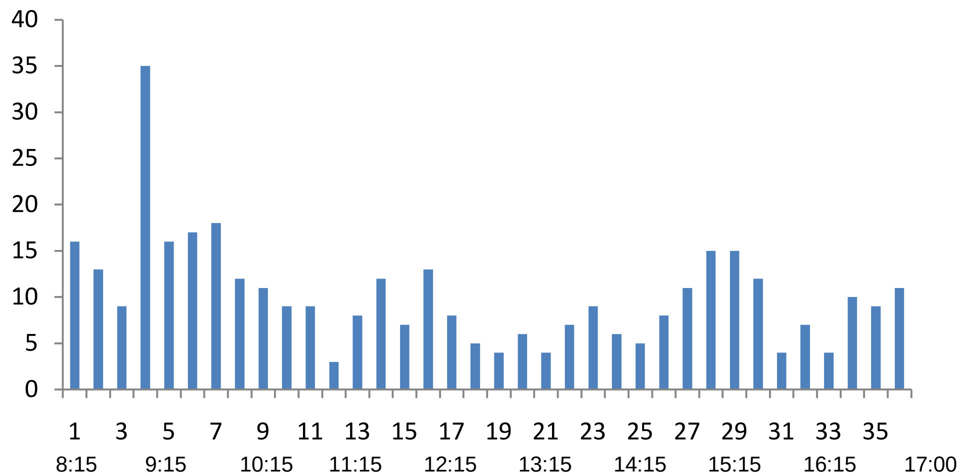
Graph 6.20(c): Number of Volatility Shifts per 15-minite interval (1-36), EU/US Relative Spread, UK Time zone



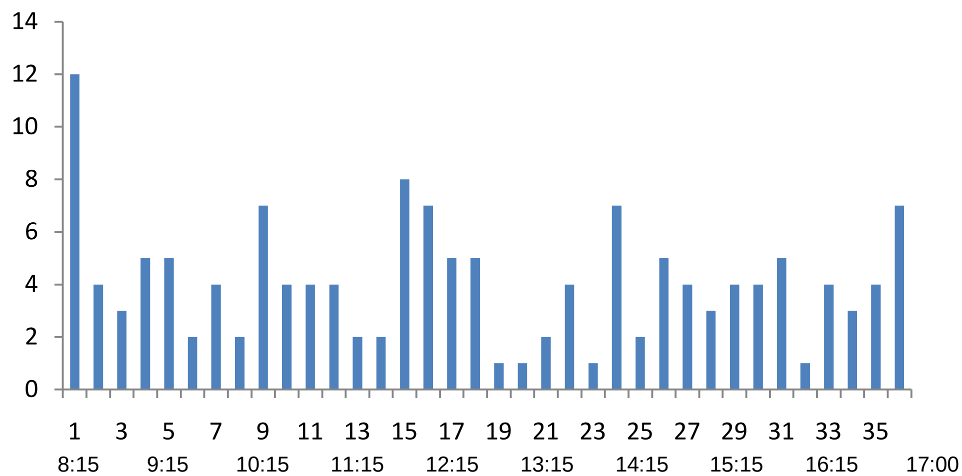
Graph 6.21(a): Number of Volatility Shifts per 15-minite interval (1-36), JP/US Relative Spread, ASIA Time zone



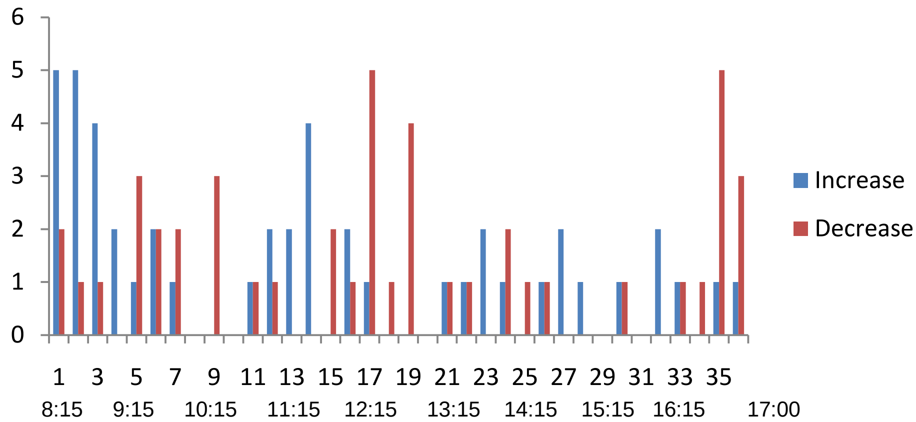
Graph 6.21(b): Number of Volatility Shifts per 15-minite interval (1-36), GB/US Relative Spread, ASIA Time zone



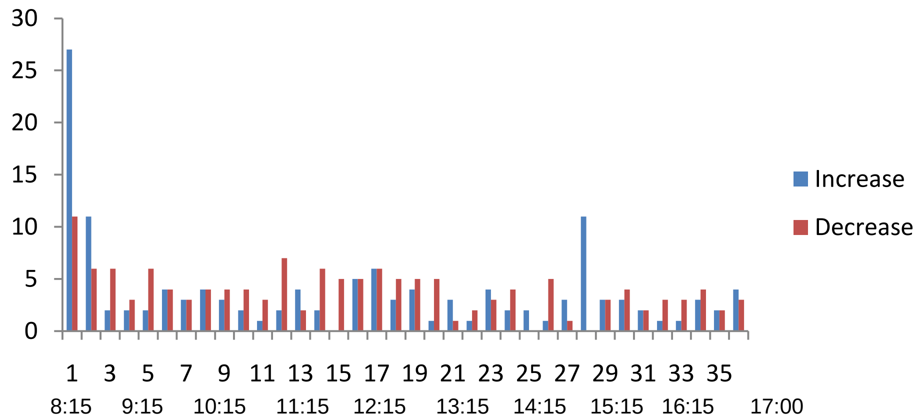
Graph 6.21(c): Number of Volatility Shifts per 15-minite interval (1-36), EU/US Relative Spread, ASIA Time zone



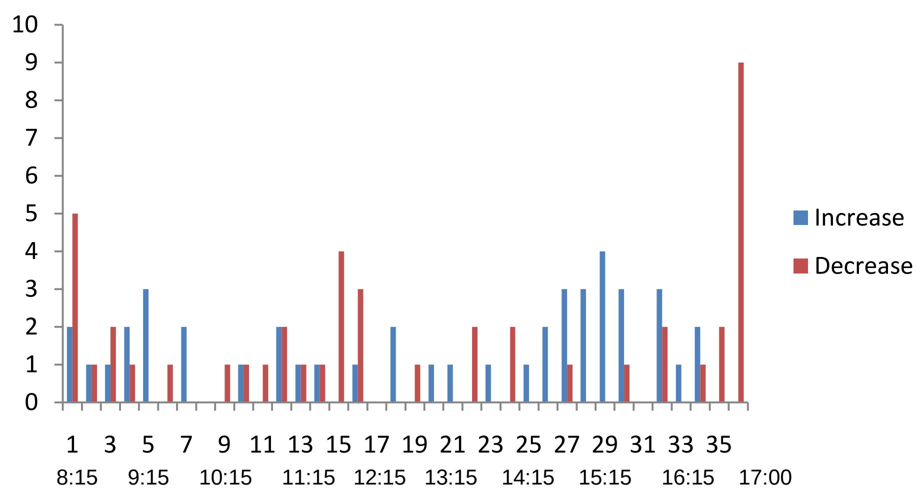
Graph 6.22(a): Volatility Increases/Decreases per 15-minite interval (1-36), JP/US Quoted Spread, US Time zone



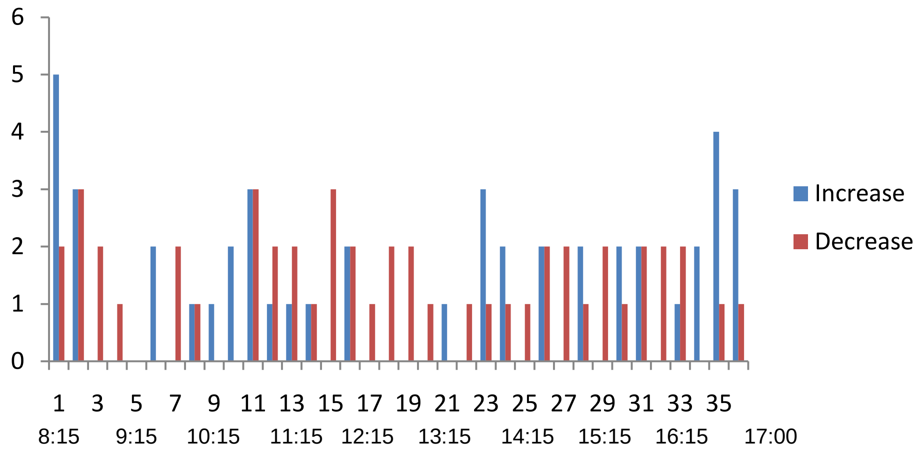
Graph 6.22(b): Volatility Increases/Decreases per 15-minite interval (1-36), GB/US Quoted Spread, US Time zone



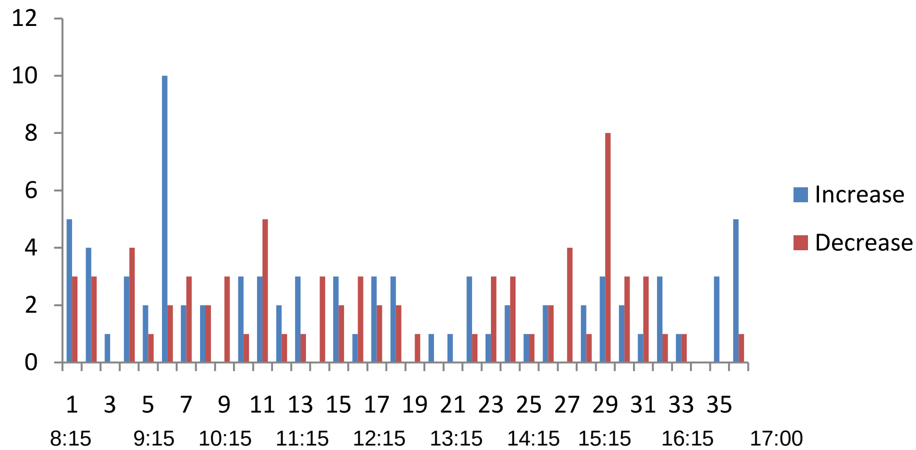
Graph 6.22(c): Volatility Increases/Decreases per 15-minite interval (1-36), EU/US Quoted Spread, US Time zone



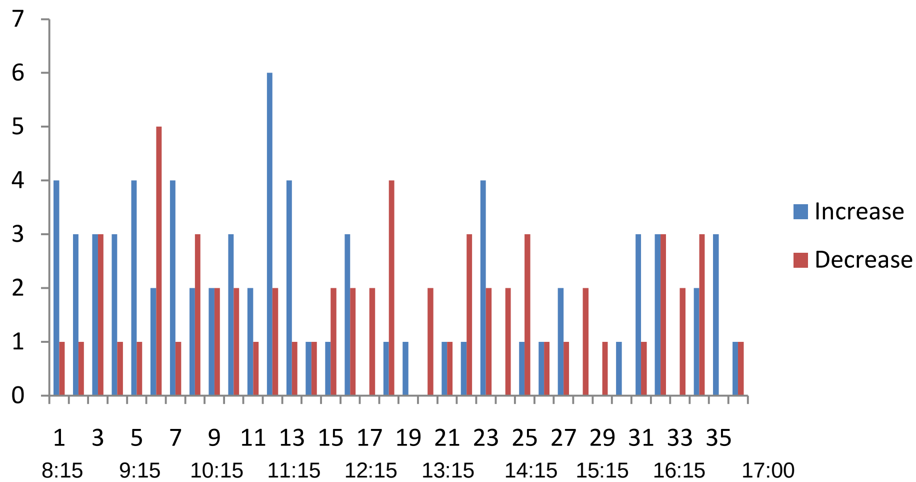
Graph 6.23(a): Volatility Increases/Decreases per 15-minite interval (1-36), JP/US Quoted Spread, UK Time zone



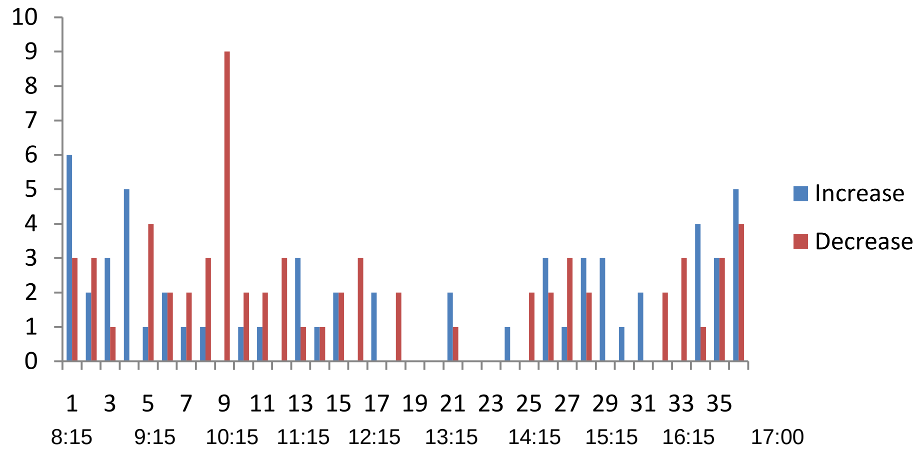
Graph 6.23(b): Volatility Increases/Decreases per 15-minite interval (1-36), GB/US Quoted Spread, UK Time zone



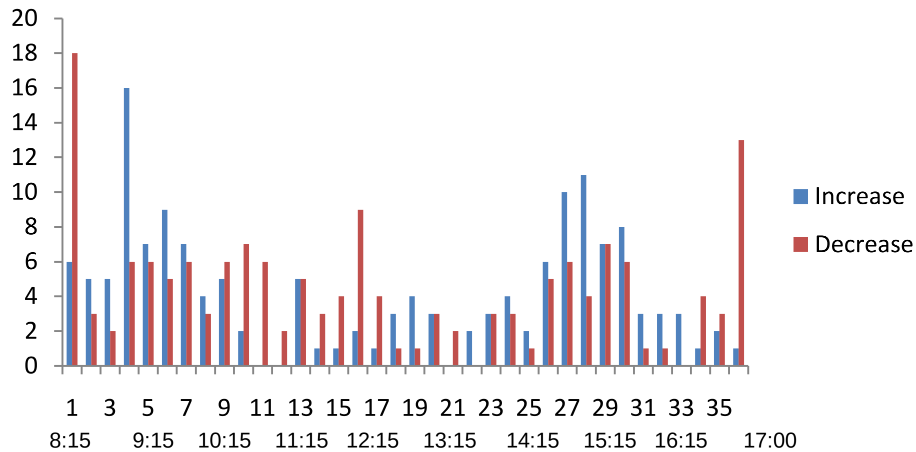
Graph 6.23(c): Volatility Increases/Decreases per 15-minite interval (1-36), EU/US Quoted Spread, UK Time zone



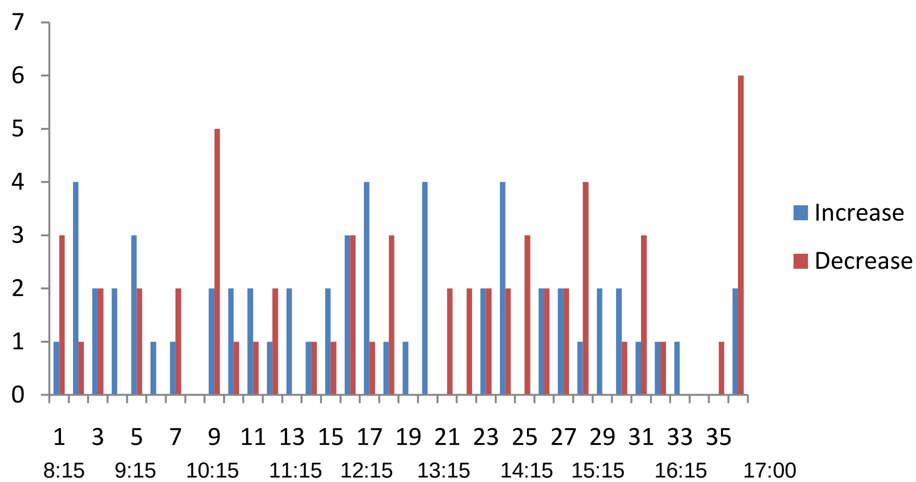
Graph 6.24(a): Volatility Increases/Decreases per 15-minite interval (1-36), JP/US Quoted Spread, ASIA Time zone



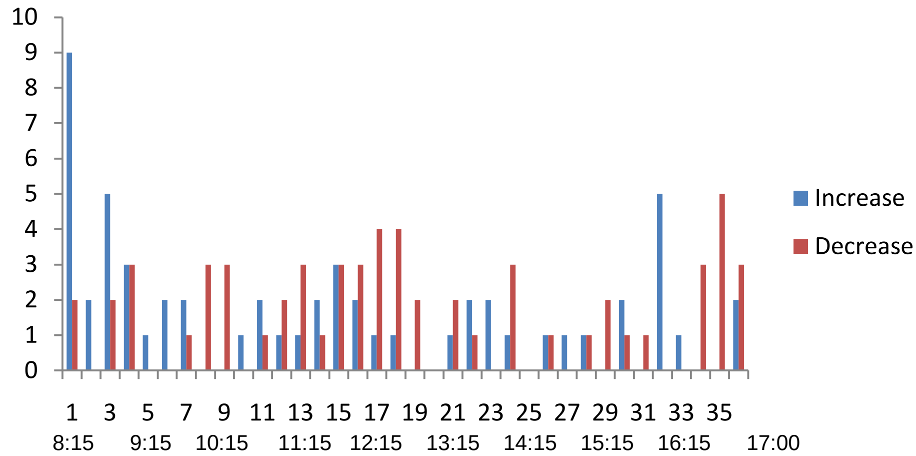
Graph 6.24(b): Volatility Increases/Decreases per 15-minite interval (1-36), GB/US Quoted Spread, ASIA Time zone



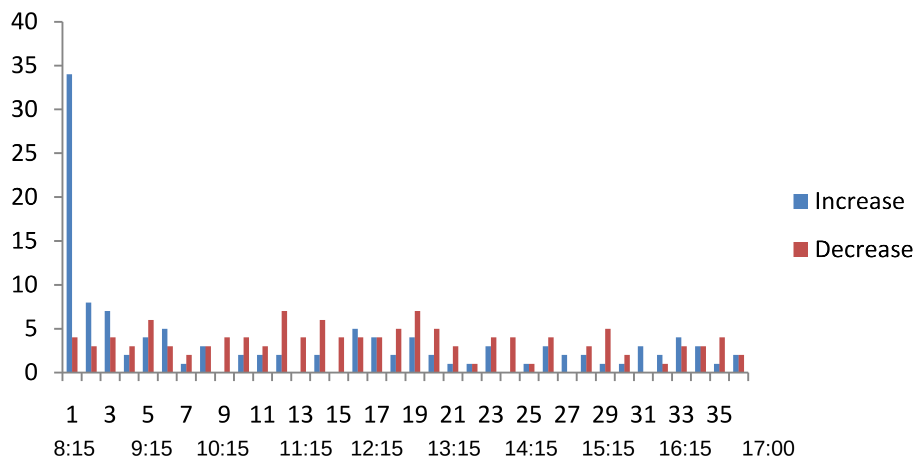
Graph 6.24(c): Volatility Increases/Decreases per 15-minite interval (1-36), EU/US Quoted Spread, ASIA Time zone



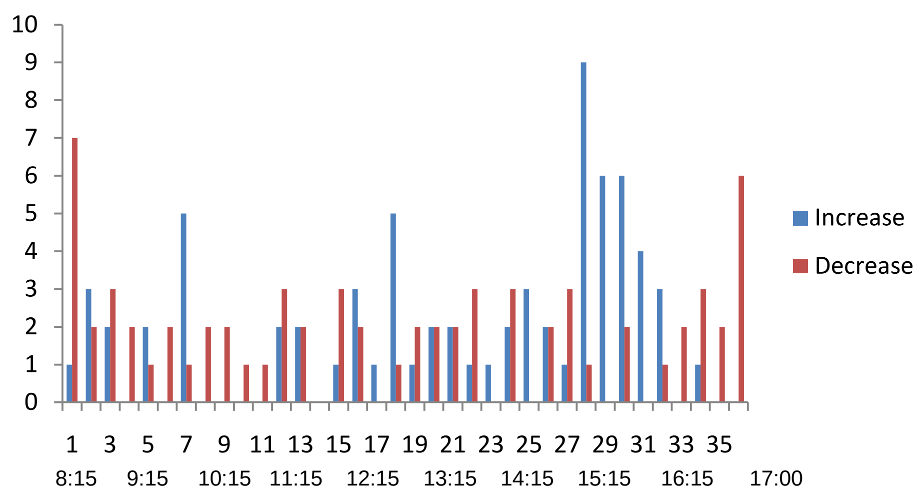
Graph 6.25(a): Volatility Increases/Decreases per 15-minite interval (1-36), JP/US Relative Spread, US Time zone



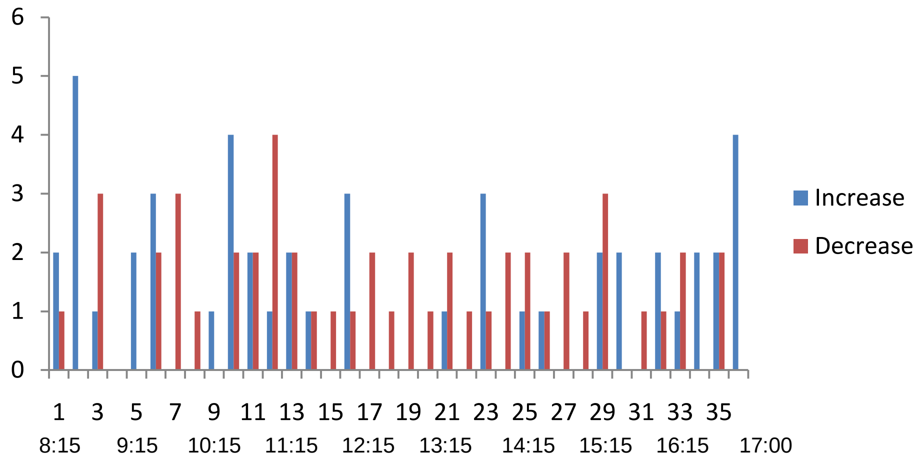
Graph 6.25(b): Volatility Increases/Decreases per 15-minite interval (1-36), GB/US Relative Spread, US Time zone



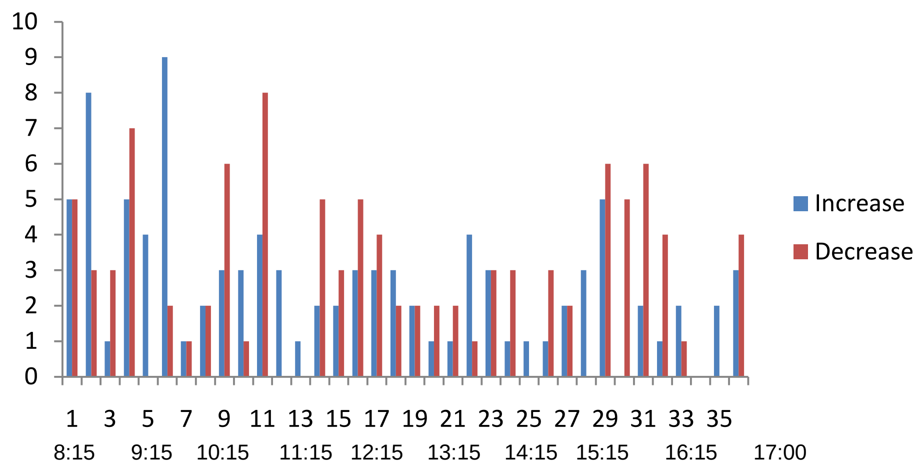
Graph 6.25(c): Volatility Increases/Decreases per 15-minite interval (1-36), EU/US Relative Spread, US Time zone



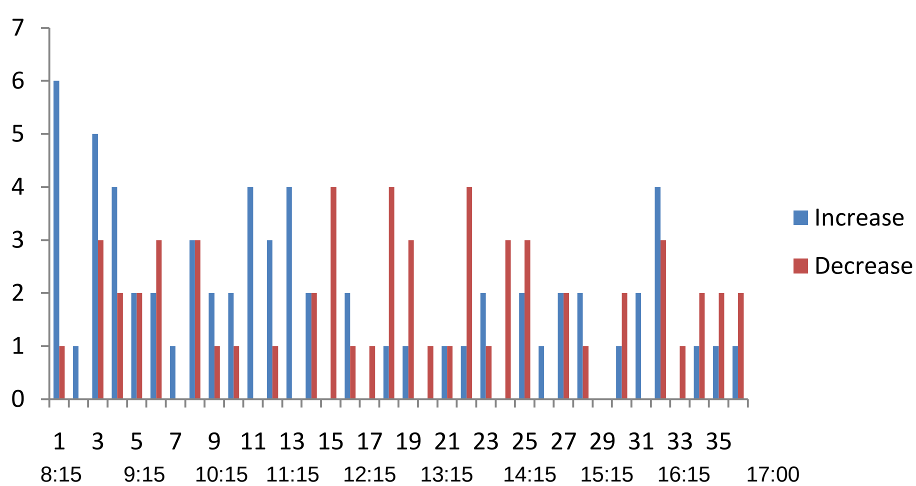
Graph 6.26(a): Volatility Increases/Decreases per 15-minite interval (1-36), JP/US Relative Spread, UK Time zone



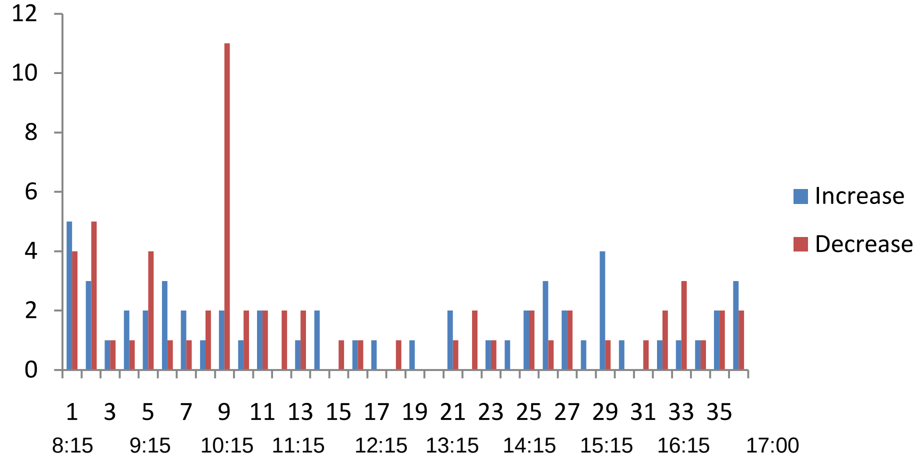
Graph 6.26(b): Volatility Increases/Decreases per 15-minite interval (1-36), GB/US Relative Spread, UK Time zone



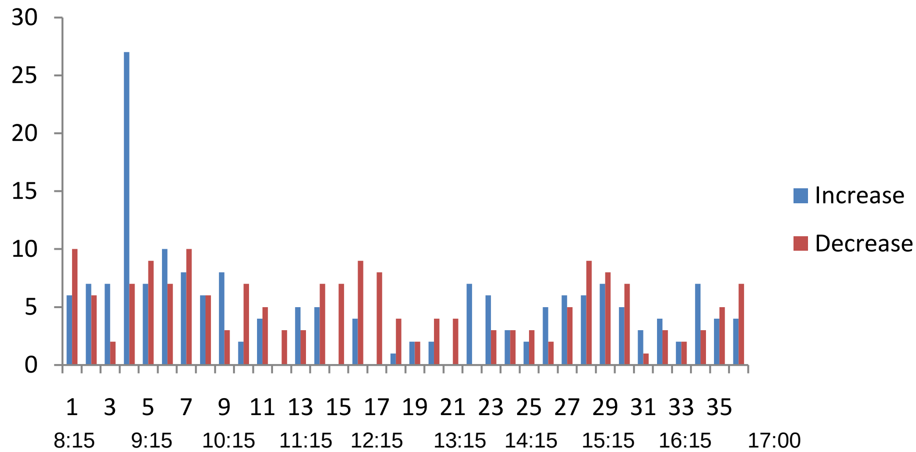
Graph 6.26(c): Volatility Increases/Decreases per 15-minite interval (1-36), EU/US Relative Spread, UK Time zone



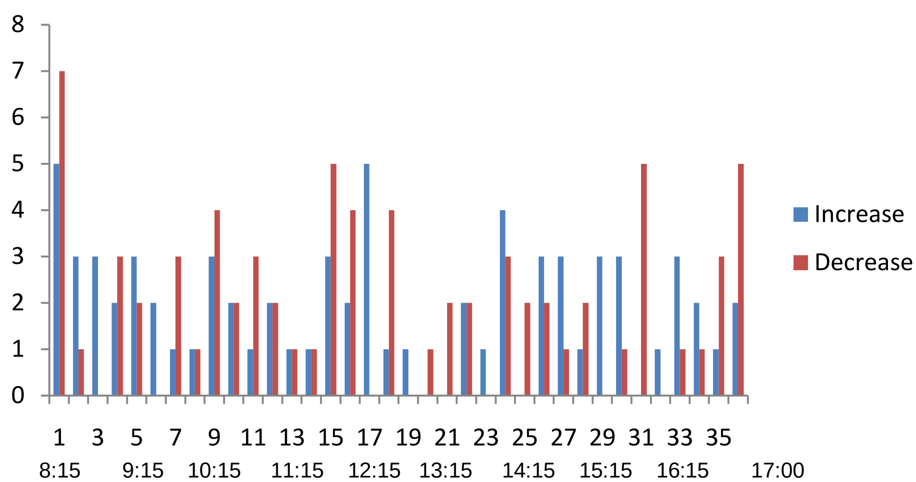
Graph 6.27(a): Volatility Increases/Decreases per 15-minite interval (1-36), JP/US Relative Spread, ASIA Time zone



Graph 6.27(b): Volatility Increases/Decreases per 15-minite interval (1-36), GB/US Relative Spread, ASIA Time zone



Graph 6.27(c): Volatility Increases/Decreases per 15-minite interval (1-36), EU/US Relative Spread, ASIA Time zone



Section 6.7 Comparison of exchange rate and spread variance changes

Results from the daily sample show that the variance of the exchange rates increased more during the Asian crisis period compared to the periods before and after the crisis. As for the spread variance, I didn't find evidence that this was higher during the Asian crisis as most of the spread variance structural breaks occur in 2003, much later from the Asian crisis. Moreover, I cannot conclude that exchange rate volatility coincides with spread volatility.

My intraday results show that spread volatility tends to increase as North American dealers enter the market (between 8am-9.15am), a finding in line with Huang and Masulis (1999) and Hsieh and Kleidon (1996), however, there is not a clear pattern observed as most of volatility shifts are spread during the day. The higher spread volatility at the opening of the market may be evidence of asymmetric information as dealers need to adjust the spread more often due to the higher uncertainty of the "true" price. In the next chapter I investigate the determinants of bid-ask spreads so this finding suggests that I should use a dummy variable to capture possible intra-day patterns that would provide evidence of asymmetric information.

I find that intraday spread series are much less volatile than the exchange rate series, as the number of change points obtained from ICSS algorithm are considerably lower. The number of variance changes for spreads range from 96 to 368, while for the exchange rates from 242 to 1447. That means that the cost of trading (as captured in the bid-ask spread) is less volatile therefore, even during periods of high exchange rate volatility market participants will not necessarily face higher trading costs. This supports the fact that the FX market is a very liquid market.

Differences between exchange rates and spreads also exist in the day patterns of their variance shifts, as these are captured by the number of variance changes per 15-minute interval. For the exchange rates, there is a similar pattern regarding the relationship between the time period of the day and the number of volatility change points. The number of change points is considerably higher at the beginning and closing of the active trading day. In particular, the highest change points occur in the first and last three 15-minute intervals. In contrast, as mentioned earlier the number of volatility shifts for the spread series are spread over the 36 15-minute intervals (in most cases). Finally, it is worth mentioning that the GB/US currency pair (intraday sample) has the most variance shifts when compared to the JP/US and EU/US both for exchange rates and spread series in all time zones.

Section 6.8 Summary and conclusions

In this chapter I use the Inclan and Tiao (1994) Iterated Cumulative Sum of Squares (ICSS) algorithm to search for structural breaks in the unconditional variance of the exchange rates and spread series of JP/US, GB/US and EU/US for three time zones (UK, US and Asia). I find that the number of volatility shifts were highest during the Asian crisis for the daily exchange rate series but not for the spread series. Moreover, I don’t find enough evidence to support that spread volatility coincides with exchange rate volatility

In line with previous work [Baillie and Bollerslev (1990), Goodhart and Giugale (1993), Hsieh and Kleidon (1996)] I find seasonal patterns in the volatility of liquidity for the exchange rates under examination. As for the spreads they tend to be higher at the opening of the trading day but overall most of the change points are spread during the day. Finally, I find that intraday spread series are much less volatile than the exchange rate series, that is, the determination of the cost of trading for market participants in general involves less risk even during periods of high exchange rate volatility.

The ICSS results from this chapter provide preliminary evidence for the plausible determinants of the bid-ask spreads which I investigate in the next chapter using a GARCH modelling approach.

Chapter 7: Determinants of Bid-Ask Spreads

Section 7.1: Introduction and overview

Market makers quote one price at which they are willing to act as counterparties to traders wishing to buy currencies (ask) and a different price to traders wishing to sell (bid). The difference between the bid and ask quotes is the bid-ask spread. In the literature review of this thesis I have discussed the three factors that influence the size of the bid-ask spread; order processing costs, inventory holding costs and information asymmetries. In the FX market order processing costs are insignificant therefore research focuses on the remaining two types.

The investigation of the determinants of the bid-ask spreads can be helpful in a number of ways: for traders the bid-ask spread is the cost of trading therefore, those who have some discretion over when they trade can choose a time when trading cost is low; market makers can improve their strategies regarding spread models and therefore provide their "immediacy" in a more efficient and profitable way; macroeconomic announcements at set times may induce regular intraday patterns therefore, discretionary traders need to allow for this when devising a trading strategy. Moreover, observed patterns may have regulatory implications. Last but not least, this research provides a good area for testing inventory-based and information based microstructure models and allows the comparison with previous empirical studies.

The results from the ICSS chapter provide some preliminary evidence of intraday patterns in the spread. In this chapter I use a wide range of variables to study the determinants of the bid-ask spread and compare my results to previous studies. I report time-series regressions of daily and intraday bid-ask spreads on various potential determinants. I first provide justification for the explanatory variables used. I use five types of explanatory variables: i) interest rate differentials, ii) exchange rate volatility iii) trading activity iv) seasonality variables and v) macroeconomic announcements.

Section 7.2: Explanatory variables

Market microstructure theory describes the bid-ask spread as a function of three different types of costs: a) order processing costs; b) inventory-carrying costs and c) asymmetric information costs. The order processing costs are minor in the foreign exchange market, therefore this work focuses on the remaining two in explaining spreads for three key currencies in three major markets.

Section 7.2.1: Inventory-carrying costs based

Demsetz (1968) described the bid-ask spread as a function of the cost of providing immediacy (liquidity) services. Many other authors have contributed in this area (for example, Stoll 1978, Ho and Stoll 1981), suggesting that bid-ask spreads depend on inventory turnover rates and inventory risks. Inventory cost models presented by Stoll (1978), Ho and Stoll (1981, 1983), O'Hara and Oldfield (1986) among others establish a link between bid-ask spreads, volatility and trading activity. Market makers maintain open positions in foreign currencies which expose them to market risk and carrying costs in terms of interest rate differentials and trading activity.

There are three components of inventory carrying costs discussed in the literature: the cost of holding a liquid currency inventory (related to interest rates), market risk, and trading activity.

Interest Rate Differentials Measures

Bid-ask spreads should depend on interest rates since the market-maker foregoes the interest rate that can be earned on less liquid inventory positions in order to function as a provider of “immediacy” (liquidity). Alternatively, the market-maker can provide this service by offsetting each of the incoming orders with transactions at another bank’s ask or bid price, paying the bid-ask spread on its offsetting transactions. A decrease in short rates could increase market liquidity and therefore reduce spreads.

A measure of the opportunity cost resulting from the requirement to maintain liquid positions is the difference between the interest rate earned on highly liquid positions and the difference that could have been achieved on less liquid positions. Bessembinder (1994) measures this cost as the difference between short (overnight deposits rates) and long interest rates (one month deposit rates) in the Eurodollar market. Becker and Sy (2005) adopt a similar approach in determining whether bid-ask spreads were excessive during the Asian crisis.

As plausible candidates for determinants of bid-ask spreads, I nominate the interest rate differential between Eurodollar overnight deposit rates (short) and Eurodollar one month deposit rate (long)[12], since the dollar is one always on one side of the currency pairs that we use.

Of course I have to assume that the long rate is always higher that the short (in order to have a cost), which is incorrect for some periods in our sample. Another more important assumption is that the market maker selects the above less liquid positions as an alternative to holding foreign exchange.

Exchange Rate Volatility Measures

In the foreign exchange market literature it is argued that market uncertainty is the main reason in determining changes in bid-ask spreads. The greater the uncertainty of future spot rates, the greater the bid-ask spread should be, to offset the increased risk of losses of a risk-averse trader. To account for

[12] Source: Datastream

uncertainty researchers use different measures of volatility such as the variance generated by GARCH models of the exchange rate. Empirical papers (Bessembinder 1994, Glassman 1987, and Boothe 1987, Bollerslev and Melvin 1994) find a positive and statistically significant relationship between volatility and spreads.

The standard deviation over a certain period of time can be only used as a first indication of the importance of volatility, but its use is limited because it is constant over the period measured while changes in volatilities occur at high frequencies. Wang et al. (1994) demonstrate that OLS estimates of the bid-ask spread equation are inconsistent if the standard deviation of transaction price changes is found in the regression. Therefore, a measure of volatility other than the standard deviation should be applied. Garman and Klass (1980) provide a volatility measure that does not contain the standard deviation but rather takes into account the open, high, low, and closing prices of each time period. Their estimator has been found to be more efficient than the traditional close-to-close estimators.

For the daily sample I consider the difference between the highest ask price and lowest bid price during a day as a measure of volatility. The higher the difference, the higher the volatility. For the intra-day sample I use the squared result of the log of the exchange rate at time t+1 minus log of the exchange rate at time t. I use the log return as it is a very common measure of unconditional volatility used also in equity studies [e.g Turner and Weigel (1992)].

Trading Activity Measures

The literature provides ample evidence that spreads tend to increase when markets are less active. The correlation results (Chapter 5, Section 5.7.3) for spread and number of quote revisions are preliminary evidence that the number of quote revisions (as a proxy for trading activity) is a determinant of bid-ask spread. My results show negative correlation between spreads and number of quote revisions, suggesting that spreads are narrower (wider) when tick activity is higher (lower). Of course correlation is not a measure of causality. There are many studies that examine this causality. Admati and Pfleiderer (1988) provide a theoretical model that suggests spread should decrease when trading activity increases, where other models (Subrahmanyam, 1989) suggest the opposite. The empirical findings of Bollerslev and Domovitz (1993) suggest that when orders increase in frequency, the spread decreases (Chapter 4, Section 4.5.5 for more details). Despite its limitations a number of studies, such as the ones of Goodhart and Figliuoli (1991) and Bollerslev and Domovitz (1993), use the frequency of quote arrival as a proxy of trading activity.

As a measure of trading activity I use for the daily sample the average number of quote revisions in the 5-minute interval. For the intra-day sample I use the actual number of quote revisions in every 5-minute interval. I enter the quote revisions in a log form as suggested by Demos and Goodhart (1996).

Seasonality effects

Rational thinking suggests that spreads prior to weekends and holidays will increase due to decreased liquidity. Glassman (1987) and Bessembinder (1994) show that spreads rise late on a Friday. The explanation they provide is that dealers avoid taking additional currency positions which they cannot easily lay off before the weekend. Huang and Masulis (1999) present estimates from bid-ask spreads on seasonal indicators including Friday closing time, Monday opening time and last day of the month. The latter indicator is included because reduced FX exposure is also sought near the end of the month when many banks calculate their FX departments' profit and loss statements.

I introduce dummy variables to account for the day of the week effects and month-end effects. In the daily sample, the day of the week dummy variable will take the value 1.0 if the trading day is a Monday or Friday, and 0 otherwise. As for the last day of month dummy variable, 1.0 if the last trading day of the month, and 0 otherwise. In the intraday sample, the day of the week dummy variable will take the value 1.0 if the first (last) three hours of active trading day is on Monday (Friday), and 0 otherwise. The last day of month dummy variable will be 1.0 in the last four hours of active trading on the last day of the month, and 0 otherwise.

I also introduce dummy variables to account for the drop-off in trading activity on bank holidays in three major market centers (New York, London and Tokyo) separately and when bank holidays occur simultaneously in all three markets. I define a holiday to occur in the US (North America) when the NYSE is closed, in the UK when the LSE is closed and in Asia when the TSE is closed. The source for bank holidays are various issues of JP Morgan's World Holiday and Time Guide. For the daily sample I include dummy variables for days preceding[13] (PRHOL, prec. holiday) and following holiday (POHOL, post holiday) closures. The preceding holiday dummy variable will take the value 1.0 if a trading day satisfies the following conditions: (1) if holiday falls on Monday, then the preceding Friday, (2) if any holiday falls on another weekday, then the preceding day, and 0 otherwise. The post holiday dummy will take the value 1.0 if a trading day satisfies the following conditions: (1) if holiday falls on Friday, then the following Monday, (2) if any holiday falls on another weekday, then the following day, and 0 otherwise. For the intra-day sample, the preceding holiday dummy variable will take the value 1.0 if a trading day satisfies the following conditions: (1) if holiday falls on Monday, then the last four hours of active trading on Friday, (2) if any holiday falls on another weekday, then the last four hours of active trading of the preceding day, and 0 otherwise. The post holiday dummy will take the value 1.0 if a trading day satisfies the following conditions: (1) if holiday falls on Friday, then the first four hours of active trading on the following Monday, (2) if any holiday falls on another weekday, then the first four hours of active trading on the following day, and 0 otherwise.

[13] In instances when Monday is a holiday, the pre holiday dummy definition is applied to Friday.

Multiplicative Dummies

I use a set of multiplicative dummies to examine whether the relationship between spread and quote revision and/or volatility might be different before market closures (Friday and before market holidays). I include in the regressions the product of the week of the day dummy variable (or preceding holiday dummy variable) and trading activity proxy. The Friday X Quote Revisions dummy variable will take the value 1.0 if the trading day is a Friday, and 0 otherwise. The Preceding Holiday X Quote Revisions dummy variable will take the value 1.0 if a trading day satisfies the following conditions: (1) if a holiday falls on Monday, then the preceding Friday, (2) if a holiday falls on another weekday, then the preceding day, and 0 otherwise. We also include in the regressions the product of the week of the day indicator (or preceding holiday indicator) and volatility variable. The Friday X Volatility dummy variable will take the value 1.0 if the trading day is a Friday, and 0 otherwise.

The Preceding Holiday X Volatility dummy variable will be 1.0 if a trading day satisfies the following conditions: (1) if a holiday falls on Monday, then the preceding Friday, (2) if a holiday falls on another weekday, then the preceding day, and 0 otherwise.

Section 7.2.2: Information based

Asymmetric information paradigms of Kyle (1985) and Admati and Pfleiderer (1988) suggest another group of plausible determinants for the spread. One way for uninformed traders to protect against informative incoming order flow is to increase the bid-ask spreads. A number of papers examine the effect of scheduled macroeconomic announcements on FX prices and find increased return volatility on days of macroeconomic announcements (Andersen, Bollerslev, Diebold and Vega 2003, Andersen and Bollerslev 1998, Harvey and

Huang 1991, Ederington and Lee 1993). However, no papers to my knowledge examine the effect of these announcements on the FX spreads. Although asymmetric information is unlikely for scheduled macroeconomic announcements, there are some reasons to expect some differences in the spread behavior of interbank traders located in London or Tokyo as opposed to New York when macroeconomic news is released in the foreign exchange market.

For example, London traders might have a geographic advantage over traders in New York or Tokyo (and vice versa), in terms of information about UK macroeconomic announcements which could reflect a local leakage of information. Moreover, local traders may have superior ability to evaluate the consequences of processing public signals generated in their own country about future domestic monetary policy; and therefore, traders in other locations may increase spreads before the macroeconomic announcements to protect themselves from this possibility.

I focus on information associated with macroeconomic announcements that are both growth related and inflation related. Since I consider three different time zones in this study, I separate macroeconomic announcements into US, UK and Asia (Japan) announcements. Table 7.1 contains a comprehensive summary of the macroeconomic announcements used in this study.

For the daily sample I use separate dummies for the day of the announcement and for the two days preceding the announcement. For the former the dummy variables will take the value 1.0 on the day of a macroeconomic announcement, and 0 otherwise. For the latter, the dummy variables will take the value 1.0 on the two trading days prior to a macroeconomic announcement, and 0 otherwise. For the intra-day sample, I include separate dummy variables for the three hours before and three hours after the macroeconomic announcement. For the former the dummy variables will take the value of 1.0 on the three hours before a macroeconomic announcement, and 0 otherwise. For the later the dummy variable will take the value 1.0 on the three hours after an interest rate announcement and 0 otherwise. I use a three hour framework after examining the significance of the dummy variables at longer horizons (starting at six hours before and after the announcement) and reducing by one hour until results became statistically significant.

U.S macroeconomic announcements

I include dummy variables for macroeconomic announcements about Federal fund rate (IRUS)[14], Gross Domestic Product (GDPUS)[15], Consumer Price Index (CPIUS), Trade Balance (TBUS). There were in total 429 announcements for the period of our sample. The information was obtained from the Bureau of Economic Analysis[16] (BEA) and the Bureau of Labor Statistics (BLS)[17].

U.K macroeconomic announcements

I include dummy variables for macroeconomic announcements about Bank of England Basic Rate (IRUK), Gross Domestic Product (GDPUK)[18], Consumer Price Index (CPIUK), Trade Balance (TBUK). There were in total 275 announcements for the period of our sample. The information was obtained from Online National Statistics (ONS)[19].

Japan macroeconomic announcements

I include dummy variables for macroeconomic announcements about Bank of Japan Basic Rate, Gross Domestic Product (GDPAS)[20], Consumer Price Index (CPIAS), Trade Balance (TBAS). There were in total 278 announcements for the

[14] IRUS: FRB (Federal Reserve Board), www.federalreserve.gov/fomc/

[15] GDP announcements include preliminary, advanced and final announcements in separate dummies.

[16] GDP, TB: BEA (Bureau of Economic Analysis), www.bea.gov/bea/newsrelarchive

[17] CPI, PPI: BLS (Bureau of Labor Statistics), www.bls.gov/cpi

[18] GDP announcements include only preliminary announcements.

[19] GDP, TB, CPI: ONS (Online National Statistics), www.statistics.gov.uk/ReleaseCalendar

[20] GDP announcements include only preliminary announcements.

period of our sample. The information was collected from the Ministry of Finance of Japan (MFJ)[21] and the Bank of Japan (BOJ).

Table 7.1 Macroeconomic Announcements (January 1995 – January 2005)

	Econ. Variable	Ann. Frequency	Ann. Time	Total No. of Ann	Source
US Macroeconomic Announcements (January 1995 – January 2005)					
IRUS	Federal Fund Rate		2.15 PM (EST)	81	FRB
GDPPUS	Gross Domestic Product Preliminary	Quarterly	8.30 AM (EST)	34[22]	BEA
GDPAUS	Gross Domestic Product Advanced	Quarterly	8.30 AM (EST)	41	BEA
GDPFUS	Gross Domestic Product Final	Quarterly	8.30 AM (EST)	38[23]	BEA
CPIUS	Consumer Price Index	Monthly	8.30 AM (EST)	120	BLS
TBUS	Trade Balance	Monthly	8.30 AM (EST)	115[24]	BEA
UK Macroeconomic Announcements (January 1995 – January 2005)					
GDPPUS	Gross Domestic Product Preliminary	Quarterly	9.30 AM (GMT)	37	ONS
CPIUS	Consumer Price Index	Monthly	9.30 AM (GMT)	118	ONS
TBUS	Trade Balance	Monthly	9.30 AM (GMT)	120	ONS
Japan Macroeconomic Announcements (January 1995 – January 2005)					
GDPPUS	Gross Domestic Product Preliminary	Quarterly	3.30 PM Tokyo (GMT+9)	38	MFJ & BOJ
CPIUS	Consumer Price Index	Monthly	9.30 AM Tokyo (GMT+9)	120	MFJ & BOJ
TBUS	Trade Balance	Monthly	8.50 AM Tokyo (GMT+9)	120	MFJ & BOJ

Note: BEA (Bureau of Economic Analysis), BLS (Bureau of Labor Statistics), ONS (Online National Statistics), MFJ (Ministry of Finance, Japan), BOJ (Bank of Japan)

[21] GDP, TB: Source: MFJ (Ministry of Finance of Japan), www.mof.go.jp/english/mf_review.htm
[22] As a result of two Federal Government shutdowns and weather-related delays, there was no release in November 1995.
[23] As a result of two Federal Government shutdowns and weather-related delays, there was no release in December 1995.
[24] 17 January: Government shutdowns and weather-related delays caused the postponement of the normal December releases.

7.2.3 Data feeder dummies

I also consider five dummies for the each of the six vendors Olsen used to collect the data as this might have caused a shift in the measurement of the spread. Table 7.2 presents the transition dates and the names of the data feeder. All the transitions were in 2001 except the last one which was in March 2005. However, the last one does not affect the data set I use.

Table 7.2: Data Feeder Dummies

Feed Name	**Start**	**End**
Reuters	02Feb86	12Sep01
Alt1	02Apr01	12Sep01
Alt2	25Mar01	11May01
Oanda1	03Sep01	Now
Oanda2	03Sep01	Now
Tenfore1	14Aug01	Now
Tenfore2	26Nov01	Now
GTIS	01Mar05	Now

Section 7.3: Correlation among explanatory variables

Before estimating the effects of the explanatory variables on the bid-ask spreads I obtain correlation results among the explanatory variables[25]. If some of the explanatory variables are correlated, multicollinearity would be present. If multicollinearity is present, the regression model has difficulty telling which explanatory variables is influencing the dependent variable. Since there is not too much that can be done to correct this problem I will use the correlation results to drop out some of the highly correlated variables from the regressions as long as I don't omit any significant variables.

Table 7.3 (Panels A, B and C) presents correlation results for the number of quote revisions, interest rate, and volatility. Results show low positive correlation between the number of quote revisions and volatility in most cases. Based on my

[25] We consider correlation results only for explanatory variables that will be in the same regressions.

results there is no correlation between the interest rate and the volatility variables and between the interest rate and number of quote revisions. Therefore, from the correlation results I see that multicollinearity will exist only between volatility and number of quote revisions variables; however, we have to keep these variables in the regressions to avoid an omitted variable bias.

Table 7.3: Correlations between Explanatory Variables

Panels A,B, and C present correlation results between the number of quote revisions, interest rate variable and volatility variable (full sample) in US, UK and Asia time zones respectively. For the number of quote revisions and the volatility variables for the JP/US and GB/US exchange rate the full sample extends from 01.01.1995 to 31.01.2005. For the number of quote revisions, and the volatility variables for the EU/US exchange rate the full sample extends from 01.01.2001 to 31.01 2005.The correlation results are based on 2630 observations for each variable for the US/JP and GB/US rate and 1066 observations for each variable for the EU/US rate. The daily mean number of quote revisions was calculated based on the number of number of quote revisions recorded in 5-minute intervals, between 8:00am and 5:00pm local time, obtained from Olsen and Executives. The exchange rate volatility is the difference between the highest ask price and lowest bid price during a trading day. The interest rate variable is the interest rate differential between Eurodollar overnight deposit rates (short) and Eurodollar one month deposit rate (long) obtained from DataStream for the period 01.01.1995 to 31.01 2005.

Panel A
Correlation between number of quote revisions, interest rate variable and volatility variable. US time zone, Full Sample

		Number of Quote revisions			Interest Rate Differential
		JP/US	GB/US	EU/US	
Interest Rate Differential		-0.07	-0.04	0.28	n.a
Volatility	JP/US	-0.02	n.a	n.a	-0.03
	GB/US	n.a	0.18	n.a	0.00
	EU/US	n.a	n.a	0.12	-0.09

Panel B
Correlation between number of quote revisions, interest rate variable and volatility variable. UK time zone, Full Sample

		Number of Quote revisions			Interest Rate Differential
		JP/US	GB/US	EU/US	
Interest Rate Differential		-0.06	-0.03	0.09	n.a
Volatility	JP/US	0.03	n.a	n.a	-0.02
	GB/US	n.a	0.28	n.a	0.01
	EU/US	n.a	n.a	0.36	0.00

Panel C
Correlation between number of quote revisions, interest rate variable and volatility variable. AS time zone, Full Sample

		Number of Quote revisions			Interest Rate Differential
		JP/US	GB/US	EU/US	
Interest Rate Differential		-0.07	-0.04	0.28	n.a
Volatility	JP/US	-0.13	n.a	n.a	-0.01
	GB/US	n.a	0.10	n.a	-0.01
	EU/US	n.a	n.a	0.24	-0.02

n.a: Not applicable since these two variables will not be in the some regressions.

Section 7.4: Regression results

Here I examine the determinants of bid-ask spreads using daily and intra-day spread measures for the Dollar/Yen (JP/US), Dollar/Sterling (GB/US) and Dollar/Euro (EU/US) exchange rates. The purpose is to provide useful information in the further development of microstructure research and compare these empirical results with previous ones. To my knowledge there is no other research that addresses these issues across different locations for a ten-year period comparing the results of three different currency pairs using both daily and intraday results.

I estimate these effects by ordinary least squares (OLS) using the various explanatory variables as previously defined. It is unlikely with financial time series data that the variance of errors will be constant over time. This is true also in my sample as documented earlier in the ICSS chapter, where results show many structural breaks in the variance of the spread. I also test the residuals from these preliminary OLS estimations and find that serial correlation of residuals is present in all regressions. Therefore, I consider a model that does not assume that the variance is constant.

I use autoregressive conditional heteroscedasticity (ARCH) statistical process to model the conditional mean and variance of the spreads. Engle (1982) introduced the ARCH model, which was generalized to a GARCH specification by Bollerslev (1986). The ARCH model allows the conditional variance, h_t, of the error term, to depend on the immediately previous value of the squared error. This is known as an ARCH(1), since the conditional variance depends only on one lagged squared error.

$$y_t = \gamma_1 + \gamma_2 x_{2t} + \ldots + \gamma_i x_{it} + \varepsilon_t \qquad \varepsilon \sim N(0,h_t) \qquad \text{eq. 7.1}$$

$$h_t = \alpha_o + \alpha_1 \varepsilon^2_{t-1} \qquad \text{eq. 7.2}$$

The model can be extended to the general case where the error variance depends on q lags of squared errors, which is known as a ARCH(q):

$y_t = \gamma_1 + \gamma_2 x_{2t} + \ldots \gamma_i x_{it} + \varepsilon_t \qquad \varepsilon \sim N(0,h_t) \qquad$ eq. 7.3

$h_t = \alpha_o + \alpha_1 \varepsilon^2_{t-1} + \alpha_2 \varepsilon^2_{t-2} + \ldots + \alpha_i \varepsilon^2_{t-i} \qquad$ eq. 7.4

In the GARCH model, the conditional variance is a function of both the past squared errors and the past conditional variance:

$y_t = \gamma_1 + \gamma_2 x_{2t} + \ldots \gamma_i x_{it} + e_t \qquad \varepsilon \sim N(0,h_t) \qquad$ eq. 7.5

$h_t = \alpha_o + \alpha_1 \varepsilon^2_{t-1} + \alpha_2 \varepsilon^2_{t-2} + \ldots + \alpha_i \varepsilon^2_{t-i} + \ldots + \beta_1 h_{t-1} + \beta_2 h_{t-2} + \ldots + \beta_j h_{t-j}$

or

$h_t = \alpha_o + \sum_{i=1}^{i} \alpha_i \varepsilon^2_{t-i} + \sum_{j=1}^{j} \beta_j h_{t-j} \qquad$ eq. 7.6

I use a GARCH (1,1) specification. A GARCH(1,1) model lags on only one squared return and only one variance:

$y_t = \gamma_1 + \gamma_2 x_{2t} + \ldots \gamma_i x_{it} + e_t \qquad \varepsilon \sim N(0,h_t) \qquad$ eq. 7.7

$h_t = \alpha_o + \sum_{i=1}^{i} \alpha_i \varepsilon^2_{t-1} + \sum_{j=1}^{j} \beta_j h_{t-1} \qquad$ eq. 7.8

In my context the model is the following:

Model for Daily sample

$S_t = \gamma_1 + \gamma_2 NQR_t + \gamma_3 IR_t + \gamma_4 V_t + \gamma_5 PRH1_t + \gamma_6 PRH2_t + \gamma_7 POH1_t + \gamma_8 POH2_t + \gamma_9 LDM_t + \gamma_{10} MON_t + \gamma_{11} FRI_t + \gamma_{12} GDP(0)_t + \gamma_{13} GDP(1\text{-}2)_t + \gamma_{13} CPI(0)_t + \gamma_{14} CPI(1\text{-}2)_t + \gamma_{15} IR(0)_t + \gamma_{16} IR(1\text{-}2)_t + \gamma_{17} TB(0)_t + \gamma_{18} TB(1\text{-}2)_t + \gamma_{19} MD1_t + \gamma_{20} MD2_t + \gamma_{21} MD3_t + \gamma_{22} MD4_t + \gamma_{23} DDF2_t + \gamma_{24} DDF3_t + \gamma_{25} DDF4_t + \gamma_{26} DDF5_t + \gamma_{27} DDF6_t + \varepsilon_t$

eq. 7.9

$h_t = \alpha_o + \alpha_1 \varepsilon^2_{t-1} + \beta_1 h_{t-1} \qquad$ eq. 7.10

Model for Intra-day sample

$S_t = \gamma_1 + \gamma_2 NQR_t + \gamma_3 IR_t + \gamma_4 V_t + \gamma_5 PRH(1)_t + \gamma_6 PRH(2)_t + \gamma_7 POH(1)_t + \gamma_8 POH(2)_t + \gamma_9 LDM_t + \gamma_{10} MON_t + \gamma_{11} FRI_t + \gamma_{12} GDP(Before)_t + \gamma_{13} GDP(After)_t + \gamma_{13} CPI(Before)_t + \gamma_{14} CPI(After)_t + \gamma_{15} IR(Before)_t + \gamma_{16} IR(After) + \gamma_{17} TB(Before)_t + \gamma_{18} TB(After)_t + \gamma_{19} MD1_t + \gamma_{20} MD2_t + \gamma_{21} MD3_t + \gamma_{22} MD4_t + \gamma_{23} DDF2_t + \gamma_{24} DDF3_t + \gamma_{25} DDF4_t + \gamma_{26} DDF5_t + \gamma_{27} DDF6_t + \varepsilon_t$

eq. 7.11

$h_t = \alpha_o + \alpha_1 \varepsilon^2_{t-1} + \beta_1 h_{t-1} \qquad$ eq. 7.12

where:

	Daily Sample	Intraday Sample
S_t	spread for one of our three currency pairs at daily intervals (JP/US, GB/US, EU/US)	spread for one of our three currency pairs at 5-minute intervals (JP/US, GB/US, EU/US)
$\gamma_{2\text{-}27}$	coefficients of the explanatory variables	coefficients of the explanatory variables
NQR	number of quote revisions	number of quote revisions
V	volatility variable	volatility variable
IR_t	interest rate differential between Eurodollar overnight deposit rates (short) and Eurodollar one month deposit rate (long)	interest rate differential between Eurodollar overnight deposit rates (short) and Eurodollar one month deposit rate (long)
PRH1	dummy variable to account for the day preceding local holidays	dummy variable to account for the last four hours of active trading preceding a local holiday
PRH2	dummy variable to account for the day preceding common holidays	dummy variable to account for the last four hours of active trading preceding a common holiday
POH1	dummy variable to account for the day following local holidays	dummy variable to account for the first four hours of active trading following a local holiday
POH2	dummy variable to account for the day following common holidays	dummy variable to account for the first four hours of active trading following a common holiday
LDM	dummy variable to account for the last day of the month	dummy variable to account for the last four hours of active trading on the last day of the month
MON/FRI	dummy variable to account for Monday/Friday (day of the week effects)	MON/FRI is a dummy variable to account for the first/last three hours of active trading on Monday/Friday (day of the week effects)
GDP(0)/ GDP (Before)	dummy variable to account for GDP announcements on the day of announcement.	GDP(Before)) is a dummy variable to account for three hours prior to a GDP announcement.
GDP (1-2)/ GDP (After)	dummy variable to account for one and two days before the GDP announcement.	dummy variable to account for the first three hours after the GDP announcement.
CPI,IR and TB	dummy variables as defined for GDP but for Consumer Price Index, Base Rate, Trade Balance	dummy variables as defined for GDP but for Consumer Price Index, Base Rate, Trade Balance
MD 1-4	set of multiplicative dummies to examine whether the relationship between spread and quote	set of multiplicative dummies to examine whether the relationship between spread and quote revision (or volatility) might be different before market closures (Friday and before market Holidays).
MD1	the product of the Friday dummy variable and number of quote revisions.	the product of the Friday dummy variable and number of quote revisions.
MD2	the product of the holiday dummy variable and number of quote revisions.	the product of the holiday dummy variable and number of quote revisions.
MD3	the product of the Friday dummy variable and the volatility variable.	the product of the Friday dummy variable and the volatility variable.
MD4	the product of the holiday dummy variable and the volatility variable.	the product of the holiday dummy variable and the volatility variable.
DDF 2-6	dummy variable to account for each of the six vendors Olsen used to collect the data.	dummy variable to account for each of the six vendors Olsen used to collect the data.
ε	residuals of the estimated model.	residuals of the estimated model.
h_t	conditional variance.	conditional variance.

Section 7.4.1 Daily sample regression results

The sample size (full sample) is 2630 and 1066 for the JP/US, GB/US and EU/US daily spreads respectively, in each time zone. I use an GARCH(1,1) specification to model the behaviour of spreads. The results of the estimated parameters for US, UK and Asia time zones for the full sample are presented in Table 7.4 (Panels D, E and F) for the quoted and relative spreads. To conserve space I present the regression results of the sub-period samples in the appendix (Appendix 6).

The estimated conditional variance coefficients are significant with few exceptions[26]. The past squared errors (α_1 coefficient) have more influence over the conditional variance of the EU/US spreads than over the JP/US and GB/US spreads for the US and UK time zones. In the Asia time zone this effect is reversed, with the JP/US spread significantly more influenced by its past errors. In particular, the coefficient α_1 in the spread regressions, takes the value 0.26 for the EU/US spread, while α_1 coefficients for JP/US and GB/US spreads are between 0.03 and 0.18 in the US time zone.

The past conditional variance (β_1 coefficient) exerts a much greater influence over the current conditional variance in all regressions for all three time zones. The estimated values of the coefficients β_1 range between 0.53 and 0.96. For the US and UK time zones the influence is considerably greater for the JP/US and GB/US spreads than the EU/US spreads. The estimated coefficients take values between 0.80 and 0.96 for the JP/US and GB/US spreads, and between 0.60 and 0.70 for the EU/US.

The combination of these results suggests that although shocks to the volatility of EU/US spread have more impact than shocks to the volatility of JP/US and GB/US spreads, they are less persistent[27]. Skewness and Kurtosis

[26] With the exceptions for JP/US quoted spread in the US time zone, EU/US quoted spread in the UK time zone and EU/US relative spread in the Asia time zone.
[27] Considering both the US and UK time zones.

statistics for residuals from the GARCH (1,1) models of JP/US, GB/US and EU/US spreads are provided in Table 7.6.

US time zone: Regression results for quoted and relative spreads

Panel D presents results of the estimated parameters in the US time zone. The adjusted R^2 in Panel D range from 67.6 to 94.1 percent; that is, the explanatory variables capture a major part of the daily time-series variation in quoted and relative foreign exchange spreads.

The number of quote revisions variable (trading activity variable) is significantly negative for all currency pairs in both the quoted spread and relative spread regressions. An increase in the level of activity (the number of ticks) would decrease the spread. This negative relationship of spread and trading activity is well-documented in the literature (Glassman 1987, Bessembinder, 1994, Ding 1999). Our results are in line with other papers (Huang and Masulis 1999, Goodhart and Figliuoli 1991, Bollerslev and Domowitz 1993) that use the number of quote revisions as a proxy for trading activity and provide additional evidence to support this relationship across locations using a much broader sample[28].

The interest rate differential is statistically significant in all estimated equations (except for the relative Yen/Dollar rate) with negative signs. Bessembinder (1994) finds that the coefficient on the Eurodollar based proxy for the opportunity cost of liquidity is positive for each currency (British pound, Swiss franc, Japanese, German mark). Becker and Sy (2005) researching bid-ask spreads for Asian emerging market currencies find that the Eurodollar short-long differential has coefficients with mixed sign and hardly turns up significant in any estimated equation.

The coefficient of our volatility variable is positive and statistically significant for both all quoted and relative spreads (except the EU/US relative spread)

[28] Previous papers cover periods ranging from a few days to one or two years. However, I need to note that some papers use tick-by-tick data while I use five-minute intervals. I refer to a time-wise broader sample.

implying that an increase in volatility will increase the spread. The positive relationship between volatility and spreads is reported in many empirical papers, among others Bessembinder 1994, Glassman 1987, Boothe 1987, Bollerslev and Melvin 1994.

I find some evidence that spreads increase before holidays in major trading centers, when either local or common holidays across markets are considered. In the JP/US and EU/US spread equations, the estimated parameter of the preceding holiday dummy (in a single financial center) is positive and statistically significant. I also find that the EU/US quoted spread increases before holidays observed simultaneously in the three financial centres. Bessembinder (1994) finds that holidays observed simultaneously in major financial centers are associated with higher spreads, while holidays in observed in only a single financial center do not decrease spreads significantly. Huang and Masulis (1999) find the deutschmark/dollar spread increases before Pacific, European and North American holidays does not change significantly before Asian holidays. I also find that post holiday dummies have explanatory power on the spread. In particular, spread decreases after holidays are observed either by a single financial market or observed simultaneously in three financial markets.

The last day of the month dummy is not significant in any spread equation indicating that the last day of the month is not a significant variable to determine the shifts of the spreads under examination (Results differ when I use intraday observations, see next section). This result is in contrast to Huang and Masulis (1999), who find that spread are higher the last day of the month for the deutschmark/dollar rate.

Theoretical and empirical research, for example Glassman (1987) and Bessembinder (1994), support the fact that spreads should be higher before weekends to reflect increased risk and reduced liquidity. However, I don’t find any evidence that spreads are higher on Fridays using daily spread measures. This may be explained by the fact that spreads only increase late on Friday towards the end of the trading day. I re-examine this issue in the next section where I re-estimate the equations using five-minute interval data and Friday closing-time indicators. However, I find that spreads decrease on Mondays reflecting lower holding risk and increased liquidity.

There is very little evidence that scheduled macroeconomic announcements have an effect on either the quoted or relative spread. Most estimated parameters (with three exceptions) for GDP, CPI, Trading Balance and Interest Rates announcements both for the dummies on the day of the announcement and for the dummies for one and two days before the announcement are statistically insignificant in the spread regressions. This indicates that the daily sample can’t capture the impact from macroeconomic announcements because it is short-lived (high speed of asymmetric information during the day). I also re-examine this issue in the next section where we re-estimate the equations using five-minute interval data and announcement-time indicators.

To explore the possibility that spreads change before Fridays and holidays due to increased sensitivity to trading activity or volatility I use the four multiplicative dummies described earlier. Bessembinder (1994) points out that coefficients on these kind of interaction variables might capture the differential effect of inventory costs on spreads for Fridays and holidays in relation to other days.

My results suggest that there is a different quote revision pattern before weekends (but not holidays) as the positive coefficients for the FridayXQuote revisions dummies show for both the quoted and relative JP/US and GB/US spreads. This implies that spreads are more sensitive to the number of quote revisions on Fridays than before holidays since the estimated parameters are not statistically significant. This means that an increase in quote revision on Friday is impacting on spreads possibly because the lack of liquidity over the weekend is offsetting any temporary higher liquidity (due to increased trading activity). In other words, market participants react differently to the increase in trading activity on different days of the week and reduce spreads when trading activity is increased on Monday to Thursday but not on Friday. It might be interesting to examine in the future whether this relationship changes over the rest of the week.

These results to some extent support the results of Bessembinder (1994) who finds that spreads are more sensitive to liquidity costs when combined with lack of liquidity over the weekends. However, Bessembinder finds that these effects hold also for days preceding holidays, whereas in my data this is not evident.

The negative coefficient estimates for the JP/US and GB/US quoted and relative spread regressions on the product of Friday indicator and volatility imply that spreads are less sensitive to increased volatility on Friday. This means that an increase in volatility has a bigger magnitude on the spread during Monday to Thursday than Friday. This might be explained by the fact that higher volatility might be expected by market participants on Friday due to the upcoming non trading interval (weekend), but when volatility increases during the other days of the week this might be considered as a sign of unknown events to them, to which they react by increasing the spread. These results contradict Bessembinder's (1994) findings that spreads are more sensitive to risk when combined with lack of liquidity over the weekends.

Overall, I can summarise the results from the US time zone as follows:

- Quoted and relative spreads respond to changes in trading activity. An increase in the number of quote revisions would decrease the spread.

- In most cases the interest rate variables are statistically significant

- There is ample evidence that the FX rate volatility is a significant determinant of the spreads.

- There is some evidence that spreads increase before holidays and no evidence that the last day of the month affects the spreads.

- There is strong evidence that spreads decrease on Mondays

- Scheduled macroeconomic announcements do not seem to influence the spread.

UK time zone: Regression results for quoted and relative spreads

Panel E shows results for regression results in the UK time zone. The adjusted R^2 range from 55.8 to 96.3 percent; that is, the explanatory variables capture a major part of the daily time-series variation in quoted and relative foreign exchange spreads.

The number of quote revisions (trading activity variable) is significantly negative for all currency pairs in both the quoted spread and relative spread regressions. An increase in the number of quote revisions would decrease the spread. The results are in line with the findings in the US time zone.

Overall, the interest rate variable is statistically significant but in fewer equations compared to the US time zone. This may be explained by the fact that I use the dollar rate to consider the inventory holding cost. Of course, not all traders use the dollar to consider holding costs.

The estimated parameters of our volatility variable is positive and statistically significant for both the quoted and relative spreads for the JP/US and GB/US currency pairs implying that an increase in volatility will increase the spread.

In contrast to the results from the US time zone, I don't find evidence that spreads increase before holidays in major trading centers either when local holidays or when common holidays across markets are considered. However, I find some evidence that post holiday dummies have explanatory power on the spread.

Different results between US and UK time zone are also found for the last day of the month dummy; it is significant for the GB/US. This provides additional evidence that spreads might be higher on the last day of the month.

As with the US sample, Monday seems to significantly influence the spread in some spread equations, while Friday dummy has mixed signs. This may be explained by the fact that since the FX market is a 24-hour market, the variables capture the increase cost only in some cases.

There is again very little evidence that scheduled macroeconomic announcements have an effect on either the quoted or relative spread. Most estimated parameters (with three exceptions) for GDP, CPI, Trading Balance and Interest Rates announcements both for the dummies on the day of the announcement and for the dummies for one and two days before the announcement are statistically insignificant in the spread regressions.

My results suggest that there is a different quote revision pattern and different volatility impact before weekends and holidays as for some spread equations the estimated parameters are significant for the FridayXQuote revisions and FridayXVolatility dummies. It is interesting to note that the signs of the estimated parameters are mixed. I will revisit that when we discuss the results of the intraday sample.

Overall, I can summarise the results from the UK time zone as follows:

- Quoted and relative spreads respond to changes in trading activity. An increase in the number of ticks would decrease the spread.

- In many cases the interest rate variable is statistically significant.

- There is evidence that the FX rate volatility is a significant determinant of the spreads for the quoted and relative spreads of JP/US and GB/US but not for the EU/US.

- There is no evidence that spreads increase before holidays and little evidence that they decrease after holidays.

- There is some evidence that the day of the week is an important determinant of spreads.

- Scheduled macroeconomic announcements do not seem to influence the spread at least when the daily sample is considered.

Asia time zone: Regression results for quoted and relative spreads

Panel F shows results for regression results in the Asia time zone. The adjusted R^2 range from 68.2 to 99.7 percent. For the number of quote revisions the results are similar to the US and UK time zones. However, there is a considerable difference when we look at the results of the interest rate and volatility variables since they don't seem to have significant influence in the Asia time zone sample.

As with the US time zone I find evidence that spreads increase before holidays in major trading centers when common holidays across markets are considered. I also find some evidence that spreads decrease after holidays.

The last day of the month has no impact on the spread as the estimated parameters are all statistically insignificant. Both Monday and Friday negatively influence the spread as the signs of the estimated parameters show.

Scheduled macroeconomic announcements don't seem to affect (with few exceptions) the spreads in the Asia time zone. Therefore, I can conclude that when daily observations are used the macroeconomic announcements in all three time zones have little, if any, impact on the spreads.

The results for the multiplicative dummies are similar to the UK time zone. There is a different quote revision pattern and different volatility impact before weekends and holiday as for some spread equations the estimated parameters are significant for the FridayXQuote revisions and FridayXVolatility dummies.

Overall, I summarise the results from the ASIA time zone as follows:

- Quoted and relative spreads respond to changes in trading activity. An increase in the number of quote revisions would decrease the spread (excluding JP/US quoted spread).

- In most cases the interest rate and volatility variables are not statistically significant.

- There is some evidence that spreads increase/decrease before/after holidays and no evidence that the last day of the month affects the spreads.

- There is strong evidence of day of the week effects.

- In almost all equations scheduled macroeconomic announcements do not influence the spread.

Section 7.4.2: Summary of daily sample results

The results for the three currency pairs in the different time zones show that there are some commonalities and some differences in the variables I examine. The key finding from the daily regressions is that macroeconomic news announcements are not significant in the determination of the bid-ask spread across different rates and across different time zones. That means that even if there is asymmetric information regarding the public macroeconomic announcements it has a short-lived effect. I revisit this issue in the next section using intraday data.

Quoted and relative spreads in all time zones respond to changes in trading activity. An increase in the number of quote revisions would decrease the spread. This result supports further the well documented negative relationship between spreads and trading activity (Huang and Masulis 1999, Goodhart and Figliuoli 1991, Bollerslev and Domowitz 1993). As for the interest rate differential variable there is strong evidence that it is a significant variable in the determination of the spread in the US and UK time zones but almost no evidence in the Asian time zone. Bessembinder (1994) has also documented the significant relationship between the two variables. Volatility has a significant impact on the spread of most currency pairs in the US and UK time zones but not in Asia time zone. Previous studies by Bessembinder (1994), Glassman (1987) and Bollerslev and Melvin (1994) report the positive relationship between spread and volatility. Finally, there is some evidence of the day of the week effect and seasonality effect in all time zones. Previous empirical studies that examine seasonality effects report mixed results [(Bessembinder (1994), Huang and Masulis (1999)].

Table 7.4: Time Series Regressions for Daily Sample (US, UK and Asia Time Zone, Full Sample)

Depended variables are daily mean quoted and relative spreads. The daily mean quoted spreads were calculated based on the last recorded bid and ask quotes at 5-minute intervals, between 8:00am and 5pm local time. The daily mean relative spreads were calculated based on the difference between the logarithm of the ask price and the logarithm of the bid price. The logarithmic bid and ask values are based on the last bid-ask quotes recorded at 5-minute intervals, between 8:00am and 5:00pm local time. Explanatory variables are the number of quote revisions: mean quote revisions were calculated based on the number of quote revisions recorded in 5-minute intervals, between 8:00am and 5:00pm local time; Interest rate differential between Eurodollar overnight deposit rates (short) and Eurodollar one month deposit rate (long); *Volatility*: the difference between the highest ask price and lowest bid price during a trading day; *Preceding Holiday*: 1.0 if a trading day satisfies the following conditions: (1) if holiday falls on Monday, then the preceding Friday, (2) if any holiday falls on another weekday, then the preceding day, and 0 otherwise; *Post Holiday*: 1.0 if a trading day satisfies the following conditions: (1) if holiday falls on Friday, then the following Monday, (2) if any holiday falls on another weekday, then the following day, and 0 otherwise; *Last Day of Month*: 1.0 if the last trading day of the month, and 0 otherwise; *Monday/Friday*: 1.0 if the trading day is a Monday/Friday and 0 otherwise; *IR(0):* 1.0 on the day of an interest rate announcement, and 0 otherwise; *IR(1-2)*: 1.0 on the two trading days prior to an interest rate announcement, and 0 otherwise; *GDPP(0)*: 1.0 on the day of a GDP (preliminary) announcement, and 0 otherwise; *GDPP(1-2)*: 1.0 on the two trading days prior to a GDP (preliminary) announcement, and 0 otherwise; *CPI(0), CPI(1-2), TB(0), TB(1-2))*: Defined as for GDP but for CPI and TB respectively; *Multiplicative Dummies:* Friday X Quote Revisions (or Volatility): 1.0 if the trading day is Friday, and 0 otherwise; Prec. Holiday X Quote Revisions (or Volatility): 1.0 if a trading day satisfies the following conditions: (1) if holiday falls on Monday, then the preceding Friday, (2) if any holiday falls on another weekday, then the preceding day, and 0 otherwise; *Lagged Spread*: the previous spread observation; *DFD (Data Feeder Dummies), DFD2:* 02Apr01 - 12Sep01 (Reuters and Alt1, this is the period for which the two data feeders overlap); *DFD3:* 25Mar01 - 11May01 (Reuters, Alt1 and Alt2, this is the period for which the three data feeders overlap)*; DFD4:* 03Sep01 - 12Sep01 (Reuters, Alt1, Alt2 and Oanda, this is the period for which the four data feeders overlap); *DFD5:* 14Aug01 - 12Sep01 (Reuters, Alt1, Alt2, Oanda, and Tenfore1, this is the period for which the five data feeders overlap); *DFD6:* 26Nov - 31Jan05 (Oanda,Tenfore1 and Tenfore2, this is the period for which these data feeders overlap); α_o: the constant in the conditional variance equation; α_1 *:* the coefficient of the past squared residuals of the conditional variance; β_1: the coefficient of the past values of the conditional variance.

Panel D: US Time Zone, Full Sample												
	Quoted Spread						Revative Spread					
	JP/US		GB/US		EU/US		JP/US		GB/US		EU/US	
Parameter	Estimate	P-value	Estimate	P-value	Estimate	P-value	Estimate	P-value	Estimate	P-value	Estimate	P-value
Number of Quote Revisions	-0.0051866200	[.000]*	-0.0001073140	[.000]*	-0.0000972303	[.000]*	-0.0000124766	[.000]*	-0.0000246528	[.000]*	-0.0000387699	[.000]*
Interest Rate	-0.8133550000	[.000]*	-0.0052603000	[.024]*	-0.0084780600	[.001]*	0.0003761480	[.646]	-0.0032286200	[.000]*	-0.0028300700	[.001]*
Volatility	0.0021801200	[.000]*	0.0018349400	[.000]*	0.0005764720	[.077]**	0.0000048095	[.000]*	0.0003049340	[.000]*	0.0001399920	[.239]
Seasonality (US)												
Preceding Holiday:												
US only	0.0053603300	[.049]*	0.0000630341	[.296]	0.0000115859	[.925]	0.0000224624	[.056]**	0.0000111835	[.443]	-0.0000269646	[.682]
Common	0.0044921900	[.249]	-0.0000102781	[.775]	0.0002272390	[.020]*	0.0000090706	[.534]	-0.0000003779	[.963]	0.0000431623	[.501]
Post Holiday:												
US only	-0.0015961700	[.008]*	-0.0000216624	[.000]*	-0.0000171412	[.004]*	-0.0000061669	[.004]*	-0.0000059645	[.000]*	-0.0000116670	[.000]*
Common	-0.0070666000	[.001]*	-0.0000296994	[.018]*	0.0000435681	[.272]	-0.0000280334	[.001]*	-0.0000113276	[.006]*	0.0000055047	[.739]
Last Day of Month	0.0005829860	[.239]	0.0000072686	[.150]	0.0000046872	[.430]	0.0000016249	[.393]	0.0000023353	[.102]	0.0000028843	[.177]
Monday	-0.0022978200	[.000]*	-0.0000189648	[.000]*	-0.0000139633	[.000]*	-0.0000089175	[.000]*	-0.0000057597	[.000]*	-0.0000093460	[.000]*
Friday	0.0000895292	[.956]	-0.0000165855	[.370]	0.0000396002	[.305]	-0.0000023720	[.687]	-0.0000047713	[.274]	0.0000277935	[.103]
Macroeconomic Ann. (US)												
GDP preliminary: GDPP(0)	-0.0004950680	[.509]	-0.0000056753	[.515]	0.0000071782	[.285]	-0.0000014278	[.655]	-0.0000013240	[.568]	0.0000024957	[.319]
GDP preliminary: GDPP(1-2)	-0.0001902810	[.754]	-0.0000084268	[.160]	0.0000012092	[.863]	0.0000005826	[.832]	-0.0000022864	[.147]	-0.0000001570	[.949]
Consumer Price Index: CPI (0)	-0.0003716900	[.361]	-0.0000004953	[.901]	0.0000013993	[.749]	-0.0000011984	[.490]	0.0000002356	[.813]	0.0000012867	[.501]
Consumer Price Index: CPI (1-2)	0.0001359890	[.685]	0.0000036426	[.211]	0.0000048430	[.147]	0.0000006564	[.605]	0.0000011097	[.113]	0.0000021088	[.194]
Federal Fund Rate (0)	0.0007487490	[.219]	-0.0000009246	[.911]	0.0000040060	[.418]	0.0000026963	[.255]	-0.0000009593	[.641]	0.0000007322	[.696]
Federal Fund Rate (1-2)	-0.0002286130	[.596]	0.0000022706	[.686]	0.0000006811	[.869]	0.0000002713	[.878]	0.0000006161	[.701]	0.0000000028	[.999]
Trade Balance (0)	-0.0000026916	[.994]	0.0000053498	[.264]	-0.0000059304	[.223]	0.0000000209	[.989]	0.0000020916	[.075]**	-0.0000024698	[.278]
Trade Balance (1-2)	0.0001395270	[.680]	-0.0000063858	[.063]**	-0.0000025745	[.430]	-0.0000000673	[.956]	-0.0000014767	[.050]*	-0.0000008370	[.510]
Multiplicative Dummies												
Friday X Quote Revisions	0.0021281600	[.010]*	0.0000252290	[.016]*	-0.0000038746	[.837]	0.0000099726	[.001]*	0.0000064731	[.007]*	-0.0000088728	[.282]
Prec. Holiday X Quote Revisions	-0.0016593300	[.217]	-0.0000278255	[.346]	-0.0000127633	[.833]	-0.0000068909	[.243]	-0.0000050641	[.461]	0.0000110383	[.729]
Friday X Volatility	-0.0015657300	[.006]*	-0.0010729500	[.059]**	0.0003673070	[.552]	-0.0000057356	[.009]*	-0.0002606990	[.050]*	0.0002435810	[.285]
Prec. Holiday X Volatility	-0.0019444700	[.122]	0.0000788000	[.942]	0.0017185200	[.275]	-0.0000068102	[.205]	0.0000457805	[.857]	0.0003490440	[.603]
Lagged Spread	0.6240780000	[.000]*	0.5565100000	[.000]*	0.4326640000	[.000]*	0.7302970000	[.000]*	0.6590210000	[.000]*	0.7118630000	[.000]*
Data Feeder Dummies												
DDF2	-0.0026441900	[.001]*	-0.0000748470	[.000]*	-0.0000132034	[.221]	-0.0000095529	[.001]*	-0.0000109534	[.000]*	-0.0000032040	[.357]
DDF3	0.0033295500	[.018]*	0.0000317897	[.185]	0.0000051149	[.532]	0.0000091638	[.071]**	0.0000064250	[.324]	-0.0000013418	[.716]
DDF4	0.0031187300	[.368]	0.0000975852	[.061]**	0.0000639361	[.029]*	0.0000168773	[.207]	0.0000273606	[.078]**	0.0000295109	[.035]*
DDF5	0.0008841330	[.559]	0.0000496790	[.148]	0.0000333291	[.012]*	0.0000050988	[.347]	0.0000087429	[.402]	0.0000114671	[.121]
DDF6	-0.0067945600	[.000]*	-0.0000560592	[.000]*	-0.0000304355	[.004]*	-0.0000189249	[.000]*	-0.0000139246	[.000]*	-0.0000151692	[.002]*
α_0	0.0000000340	[.744]	0.0000000001	[.515]	0.0000000002	[.001]*	0.0000000000	[.285]	0.0000000000	[.290]	0.0000000000	[.290]
α_1	0.0354030000	[.285]	0.1795420000	[.005]*	0.2631220000	[.000]*	0.1126820000	[.013]*	0.1613410000	[.001]*	0.2624220000	[.010]*
β_1	0.9645500000	[.000]*	0.8360350000	[.000]*	0.6033370000	[.000]*	0.8739900000	[.000]*	0.8606790000	[.000]*	0.7143690000	[.000]*
Intercept	0.0306290000		0.0004507950		0.0004627300		0.0000771726		0.0000980897		0.0001635020	
Adjusted R-squared	0.90721		0.911102		0.676613		0.888843		0.941215		0.812217	
*: 5 percent level of significance, **: 10 percent level of significance												

Panel E: UK Time Zone, Full Sample												
	Quoted Spread						Revative Spread					
	JP/US		GB/US		EU/US [a]		JP/US		GB/US		EU/US	
Parameter	Estimate	P-value	Estimate	P-value	Coefficient	P-value	Estimate	P-value	Estimate	P-value	Estimate	P-value
Number of Quote Revisions	-0.0045837500	[.000]*	-0.0000252173	[.023]*	-0.0000565802	[.000]*	-0.0000148633	[.001]*	-0.0000114990	[.000]*	-0.0000386896	[.099]**
Interest Rate	-0.4248550000	[.075]**	-0.0013601700	[.477]	-0.0061518200	[.021]*	0.0007661380	[.341]	-0.0011190800	[.027]*	-0.0022283900	[.056]**
Volatility	0.0013633800	[.000]*	0.0009405850	[.001]*	0.0000594955	[.893]	0.0000030330	[.004]*	0.0001430620	[.027]*	0.0002976710	[.102]
Seasonality (UK)												
Preceding Holiday:												
UK only	-0.0007930290	[.854]	-0.0000714364	[.325]	0.0000392175	[.210]	-0.0000015299	[.928]	-0.0000203160	[.215]	0.0000222558	[.487]
Common	0.0039903600	[.493]	0.0000575583	[.353]	0.0000367930	[.154]	0.0000168162	[.496]	0.0000195130	[.386]	-0.0000131724	[.755]
Post Holiday:												
UK only	-0.0010205800	[.173]	-0.0000194849	[.070]**	-0.0000409001	[.000]*	-0.0000024099	[.447]	-0.0000042458	[.030]*	-0.0000161219	[.000]*
Common	-0.0022723600	[.484]	0.0000241218	[.223]	0.0000073791	[.735]	0.0000079114	[.624]	0.0000048982	[.340]	-0.0000149601	[.085]**
Last Day of Month	0.0001113060	[.821]	0.0000073259	[.051]**	0.0000013181	[.830]	-0.0000002814	[.886]	0.0000020367	[.037]*	0.0000003158	[.888]
Monday	-0.0005746500	[.051]**	-0.0000050343	[.160]	-0.0000006636	[.849]	-0.0000021468	[.062]**	-0.0000018653	[.014]*	-0.0000025723	[.397]
Friday	0.0015470300	[.132]	0.0000276877	[.005]*	0.0000055472	[.665]	0.0000050109	[.285]	0.0000033465	[.232]	-0.0000057578	[.083]**
Macroeconomic Ann. (UK)												
GDP preliminary: GDPP(0)	-0.0005367640	[.461]	-0.0000012798	[.867]	-0.0000094046	[.350]	-0.0000023012	[.418]	-0.0000010132	[.564]	-0.0000022863	[.527]
GDP preliminary: GDPP(1-2)	0.0001454480	[.777]	0.0000072681	[.237]	-0.0000018925	[.788]	-0.0000001459	[.938]	0.0000013833	[.259]	-0.0000007558	[.787]
Consumer Price Index: CPI (0)	0.0001134260	[.824]	0.0000138575	[.073]**	-0.0000052424	[.379]	-0.0000010107	[.655]	0.0000027772	[.015]*	-0.0000004253	[.815]
Consumer Price Index: CPI (1-2)	-0.0003493220	[.358]	-0.0000006809	[.878]	0.0000051922	[.259]	-0.0000018576	[.197]	-0.0000012429	[.183]	0.0000015115	[.323]
Bank of England Base Rate (0)	0.0001046370	[.823]	0.0000046156	[.430]	-0.0000053295	[.375]	-0.0000004168	[.819]	0.0000003977	[.752]	-0.0000028624	[.291]
Bank of England Base Rate (1-2)	-0.0004588930	[.146]	0.0000072773	[.100]	-0.0000041644	[.353]	-0.0000027601	[.026]*	0.0000014619	[.093]	-0.0000018384	[.186]
Trade Balance (0)	-0.0005810330	[.279]	-0.0000085342	[.296]	0.0000000992	[.986]	-0.0000019278	[.372]	-0.0000013363	[.338]	-0.0000027550	[.232]
Trade Balance (1-2)	-0.0000878746	[.781]	-0.0000134466	[.054]**	-0.0000000734	[.987]	-0.0000002825	[.819]	-0.0000024882	[.019]*	-0.0000000681	[.960]
Multiplicative Dummies												
Friday X Quote Revisions	-0.0008162920	[.096]**	-0.0000041702	[.547]	0.0000006821	[.925]	-0.0000026491	[.221]	0.0000004262	[.820]	0.0000051073	[.004]*
Prec. Holiday X Quote Revisions	0.0006933170	[.711]	0.0000132729	[.678]	-0.0000319195	[.032]*	0.0000025818	[.702]	0.0000052939	[.460]	-0.0000279479	[.080]**
Friday X Volatility	-0.0000335904	[.959]	-0.0008181200	[.121]	-0.0006655880	[.423]	-0.0000001958	[.942]	-0.0001936730	[.102]	-0.0004625240	[.055]**
Prec. Holiday X Volatility	0.0006476390	[.760]	0.0008661340	[.707]	0.0054877500	[.043]*	0.0000011832	[.886]	0.0000983323	[.829]	0.0040586100	[.104]
Lagged Spread	0.6830880000	[.000]*	0.7893970000	[.000]*	0.4345110000	[.000]*	0.7258930000	[.000]*	0.7401700000	[.000]*	0.6868850000	[.000]*
Data Feeder Dummies												
DDF2	-0.0049488500	[.000]*	-0.0000655400	[.001]*	0.0000061355	[.305]	-0.0000176427	[.000]*	-0.0000167605	[.000]*	0.0000006901	[.942]
DDF3	0.0007080880	[.522]	0.0000102709	[.544]	0.0000055752	[.484]	0.0000031902	[.435]	0.0000029922	[.552]	0.0000003165	[.960]
DDF4	0.0023127800	[.535]	-0.0000201953	[.495]	0.0000290422	[.100]	0.0000100016	[.443]	-0.0000034190	[.711]	0.0000149759	[.133]
DDF5	0.0016054500	[.276]	0.0000537483	[.006]*	0.0000074999	[.519]	0.0000065323	[.209]	0.0000151306	[.007]*	0.0000038047	[.452]
DDF6	-0.0074149500	[.000]*	-0.0000699655	[.015]*	-0.0000341803	[.000]*	-0.0000234252	[.000]*	-0.0000228812	[.000]*	-0.0000200195	[.215]
α_0	0.0000000243	[.489]	0.0000000001	[.502]			0.0000000000	[.376]	0.0000000000	[.345]	0.0000000000	[.203]
α_1	0.0411050000	[.035]*	0.2417060000	[.009]*			0.0500550000	[.003]*	0.2175890000	[.002]*	0.3446710000	[.000]*
β_1	0.9613110000	[.000]*	0.8031590000	[.000]*			0.9517800000	[.000]*	0.8308780000	[.000]*	0.6480910000	[.000]*
Intercept	0.028036		2.03E-04		3.38E-04		9.18E-05		7.43E-05		1.43E-04	
Adjusted R-squared	0.92885		0.946306		0.55823		0.918171		0.9633		0.842133	
a: resutls estimated with OLS, *: 5 percent level of significance, **: 10 percent level of significance												

Panel F: ASIA Time Zone, Full Sample												
	Quoted Spread						**Revative Spread**					
	JP/US		**GB/US**		**EU/US** [a]		**JP/US**		**GB/US**		**EU/Us**[a]	
Parameter	Estimate	P-value	Estimate	P-value	Estimate	P-value	Estimate	P-value	Estimate	P-value	Coefficient	P-value
Number of Quote Revisions	-0.0000091310	[.349]	-0.0000761270	[.000]*	0.0000165977	[.000]*	-0.0000159553	[.000]*	-0.0000281380	[.000]*	0.0000123770	[.002]*
Interest Rate	-0.0000015822	[.715]	0.0000051628	[.166]	0.0000060517	[.006]*	0.0000007288	[.461]	-0.0000015036	[.432]	0.0000068832	[.001]*
Volatility	-0.0002230550	[.869]	-0.0007174190	[.587]	-0.0000004425	[.661]	0.0003363000	[.028]*	-0.0005645840	[.161]	-0.0000017174	[.130]
Seasonality (ASIA)												
Preceding Holiday:												
ASIA only	0.0000168025	[.587]	0.0000478626	[.635]	0.0000131876	[.373]	-0.0000036829	[.597]	-0.0000378213	[.161]	-0.0000018192	[.852]
Common	0.0000038062	[.635]	-0.0000073928	[.115]	0.0000038250	[.038]*	-0.0000033206	[.008]*	-0.0000020979	[.397]	0.0000071817	[.003]*
Post Holiday:												
ASIA only	-0.0001170530	[.000]*	0.0000263674	[.484]	-0.0000466750	[.052]**	0.0000012433	[.822]	-0.0000004442	[.980]	-0.0000582582	[.000]*
Common	0.0000063002	[.354]	0.0000046721	[.470]	0.0000037095	[.087]**	0.0000013386	[.388]	-0.0000039438	[.122]	0.0000033156	[.198]
Last Day of Month	0.0000092142	[.397]	-0.0000132021	[.102]	0.0000025175	[.409]	-0.0000021343	[.430]	-0.0000048895	[.232]	0.0000008531	[.876]
Monday	-0.0000060063	[.075]**	-0.0000047602	[.074]**	-0.0000070367	[.000]*	-0.0000022386	[.004]*	-0.0000083192	[.000]*	-0.0000067036	[.000]*
Friday	-0.0022758800	[.451]	-0.0115010000	[.000]*	-0.0022709500	[.010]*	-0.0040129900	[.000]*	-0.0050745500	[.000]*	-0.0013058800	[.065]**
Macroeconomic Ann. (ASIA)												
GDP preliminary: GDPP(0)	-0.0000029318	[.580]	-0.0000021440	[.585]	-0.0000029077	[.174]	0.0000001126	[.938]	-0.0000020198	[.344]	-0.0000022314	[.568]
GDP preliminary: GDPP(1-2)	-0.0000121214	[.076]**	-0.0000038841	[.534]	-0.0000009768	[.671]	-0.0000036413	[.017]*	0.0000005338	[.866]	-0.0000012936	[.634]
Consumer Price Index: CPI (0)	-0.0000068089	[.132]	0.0000061116	[.152]	0.0000007182	[.612]	0.0000002775	[.775]	0.0000019471	[.339]	0.0000007138	[.707]
Consumer Price Index: CPI (1-2)	-0.0000030888	[.592]	0.0000030707	[.433]	0.0000015510	[.331]	0.0000009933	[.373]	0.0000021217	[.341]	-0.0000018764	[.430]
Bank of Japan Base Rate (0)	0.0000000637	[.986]	-0.0000001061	[.970]	0.0000003495	[.785]	-0.0000009081	[.208]	0.0000008700	[.517]	-0.0000012102	[.482]
Bank of Japan Base Rate (1-2)	0.0000110545	[.116]	-0.0000049730	[.407]	-0.0000025571	[.225]	-0.0000001851	[.899]	-0.0000000874	[.973]	-0.0000021649	[.507]
Trade Balance (0)	0.0000027089	[.509]	-0.0000016588	[.653]	0.0000006991	[.661]	0.0000006601	[.474]	-0.0000025485	[.218]	0.0000027074	[.251]
Trade Balance (1-2)	-0.0000287917	[.000]*	-0.0000138690	[.000]*	0.0000058266	[.000]*	0.0000011403	[.160]	0.0000037528	[.011]*	0.0000025848	[.068]**
Multiplicative Dummies												
Friday X Quote Revisions	-0.0000174413	[.001]*	-0.0000155786	[.000]*	-0.0000008449	[.849]	0.0000015041	[.023]*	-0.0000004093	[.744]	-0.0000013317	[.817]
Prec. Holiday X Quote Revisions	0.0000256740	[.096]**	-0.0000128724	[.756]	-0.0000019458	[.417]	-0.0000054714	[.216]	0.0000234897	[.174]	-0.0000014378	[.512]
Friday X Volatility	0.0009932100	[.492]	0.0003013520	[.829]	0.0000009164	[.832]	-0.0005216580	[.004]*	0.0004299490	[.323]	-0.0000038580	[.445]
Prec. Holiday X Volatility	-0.0002256330	[.912]	0.0013463500	[.567]	0.0007630700	[.000]*	0.0000855541	[.862]	0.0002971660	[.759]	0.0006686540	[.000]*
Lagged Spread	0.9986750000	[.000]*	0.4159620000	[.000]*	0.6250440000	[.000]*	0.7713310000	[.000]*	0.7807580000	[.000]*	0.7407050000	[.000]*
Data Feeder Dummies												
DDF2	0.0000139959	[.385]	0.0000012189	[.869]	-0.0000016118	[.646]	-0.0000038839	[.557]	-0.0000039567	[.264]	-0.0000046739	[.295]
DDF3	0.0000701651	[.138]	0.0000626859	[.040]*	0.0000164064	[.411]	0.0000333146	[.097]**	0.0000265027	[.094]**	0.0000118929	[.293]
DDF4	0.0000182842	[.503]	0.0000275226	[.048]*	-0.0000121302	[.018]*	0.0000060300	[.529]	0.0000033340	[.699]	-0.0000094750	[.171]
DDF5	0.0000137268	[.031]*	-0.0000223905	[.000]*	0.0000001241	[.960]	-0.0000068932	[.000]*	-0.0000114405	[.007]*	0.0000028471	[.444]
DDF6	-0.0000263024	[.332]	0.0000225573	[.799]	-0.0000007122	[.938]	0.0000100463	[.345]	-0.0000579195	[.142]	0.0000027412	[.792]
α_0	0.0000000008	[.030]*	0.0000000002	[.001]*	0.0000000000	[.159]	0.0000000000	[.337]	0.0000000000	[.047]*		
α_1	0.3489940000	[.000]*	0.2471170000	[.000]*	0.0685300000	[.004]*	0.1097110000	[.003]*	0.2416970000	[.000]*		
β_1	0.5387560000	[.000]*	0.6361550000	[.000]*	0.9276880000	[.000]*	0.9018610000	[.000]*	0.7638120000	[.000]*		
Intercept	0.0000383235		0.0004175300		0.0000252132		0.0000686073		0.0001103040		0.0000106875	
Adjusted R-squared	0.9976040000		0.6824200000		0.8801790000		0.9326150000		0.8999310000		0.7902720000	
a: resutls estimated with OLS, *: 5 percent level of significance, **: 10 percent level of significance												

Section 7.4.3: Intraday regression results

The number of observations on the full sample is 284,148 and 115,058 for the JP/US, GB/US and EU/US 5-minute interval spreads respectively, in each time zone.

I use an GARCH(1,1) specification to model the behaviour of spreads. The results of the estimated parameters for US, UK and Asia time zones, for the full sample are presented in Panels G, H and I for the quoted and relative spreads. To conserve space I present the regression results of the sub-period samples in the appendix (Appendix 6).

In general the intraday results show that the explanatory variables work better when I use higher frequency data however, their explanatory power is significantly lower as the R square statistics indicate. This observation suggests that although daily spreads and intraday spreads have some common determinants, other factors determine the behaviour of spreads at high frequencies.

The estimated conditional variance coefficients are all significant. The past squared errors have more influence over the conditional variance of the JP/US, GB/US and EU/US spreads for the US time zone than they do for the UK and Asia time zone. The coefficient α_1 in the spread regressions takes values between 0.023 and 0.089, 0.012 and 0.016, 0.018 and 0.045 for the US, UK and ASIA time zones respectively. The past conditional variance exerts a much greater influence over the current conditional variance in all regressions for all three time zones. The estimate values of the coefficients β_1 range between 0.90 and 0.98. The above results suggest that shocks to the volatility of spreads have a low impact on spreads but are highly persistent.

When specific time zones are considered, the past squared errors have more influence over the conditional variance of the JP/US and GB/US spreads than they do for the EU/US spread. The past conditional variance influences our three currency spreads with very similar magnitudes in all three time zones.

Skewness and Kurtosis statistics for residuals from the GARCH (1,1) models of JP/US, GB/US and EU/US spreads are provided in Table 7.6. Below I discuss separately the results of the intra-day sample in our three time zones.

US time zone: Regression results for quoted and relative spreads

Panel G presents results of the estimated parameters in the US time zone. The adjusted R^2 in Panel G range from 20.4 to 50.8 percent; that is, the explanatory variables capture a good part of the daily time-series variation in quoted and relative foreign exchange spreads.

The results for the number of quote revisions variable for the intraday sample are the same as the daily sample. All estimated parameters are significantly negative for all currency pairs in both the quoted spread and relative spread regressions. That means that an increase in the level of activity measured by the number of quote revisions would decrease the spread. These results are in line with other papers (Huang and Masulis 1999, Goodhart and Figliuoli 1991, Bollerslev and Domowitz 1993) that use the number of quote revisions as a proxy for trading activity and provide additional evidence to support this relationship across locations using both daily and intraday samples.

The interest rate differential variable is statistically significant with negative signs for the JP/US, EU/US quoted and GB/US and EU/US relative spreads. This is in contrast to the results of Bessembinder (1994), who finds that the coefficient on the Eurodollar based proxy for the opportunity cost of liquidity is positive for each currency (British pound, Swiss franc, Japanese, German mark). Becker and Sy (2005) researching bid-ask spreads for Asian emerging market currencies find that the Eurodollar short-long differential has coefficients with mixed sign and hardly turns up significant in any estimated equation. Both my daily and intraday results suggest that the Eurodollar short-long differential variable is influencing the spread.

The coefficient of the volatility variable is positive but in fewer spread equations compared to the daily sample. Bessembinder 1994, Glassman

1987, Boothe 1987, Bollerslev and Melvin 1994, have all reported the positive relationship between volatility and spreads.

Using the intraday sample I find much stronger evidence that spreads increase before holidays in major trading centers both when local holidays and when common holidays across markets are considered. This stronger effect is probably due to the fact that I have considered the four hours before the end of the active trading day before the holiday to capture the effect and not the entire trading day. Spreads for the JP/US, EU/US quoted and relative spreads increase both when New York holidays and simultaneous holidays in New York, London and Tokyo are observed. The same applies for the GB/US relative spread but only in the case of commonly observed holidays. My findings support the results of Bessembinder (1994), who finds that holidays observed simultaneously in major financial centers are associated with higher spreads. However, he finds that holiday observed in only a single financial center does not decrease spreads significantly. Huang and Masulis (1999) find the deutschmark/dollar spread increases before Pacific, European and North American holidays but does not change significantly before Asian holidays.

I also find that post holiday dummies in some spread regressions have explanatory power on the spread; however, these findings are different from the ones in our daily sample. In particular, in four out of five spread regressions where the post holiday dummy is significant, the estimated parameters have positive signs indicating that spreads increase in the first four hours of the active trading day after a holiday is observed by a single financial market or simultaneously in three financial markets.

My results suggest that the EU/US quoted spread increased due to last day of the month effect. This provides some additional evidence to the work of Huang and Masulis (1999) who find that spreads are higher on the last day of the month for the deutschmark/dollar rate. However, the estimated parameters for the JP/US and GB/US spreads are not statistically significant.

Theoretical and empirical research, for example Glassman (1987) and Bessembinder (1994), support the fact that spreads should be higher before weekends to reflect the increased risk and the reduced liquidity. I find that spreads are higher on Friday for the JP/US quoted and relative spread. Moreover, I find some evidence that spreads decrease on Mondays reflecting the lower holding risk and increased liquidity.

As expected, using the intraday sample and including announcement-time indicators[29], I find good evidence that spreads depend on scheduled macroeconomic announcements. Federal Fund interest rate announcements affect the spread of all three currency pairs. The spreads decrease four hours before the announcement suggesting that very close to the Fed announcement, there is no uncertainty regarding the outcome of it. CPI and trade balance (TB) announcements have an effect on almost all currency spreads under consideration. In particular, spreads increase after a CPI or a TB announcement.[30] Since CPI and TB are part of the data used to determine future interest rates targets by Fed, it is possible that there are few hours after these announcements where market participants wait to see how agents will interpret the news and therefore incorporate them in the price.

To explore the possibility that spreads change before Fridays and holidays due to increased sensitivity to trading activity or volatility, I use the four multiplicative dummies described earlier. Bessembinder (1994) points out that coefficients on these kind of interaction variables might capture the differential effect of inventory costs on spreads for Fridays and holidays in relation to other days. My results suggest that in almost all spread regression there is not enough evidence to suggest a different quote revision pattern before Fridays or weekends. These results are in contrast both to my daily sample and the results of Bessembinder (1994), who finds that spreads are more sensitive to liquidity costs when combined with lack of liquidity over the weekends or before holidays.

[29] Four hours before and four hours after the scheduled macroeconomic announcement.
[30] With the exception of EU/US quoted spread where the sign is negative.

The positive coefficient estimates for the GB/US quoted and relative spread regressions on the product of preceding holiday indicator and volatility imply that spreads are more sensitive to increased volatility before holidays. These findings support Bessembinder's (1994) results, that spreads are more sensitive to risk when combined with lack of liquidity. [31]

Overall, I can summarise the results from the US time zone as follows:

- Quoted and relative spreads respond changes in trading activity. An increase in the number of quote revisions would decrease the spread.

- In most cases the interest rate variables are statistically significant

- There is some evidence that the FX rate volatility is a significant determinant of the spreads.

- There is good evidence that spreads increase before holidays and little evidence that the last day of the month variable affects the spreads.

- There is strong evidence that spreads decrease on Mondays and some evidence that spreads increase before weekends.

- Some scheduled macroeconomic announcements do influence the spread.

UK time zone: Regression results for quoted and relative spreads

Panel H shows results for regression results in the UK time zone. The adjusted R^2 range from 6.7 to 51 percent; that is, the explanatory variables capture in a good part of the daily time-series variation in JP/US and GB/US quoted and relative foreign exchange spreads but only a very small portion of the variations in the EU/US spreads.

[31] Bessembider's results show higher sensitivity to risk before weekends.

The number of quote revisions is significantly negative for all currency pairs in both the quoted spread and relative spread regressions. An increase in the number of quote revisions would decrease the spread. The results are in line with the findings in the US time zone.

The interest rate differential variable is statistically significant with negative signs for the all spreads except the JP/US relative one that has a positive sign.

The estimated parameter of the volatility variable is positive and significant for the JP/US and GB/US spreads. There is therefore a small difference from the results for US time zone where that GB/US spread was not affected by our volatility proxy.

For the UK time zone sample I find evidence that spreads increase before holidays in major trading centres when common holidays across markets are considered but not when holidays in single centres are considered. My findings support the results of Bessembinder (1994) who finds that holidays observed simultaneously in major financial centers are associated with higher spreads but holiday observed in only a single financial center do not decrease spreads significantly.

I also find that post holiday dummies in some spread regressions have explanatory power on the spread. In particular, I find that GB/US, EU/US quoted and JP/US relative spreads will increase when markets open after a holiday in the UK. Also, when a common holiday is observed in the UK time zone, the EU/US spreads is decreased in the first four hours of active trading after the holiday.

The estimated parameter for the last day of the month variable in all the spread regressions is not statistically significant.

I find that spreads are higher on Friday for the GB/US quoted spread. Moreover, there is some evidence that spreads decrease on Mondays reflecting the lower holding risk and increased liquidity. This is similar to the findings from the US time zone sample.

UK macroeconomic announcements seem to play a less important role in the determination of spreads than US macroeconomic announcements. I still find some evidence that spreads depend on scheduled macroeconomic announcements such as CPI, interest rates and TB but in fewer spread regressions.

As with the US time zone, intraday results suggest that in almost all spread regressions there is not enough evidence to suggest a different quote revision pattern before Fridays or weekends. These results are in contrast both to my daily sample results and the results of Bessembinder (1994) who finds that spreads are more sensitive to liquidity costs when combined with lack of liquidity over the weekends or before holidays.

As with the US time zone, there are positive coefficient estimates for some spread regressions on the product of preceding holiday indicator and volatility imply that spreads are more sensitive to increased volatility before holidays.

Overall, I can summarise the results from the UK time zone as follows:

- Quoted and relative spreads respond changes in trading activity. An increase in the number of quote revisions would decrease the spread.

- In most cases the interest rate variables are statistically significant

- FX rate volatility is a significant determinant of the JP/US and GB/US quoted and relative spreads.

- There is good evidence that spreads increase before holidays and no evidence that the last day of the month affects the spreads.

- There is strong evidence that spreads decrease on Mondays and little evidence that spreads increase before weekends.

- Some scheduled macroeconomic announcements do influence the spread.

ASIA time zone: Regression results for quoted and relative spreads

Panel I shows results for regression results in the Asia time zone. The adjusted R^2 range from 13.5 to 45.5 percent; that is, the explanatory variables capture in a good part of the daily time-series variation in JP/US and GB/US quoted and relative foreign exchange spreads but only a small portion of the variations in the EU/US spreads.

The number of quote revisions is significantly negative for all currency pairs in both the quoted spread and relative spread regressions. An increase in the number of quote revisions would decrease the spread. The results are in line with the findings in the US and UK time zone.

The interest rate differential variable is statistically significant with negative signs for the all spreads.

The estimated parameter of our volatility variable is positive and significant only for the GB/US spreads. I can therefore conclude that the significance of the volatility proxy differs among our three time zones in the intraday sample.

As with the UK time zone I find evidence that spreads change before holidays in major trading centres when common holidays across markets are considered but not when holidays in single centres are considered. However, the signs of the estimated parameters are mixed.

I also find that post holiday dummies in some spread regressions have explanatory power on the spread. In particular, the GB/US, JP/US EU/US quoted and JP/US, EU/US relative spreads will increase when markets open after a holiday is observed simultaneously in New York, London and Tokyo.

The estimated parameter for the last day of the month variable is statistically significant for the JP/US and EU/US spreads but with mixed signs. JP/US spreads tend to increase on the last day of the month while EU/US tend to decrease.

As for the day of week effect, we find that in Asia time zone this is present for all the spreads under examination in this study. I find that spreads increase both on Monday opening and Friday closure.

Like UK macroeconomic announcements, Japan macroeconomic announcements seem to play a less important role in the determination of spreads than US macroeconomic announcements. There is some evidence that spreads depend on scheduled macroeconomic announcements such as CPI, interest rates and TB but in fewer spread regressions.

In contrast to the US and UK time zone results, we find evidence that there is a different quote revision pattern on Fridays in five out of our six spread regressions. The estimated parameters are statistically significant with negative signs.

Unlike to the US and UK time zone results, I don't find any different volatility pattern on Fridays or before holidays. All estimated parameters are statistically insignificant.

Overall, I can summarise the results from the Asia time zone as follows:

- Quoted and relative spreads respond to changes in trading activity. An increase in the number of quote revisions would decrease the spread.

- In all spread regressions the interest rate variables are statistically significant

- Our volatility proxy is a significant determinant of the spread only in the GB/US regressions.

- There is some evidence that spreads change before holidays and little evidence that the last day of the month affects the spreads.

- There is strong evidence of day of the week effects.

- Some scheduled macroeconomic announcements do influence the spread.

Section 7.4.4: Summary of intraday sample results

In contrast to the results from the daily sample I find that macroeconomic news announcements have significant impact on the bid-ask spread when higher frequencies (intraday) are considered. In particular, for the US time zone, I find that Federal Fund interest rate announcements and CPI announcements are significant for the spreads of all three currency pairs. The trade balance announcements are also significant for the JP/US and GB/US spreads but not for the EU/US relative spread. GDP announcements are significant only for the quoted EU/US spread. In the UK time zone, CPI announcements are significant for the GB/US quoted and relative spreads and for the JP/US relative spread but GDP announcements are not significant in any spread regression. Bank of England base rate announcements are influencing the spreads of EU/US and JP/US currency pairs while trade balance announcements influence only the JP/US spread. In the Asia time zone, Bank of Japan base rate announcements are significant across all rates but GDP announcements are only significant for the JP/US relative spread. CPI announcements affect the GB/US spread and trade balance announcements the EU/US spread. From the above results I conclude that macroeconomic announcements induce regular intraday patterns as these announcements are made on set times. My results show that the arrival of news changes bid-ask spreads therefore when traders devise a trading strategy they have to allow for the relevant factors in relevant markets. Moreover, regulators may use this information when considering the timing of the announcements. My findings on the significant impact of macroeconomic announcements on the FX bid-ask spreads add to the existing literature of empirical studies on the effect of macroeconomic announcements on various variables such as FX volatility [Andersen and Bollerslev (1998), Payne (1997)] and FX spot rate returns [Goodhart and Payne (1998)].

Results from the impact of the number of quote revisions on spreads are in line with those of the daily sample. I find a negative relationship between the two variables across all rates and in all three time zones. Interest rate differential variable is a significant determinant of almost all spreads in all time zones. For the volatility variable I find mixed results when I look across major financial markets. Finally, using the intraday sample if find much stronger evidence of day of the week effects and seasonality effects compared to the daily sample in all time zones.

Table 7.5: Time Series Regressions for Intraday Sample (US,UK and Asia Time Zone, Full Sample)

Depended variables the last recorded bid and ask quotes at 5-minute intervals, between 8:00am and 5pm local time. The relative spreads were calculated based on the difference of the logarithm of the ask price and the logarithm of the bid price recorded at 5-minute intervals, between 8:00am and 5:00pm local time. Explanatory variables are the number of quote revision: number of quote revisions recorded in 5-minute intervals, between 8:00am and 5:00pm local time; Interest rate differential between Eurodollar overnight deposit rates (short) and Eurodollar one month deposit rate (long); *Volatility*: the squared result of the log of the exchange rate at time t+1 minus log of the exchange rate at time t, in 5-minute intervals; *Preceding Holiday*: 1.0 if a trading day satisfies the following conditions: (1) if holiday falls on Monday, then the last four hours of active trading on Friday, (2) if any holiday falls on another weekday, then the last four hours of active trading of the preceding day, and 0 otherwise; *Post Holiday*: 1.0 if a trading day satisfies the following conditions: (1) if holiday falls on Friday, then the first four hours of active trading on following Monday, (2) if any holiday falls on another weekday, then the first four hours of active trading on the following day, and 0 otherwise; *Last Day of Month*: 1.0 if the last four hours of active trading on the last day of the month, and 0 otherwise; *Monday/Friday*: 1.0 if the first/last three hours of active trading day is on Monday/Friday, and 0 otherwise; *IR(Before):* 1.0 on the three hours before an interest rate announcement, and 0 otherwise; *IR(After)*: 1.0 on the three hours after an interest rate announcement, and 0 otherwise; *GDPP(Before)*: 1.0 on the three hours before a GDP (preliminary) announcement, and 0 otherwise; *GDPP(After)*: 1.0 on the three hours after a GDP (preliminary) announcement, and 0 otherwise; *CPI(Before), CPI(After), TB(Before), TB(After)*: Defined as for GDP but for CPI and TB respectively; *Multiplicative Dummies: Friday X Quote Revisions:* 1.0 if the trading day is a Friday, and 0 otherwise; *Prec. Holiday X Quote Revisions:* 1.0 if a trading day satisfies the following conditions: (1) if holiday falls on Monday, then the preceding Friday, (2) if any holiday falls on another weekday, then the preceding day, and 0 otherwise; *Friday X Quote Volatility:* 1.0 if the trading day is a Friday, and 0 otherwise; *Prec. Holiday X Quote Volatility:* 1.0 if a trading day satisfies the following conditions: (1) if holiday falls on Monday, then the preceding Friday, (2) if any holiday falls on another weekday, then the preceding day, and 0 otherwise; *Lagged Spread*: the previous spread observation; *DFD (Data Feeder Dummies), DFD2:* 02Apr01 - 12Sep01 (Reuters and Alt1, this is the period for which the two data feeders overlap); *DFD3:* 25Mar01 - 11May01 (Reuters, Alt1 and Alt2, this is the period for which the three data feeders overlap)*; DFD4:* 03Sep01 - 12Sep01 (Reuters, Alt1, Alt2 and Oanda, this is the period for which the four data feeders overlap); *DFD5:* 14Aug01 - 12Sep01 (Reuters, Alt1, Alt2, Oanda, and Tenfore1, this is the period for which the five data feeders overlap); *DFD6:* 26Nov - 31Jan05 (Oanda,Tenfore1 and Tenfore2, this is the period for which these data feeders overlap); α_o: the constant in the conditional variance equation; α_1 : the coefficient of the past squared residuals of the conditional variance; β_1: the coefficient of the past values of the conditional variance.

Panel G: US Time Zone, Full Sample: Intraday												
	Quoted Spread						Revative Spread					
	JP/US		GB/US		EU/US		JP/US[a]		GB/US		EU/US	
Parameter	Estimate	P-value	Estimate	P-value	Estimate	P-value	Coefficient	P-value	Estimate	P-value	Estimate	P-value
Number of Quote Revisions	-0,00589188	[.000]*	-0,00006223	[.000]*	-0,00010279	[.000]*	-0,00001950	[.000]*	-0,00001577	[.000]*	-0,00005023	[.000]*
Interest Rate	-1,26990000	[.000]*	0,00106247	[.759]	-0,01571000	[.000]*	0,00034560	[.172]	-0,00364219	[.000]*	-0,01386100	[.000]*
Volatility	88,17060000	[.005]*	-1,15978000	[.593]	0,90954000	[.193]	0,32815800	[.001]*	-0,14383900	[.774]	0,49591100	[.091]**
Seasonality (US)												
Preceding Holiday:												
US only	0,00104826	[.035]*	0,00000050	[.964]	0,00002646	[.000]*	0,00000583	[.000]*	-0,00000006	[.977]	0,00000449	[.059]**
Common	0,00867860	[.000]*	0,00004677	[.319]	0,00011047	[.000]*	0,00001831	[.001]*	0,00002090	[.012]*	0,00004638	[.000]*
Post Holiday:												
US only	0,00061542	[.146]	0,00001005	[.027]*	-0,00000644	[.138]	0,00000402	[.005]*	0,00000122	[.290]	-0,00000330	[.040]*
Common	0,00479563	[.008]*	0,00005637	[.000]*	0,00000465	[.756]	0,00000518	[.286]	0,00001529	[.000]*	-0,00000182	[.806]
Last Day of Month	0,00108263	[.211]	-0,00000073	[.923]	0,00001205	[.012]*	-0,00000017	[.898]	-0,00000032	[.830]	0,00000143	[.444]
Monday	-0,00039280	[.006]*	-0,00000127	[.486]	-0,00000512	[.000]*	0,00000016	[.746]	-0,00000071	[.067]**	-0,00000325	[.000]*
Friday	0,00312304	[.000]*	0,00000405	[.466]	0,00001148	[.152]	0,00000624	[.000]*	0,00000064	[.601]	0,00000185	[.611]
Macroeconomic Ann. (US)												
GDP preliminary: GDPP(Before)	0,00064891	[.386]	0,00001942	[.174]	0,00001101	[.179]	0,00000016	[.952]	0,00000470	[.295]	-0,00000003	[.993]
GDP preliminary: GDPP(After)	-0,00098553	[.141]	0,00000930	[.233]	-0,00001624	[.019]*	-0,00000062	[.815]	0,00000243	[.226]	-0,00000306	[.270]
Consumer Price Index: CPI (Before)	-0,00000856	[.982]	-0,00000100	[.803]	0,00001026	[.025]*	-0,00000219	[.147]	-0,00000058	[.557]	0,00000291	[.106]
Consumer Price Index: CPI (After)	0,00098072	[.009]*	0,00000785	[.039]*	0,00000418	[.367]	0,00000440	[.003]*	0,00000232	[.011]*	0,00000413	[.021]*
Federal Fund Rate (Before)	-0,00124817	[.008]*	-0,00001697	[.000]*	-0,00000888	[.042]*	-0,00000539	[.003]*	-0,00000426	[.000]*	-0,00000385	[.031]*
Federal Fund Rate (After)	-0,00012525	[.786]	-0,00001161	[.105]	0,00000802	[.122]	-0,00000156	[.390]	-0,00000296	[.113]	0,00000346	[.083]**
Trade Balance (Before)	-0,00019248	[.627]	-0,00001228	[.035]*	0,00000858	[.043]*	-0,00000341	[.026]*	-0,00000334	[.035]*	0,00000152	[.365]
Trade Balance (After)	0,00126398	[.001]*	0,00001542	[.000]*	-0,00000817	[.067]**	0,00000501	[.001]*	0,00000370	[.001]*	-0,00000028	[.874]
Multiplicative Dummies												
Friday X Quote Revisions	-0,00054785	[.018]*	0,00000459	[.140]	0,00000457	[.240]	0,00000070	[.344]	0,00000166	[.020]*	0,00000314	[.068]**
Prec. Holiday X Quote Revisions	0,00008057	[.632]	0,00000298	[.245]	-0,00000209	[.293]	0,00000099	[.156]	0,00000023	[.691]	-0,00000085	[.291]
Friday X Volatility	-37,55140000	[.699]	4,13673000	[.319]	-1,23302000	[.520]	0,05351200	[.864]	0,66140800	[.597]	-0,48308500	[.557]
Prec. Holiday X Volatility	671,55700000	[.152]	14,27770000	[.002]*	-1,52234000	[.739]	3,50446000	[.000]*	7,74482000	[.000]*	-0,11805400	[.946]
Lagged Spread	0,22285400	[.000]*	0,26533800	[.000]*	0,09716400	[.000]*	0,29135800	[.000]*	0,28107500	[.000]*	0,13446900	[.000]*
Data Feeder Dummies												
DDF2	-0,00776325	[.000]*	-0,00014118	[.000]*	-0,00003202	[.000]*	-0,00003217	[.000]*	-0,00002807	[.000]*	-0,00000228	[.066]**
DDF3	0,00985309	[.000]*	0,00004414	[.000]*	0,00002026	[.000]*	0,00002265	[.000]*	0,00000982	[.000]*	0,00000203	[.200]
DDF4	0,00084056	[.510]	-0,00002040	[.133]	0,00001755	[.358]	0,00001003	[.016]*	-0,00000601	[.112]	0,00001066	[.281]
DDF5	0,00173461	[.009]*	0,00007887	[.000]*	0,00005070	[.000]*	0,00000409	[.139]	0,00001961	[.000]*	0,00001568	[.000]*
DDF6	-0,01770000	[.000]*	-0,00018491	[.000]*	-0,00005023	[.000]*	-0,00006116	[.000]*	-0,00005980	[.000]*	-0,00004194	[.000]*
α_0	0,00000314	[.000]*	0,00000000	[.000]*	0,00000000	[.000]*			0,00000000	[.023]*	0,00000000	[.000]*
α_1	0,05849000	[.000]*	0,08952600	[.000]*	0,02983300	[.000]*			0,05638500	[.000]*	0,02354300	[.000]*
β_1	0,93785000	[.000]*	0,90154600	[.000]*	0,96375200	[.000]*			0,94263700	[.000]*	0,97581600	[.000]*
Intercept	0,05907		0,00065		0,00057		0,00020		0,00017		0,00026	
Adjusted R-squared	0,338289		0,427624		0,118299		0,271012		0,508741		0,204047	

a: resutls estimated with OLS, *: 5 percent level of significance, **: 10 percent level of significance

Panel H: UK Time Zone, Full Sample: Intraday												
	Quoted Spread						**Revative Spread**					
	JP/US		**GB/US**		**EU/US**		**JP/US**		**GB/US**		**EU/US**	
Parameter	Estimate	P-value	Estimate	P-value	Estimate	P-value	Estimate	P-value	Estimate	P-value	Estimate	P-value
Number of Quote Revisions	-0,01009300	[.000]*	-0,00005584	[.000]*	-0,00006378	[.000]*	-0,00003917	[.000]*	-0,00001927	[.000]*	-0,00005093	[.000]*
Interest Rate	-1,10756000	[.000]*	-0,00659582	[.000]*	-0,01054000	[.000]*	0,00230233	[.000]*	-0,00514670	[.000]*	-0,01052500	[.000]*
Volatility	277,59600000	[.000]*	8,70007000	[.000]*	0,49983800	[.665]	0,90871200	[.000]*	2,06134000	[.000]*	0,63434100	[.247]
Seasonality (UK)												
Preceding Holiday:												
UK only	0,00030335	[.600]	-0,00000170	[.762]	-0,00002142	[.020]*	0,00000253	[.259]	0,00000009	[.949]	0,00000033	[.911]
Common	0,00032308	[.837]	0,00002197	[.046]*	0,00005069	[.000]*	-0,00000013	[.978]	0,00000503	[.080]**	0,00000404	[.325]
Post Holiday:												
UK only	0,00073443	[.128]	0,00000975	[.085]**	0,00002055	[.000]*	0,00000486	[.012]*	0,00000040	[.779]	0,00000182	[.374]
Common	-0,00120708	[.341]	0,00000692	[.731]	-0,00011906	[.000]*	-0,00000380	[.451]	0,00000196	[.712]	-0,00005076	[.000]*
Last Day of Month	0,00048340	[.131]	0,00000900	[.143]	0,00000440	[.221]	0,00000112	[.367]	0,00000195	[.195]	0,00000221	[.118]
Monday	-0,00063317	[.000]*	-0,00000395	[.002]*	-0,00000135	[.355]	-0,00000241	[.000]*	-0,00000178	[.000]*	-0,00000241	[.000]*
Friday	0,00006201	[.892]	0,00001063	[.028]*	0,00000901	[.486]	-0,00000269	[.147]	0,00000181	[.147]	-0,00000946	[.069]**
Macroeconomic Ann. (UK)												
GDP preliminary: GDPP(Before)	-0,00046544	[.491]	-0,00000453	[.471]	0,00000768	[.277]	-0,00000229	[.366]	-0,00000217	[.151]	0,00000146	[.582]
GDP preliminary: GDPP(After)	-0,00002131	[.973]	0,00000437	[.433]	0,00000402	[.636]	-0,00000080	[.739]	0,00000062	[.665]	0,00000111	[.741]
Consumer Price Index: CPI (Before)	-0,00048924	[.207]	-0,00000832	[.032]*	-0,00000115	[.780]	-0,00000292	[.040]*	-0,00000272	[.008]*	-0,00000062	[.704]
Consumer Price Index: CPI (After)	-0,00041268	[.285]	-0,00001189	[.006]*	-0,00000088	[.827]	-0,00000252	[.080]**	-0,00000377	[.001]*	-0,00000248	[.116]
Bank of England Base Rate (Before)	0,00004210	[.908]	-0,00000396	[.425]	-0,00000356	[.378]	-0,00000226	[.098]**	-0,00000042	[.771]	-0,00000064	[.695]
Bank of England Rate (After)	-0,00015102	[.682]	0,00000484	[.589]	-0,00001281	[.001]*	-0,00000290	[.036]*	0,00000209	[.421]	-0,00000556	[.000]*
Trade Balance (Before)	-0,00073937	[.047]*	0,00000190	[.842]	0,00000159	[.723]	-0,00000397	[.004]*	0,00000097	[.735]	0,00000018	[.920]
Trade Balance (After)	-0,00151809	[.000]*	-0,00000380	[.451]	-0,00000084	[.838]	-0,00000688	[.000]*	-0,00000139	[.296]	-0,00000195	[.236]
Multiplicative Dummies												
Friday X Quote Revisions	0,00003875	[.869]	-0,00000349	[.186]	-0,00000361	[.530]	0,00000142	[.136]	-0,00000051	[.457]	0,00000435	[.057]**
Prec. Holiday X Quote Revisions	0,00012574	[.542]	0,00000237	[.237]	0,00001543	[.000]*	0,00000165	[.038]*	-0,00000053	[.310]	0,00000084	[.253]
Friday X Volatility	180,44200000	[.386]	-1,56092000	[.615]	1,84374000	[.404]	0,47197000	[.557]	-0,23761300	[.763]	0,46969500	[.611]
Prec. Holiday X Volatility	43,31400000	[.942]	34,99540000	[.021]*	-41,00560000	[.056]**	-1,07058000	[.675]	9,16983000	[.023]*	-5,02055000	[.601]
Lagged Spread	0,12431100	[.000]*	0,16908900	[.000]*	0,06927700	[.000]*	0,13150600	[.000]*	0,16259900	[.000]*	0,10235200	[.000]*
Data Feeder Dummies												
DDF2	-0,01392700	[.000]*	-0,00023933	[.000]*	0,00000770	[.004]*	-0,00005893	[.000]*	-0,00005312	[.000]*	0,00001262	[.000]*
DDF3	0,00217474	[.000]*	0,00003849	[.000]*	0,00000194	[.553]	0,00001011	[.000]*	0,00000877	[.000]*	-0,00000582	[.000]*
DDF4	0,00114082	[.354]	0,00001913	[.123]	0,00003839	[.159]	0,00000554	[.213]	0,00000488	[.195]	0,00002228	[.095]**
DDF5	0,00298395	[.000]*	0,00006150	[.000]*	-0,00000159	[.756]	0,00001454	[.000]*	0,00001686	[.000]*	-0,00000581	[.020]*
DDF6	-0,02223500	[.000]*	-0,00026652	[.000]*	-0,00006819	[.000]*	-0,00008222	[.000]*	-0,00007908	[.000]*	-0,00005211	[.000]*
α_0	0,00000012	[.000]*	0,00000000	[.000]*	0,00000000	[.000]*	0,00000000	[.000]*	0,00000000	[.000]*	0,00000000	[.007]*
α_1	0,01619400	[.000]*	0,01618500	[.000]*	0,01386100	[.000]*	0,01676000	[.000]*	0,01480500	[.000]*	0,01273100	[.000]*
β_1	0,98375800	[.000]*	0,98302800	[.000]*	0,98540800	[.000]*	0,98308700	[.000]*	0,98481000	[.000]*	0,98730700	[.000]*
Intercept	0,07560900		0,00075166		0,00049929		0,00028475		0,00021383		0,00027344	
Adjusted R-squared	0,37697		0,437605		0,067236		0,360831		0,510709		0,197593	
*: 5 percent level of significance, **: 10 percent level of significance												

Panel I: ASIA Time Zone, Full Sample: Intraday												
	Quoted Spread						**Revative Spread**					
	JP/US		**GB/US**		**EU/US**		**JP/US**		**GB/US**		**EU/US**	
Parameter	Estimate	P-value	Estimate	P-value	Estimate	P-value	Estimate	P-value	Estimate	P-value	Estimate	P-value
Number of Quote Revisions	-0,00503631	[.000]*	-0,00005742	[.000]*	-0,00008489	[.000]*	-0,00002091	[.000]*	-0,00001520	[.000]*	-0,00003837	[.000]*
Interest Rate	-2,90952000	[.000]*	-0,02393000	[.000]*	-0,03239000	[.000]*	-0,00535972	[.000]*	-0,00930516	[.000]*	-0,01963100	[.000]*
Volatility	72,36260000	[.120]	2,00865000	[.005]*	0,52545400	[.333]	0,17264200	[.327]	0,46812000	[.010]*	0,22910200	[.302]
Seasonality (ASIA)												
Preceding Holiday:												
ASIA only	0,00025002	[.575]	-0,00000243	[.570]	-0,00000840	[.096]**	0,00000166	[.325]	-0,00000043	[.704]	-0,00000222	[.247]
Common	0,00254770	[.015]	0,00005094	[.000]*	-0,00007704	[.000]*	0,00000881	[.021]*	0,00001644	[.000]*	-0,00002390	[.000]*
Post Holiday:												
ASIA only	-0,00070922	[.025]*	-0,00000347	[.246]	0,00000672	[.069]**	-0,00000119	[.335]	-0,00000098	[.195]	0,00000027	[.849]
Common	0,00599612	[.011]*	0,00004740	[.044]*	0,00003341	[.017]*	0,00002132	[.020]*	0,00001053	[.164]	0,00001933	[.004]*
Last Day of Month	0,00132468	[.000]*	0,00000162	[.632]	-0,00000985	[.013]*	0,00000516	[.000]*	0,00000012	[.888]	-0,00000370	[.018]*
Monday	0,00176093	[.000]*	0,00000523	[.000]*	0,00001037	[.000]*	0,00000614	[.000]*	0,00000146	[.000]*	0,00000368	[.000]*
Friday	0,00227063	[.000]*	0,00001848	[.000]*	0,00001431	[.059]**	0,00000921	[.000]*	0,00000451	[.000]*	0,00000554	[.094]**
Macroeconomic Ann. (ASIA)												
GDP preliminary: GDPP(Before)	0,00104531	[.217]	0,00000218	[.828]	0,00000764	[.346]	0,00000554	[.079]**	0,00000175	[.481]	0,00000181	[.566]
GDP preliminary: GDPP(After)	0,00142970	[.184]	0,00000370	[.726]	-0,00001090	[.240]	0,00000745	[.059]**	0,00000285	[.293]	-0,00000212	[.566]
Consumer Price Index: CPI (Before)	0,00014174	[.694]	0,00000614	[.150]	-0,00000667	[.130]	0,00000114	[.423]	0,00000114	[.302]	-0,00000226	[.195]
Consumer Price Index: CPI (After)	0,00024769	[.526]	-0,00000925	[.012]*	0,00000111	[.801]	0,00000165	[.279]	-0,00000329	[.001]*	-0,00000111	[.527]
Bank of Japan Base Rate (Before)	0,00180431	[.000]*	-0,00000502	[.091]**	0,00001362	[.000]*	0,00000380	[.003]*	-0,00000123	[.121]	0,00000487	[.001]*
Bank of Japan Base Rate (After)	0,00118483	[.001]*	0,00000115	[.733]	-0,00000889	[.021]*	0,00000227	[.085]**	0,00000141	[.106]	-0,00000121	[.429]
Trade Balance (Before)	-0,00079905	[.066]**	-0,00000618	[.160]	-0,00000940	[.028]*	-0,00000113	[.492]	-0,00000055	[.636]	-0,00000337	[.047]*
Trade Balance (After)	-0,00031164	[.459]	-0,00000418	[.190]	-0,00000301	[.472]	0,00000075	[.638]	0,00000033	[.704]	-0,00000195	[.233]
Multiplicative Dummies												
Friday X Quote Revisions	-0,00115314	[.000]*	-0,00001124	[.000]*	-0,00000691	[.090]**	-0,00000498	[.000]*	-0,00000261	[.000]*	-0,00000262	[.131]
Prec. Holiday X Quote Revisions	0,00001662	[.933]	0,00000509	[.007]*	0,00000083	[.648]	0,00000059	[.406]	0,00000093	[.070]**	-0,00000064	[.345]
Friday X Volatility	74,26500000	[.507]	0,07662600	[.959]	-0,45518800	[.669]	0,27175200	[.474]	0,05461800	[.889]	-0,11354400	[.784]
Prec. Holiday X Volatility	481,89600000	[.109]	5,69692000	[.204]	0,43196800	[.862]	1,47268000	[.117]	1,12615000	[.314]	-0,13402500	[.888]
Lagged Spread	0,17617600	[.000]*	0,24399000	[.000]*	0,11684700	[.000]*	0,19843800	[.000]*	0,27256000	[.000]*	0,16787900	[.000]*
Data Feeder Dummies												
DDF2	-0,00504147	[.000]*	-0,00011670	[.000]*	-0,00002096	[.000]*	-0,00002626	[.000]*	-0,00001999	[.000]*	0,00000434	[.003]*
DDF3	0,00681718	[.000]*	0,00000090	[.865]	0,00000392	[.252]	0,00002503	[.000]*	-0,00000185	[.235]	-0,00000546	[.001]*
DDF4	0,00014750	[.905]	0,00000787	[.513]	0,00001035	[.378]	0,00000207	[.641]	0,00000108	[.762]	0,00000720	[.189]
DDF5	-0,00476675	[.000]*	0,00007454	[.000]*	0,00002660	[.000]*	-0,00001156	[.000]*	0,00001833	[.000]*	0,00000161	[.596]
DDF6	-0,02019200	[.000]*	-0,00014396	[.000]*	-0,00003702	[.000]*	-0,00007010	[.000]*	-0,00004984	[.000]*	-0,00004330	[.000]*
α_0	0,00000071	[.000]*	0,00000000	[.000]*	0,00000000	[.002]*	0,00000000	[.000]*	0,00000000	[.000]*	0,00000000	[.003]*
α_1	0,03482000	[.000]*	0,04596000	[.000]*	0,02187800	[.000]*	0,03479400	[.000]*	0,04101500	[.000]*	0,01819600	[.000]*
β_1	0,96474200	[.000]*	0,95498400	[.000]*	0,97712500	[.000]*	0,96436900	[.000]*	0,96020300	[.000]*	0,98180400	[.000]*
Intercept	0,062456		6,28E-04		5,49E-04		2,30E-04		1,68E-04		2,42E-04	
Adjusted R-squared	0,333209		0,345915		0,135375		0,309178		0,455897		0,299421	
*: 5 percent level of significance, **: 10 percent level of significance												

Table 7.6 Skewness and Kurtosis statistics for residuals from the GARCH (1,1) models of JP/US, GB/US and EU/US spreads

Daily Sample (January 1995 – January 2005)																		
	US Time zone						UK Time Zone						ASIA Time Zone					
	Quoted Spread			Relative Spread			Quoted Spread			Relative Spread			Quoted Spread			Relative Spread		
	JP/US	GB/US	EU/US	JP/US	GB/US	EU/US	JP/US	GB/US	EU/US	JP/US	GB/US	EU/US	JP/US	GB/US	EU/US	JP/US	GB/US	EU/US
Skewness	-0.1852	-0.1447	1.3463	0.3391	-0.2845	-0.4947	0.0147	0.5647	1.536	0.2284	0.4052	-0.2547	-0.2237	1.5659	0.3044	0.1897	0.3762	-4.024
Kurtosis	2.9125	7.8183	36.533	3.0839	8.0264	21.171	6.8037	12.192	19.136	5.5582	12.323	10.627	9.9164	36.725	4.3224	5.1721	10.792	41.196
Durbin-Watson	2.348	2.2415	2.0992	2.4103	2.3448	2.3699	2.3577	2.3208	2.081	2.4042	2.2669	2.2893	2.651	2.0501	2.2113	2.5047	2.4364	1.4183

Intraday Sample (January 1995 – January 2005)																		
	US Time zone						UK Time Zone						ASIA Time Zone					
	Quoted Spread			Relative Spread			Quoted Spread			Relative Spread			Quoted Spread			Relative Spread		
	JP/US	GB/US	EU/US	JP/US	GB/US	EU/US	JP/US	GB/US	EU/US	JP/US	GB/US	EU/US	JP/US	GB/US	EU/US	JP/US	GB/US	EU/US
Skewness	0.6096	0.3592	1.9843	0.6372	0.3914	2.2943	0.5747	0.1104	2.0954	0.6203	0.2003	2.3351	0.5128	0.9256	1.3245	0.5849	0.8378	1.5441
Kurtosis	2.7401	2.9584	13.274	1.9295	2.9026	19.44	2.6509	1.6653	14.384	1.861	2.0403	20.331	1.6231	6.2617	3.2278	1.4768	5.3416	4.7036
Durbin-Watson	2.0312	2.0765	2.0177	2.1202	2.0937	2.0331	2.0324	2.0453	2.0097	2.0349	2.0448	2.0228	2.0438	2.0676	2.0285	2.0539	2.0886	2.0551

Section 7.4.5: Summary and conclusions

In this chapter I investigate the determinants of the bid-ask spreads in the FX market using GARCH modelling. I use five types of explanatory variables; interest rate differentials, exchange rate volatility, trading activity, seasonality variables, and macroeconomic announcements. In general the intraday results show that the above explanatory variables work better when I use intraday data however their explanatory power is significantly lower as the R square statistics indicate. This observation suggests that although daily spreads and intraday spreads have some common determinants, other factors determine the behaviour of spreads at high frequencies. The key finding of this chapter is that macroeconomic news announcements, such as base rate, GDP, CPI and trade balance announcements are significant in the determination of the intraday bid-ask spreads. This finding contributes to the existing microstructure literature on the effect of macroeconomic announcements on returns, trading volume and volatility. In the next chapter I examine in more detail the documented relationship between spreads, trading activity, volatility and interest rate differential using a vector autoregression analysis.

Chapter 8: Vector Autoregression Models: Analysis of Spreads, Trading Activity and Volatility in the FX Market

Section 8.1: Introduction and overview

This chapter examines the effect of trading activity, exchange rate volatility and inventory holding costs on both quoted and relative spreads using vector autoregression analysis. I first describe a simple vector autoregression model and provide a concise review of its main applications. The remainder of this chapter presents results from simultaneous equation models both for our daily and intra-day sample including impulse responses and variance decomposition analysis.

The main contribution of this chapter is the examination of the commonality in liquidity, focusing on the information content of trading activity and its effect on the spread, with the elaboration of FX market microstructure variables in financial centers across the world (US, UK, ASIA) based on the quotes of three exchange rate currency pairs (JP/US, GB/US, EU/US) over a ten-year period. As mentioned in the literature review the main scope of Demsetz's study (Demsetz 1968) was to investigate the extent to which transaction costs are affected by trading activity. Demsetz described the frequency of transacting as the basic element that forces the bid-ask spread (a negative relationship between spread and time rate of transactions is to be expected). Therefore, I examine the relationships between bid-ask spreads, number of quote revisions, exchange rate volatility and interest rate differential for each currency pair and look for differences and similarities in the variable behaviour between the three different currency pairs in a particular time zone. In addition, I examine whether these relationships are different for the same currency pair in different time zones. My sample covers the period between 01.01.1995 and 31.01.2005.

Sims (1980) provided a new econometric framework called vector autoregression (VAR) as a better alternative to conventional dynamic simultaneous equation models. In a univariate autoregression (single equation, single variable) the current value of a variable is explained by its own lagged values. In a VAR model (n equation, n variable linear model) each variable is explained by its own lagged values, plus current and past values of the remaining n-1 variables.

Vector autoregressions (VARs) are widely used in empirical research because of their advantages, including zero restrictions and assumed knowledge of the way the world actually works. They provide a simple means of explaining/predicting the dynamics of multiple time series of economic variables with relatively easy to use statistical techniques. (Doan *et al*., 1984; Sims, 1980; Todd, 1984). However, it is well documented in the literature that the original Sims models do not perform well in forecasting (Lutkepohl, 1991; Joseph, 2001). Therefore, different types of VAR models have been developed in the literature to improve the accuracy of forecasts (Holden, 1995).

Section 8.2: A simple VAR model

A VAR is a system of dynamic equations where each dependent variable is regressed on the lagged values of itself and of other variables. For example, let us consider a simple bivariate model:

$$y_t = a_{10} + a_{11}y_{t-1} + a_{12}x_{t-1} + u_{1t} \qquad \text{Eq. 8.1}$$

$$x_t = a_{20} + a_{21}y_{t-1} + a_{22}x_{t-1} + u_{2t}, \qquad \text{Eq. 8.2}$$

where y_t is the time path of the y variable and x_t is the time path of the x variable, $t - 1$ refers to one period lagged value and u_{1t}, u_{2t} are the white noise error terms. This system of equations is known as a first order VAR model in standard form. This simple model can be extended to include n variables and more than one period lagged values:

$$y_t = A_0 + A_1 y_{t-1} + A_2 y_{t-2} + A_3 y_{t-3} + \cdot \cdot \cdot + A_i y_{t-i} + u_t, \qquad \text{Eq. 8.3}$$

where y_t is an $n \times 1$ vector containing n variables, A_0 is an $n \times 1$ vector of constant terms, A_i is an $n \times n$ matrix of coefficients, $i = 1, 2, \ldots, n$, and u_t is an $n \times 1$ vector of white noise error terms and i is the number of lagged values used in the system. In general, the variables to be included in the system are supposed to be determined by economic theories. By assumption, the random error terms u_t are uncorrelated with one another with constant variance and the right-hand side of the equation contains only the lagged or predetermined variables. Therefore, each of these n equations can be estimated efficiently using OLS. From this simple standard VAR model, we can use the Granger causality test to measure the importance of one variable for the prediction of another variable. According to Granger (1969), if x_t causes y_t, then changes in x_t should precede changes in y_t, hence, x_t should help to predict y_t but y_t should not help in predicting x_t. In other words, for a first order model as given by equations (8.1 and 8.2), the coefficient a_{12} should be statistically different from zero whereas the coefficient a_{21} should not be different from zero.

Hasbrouck (1991a,b) set the foundations in examining the interactions of securities trades and quote revisions using a VAR system to sidestep the difficulty of distinguishing the effects of asymmetric information on quote revisions from liquidity effects and inventory control behaviour.

In particular, he used the concept of trade innovation rather than the total trade. As he described in another paper (Hasbrouck 1988) "if there were to be any private information inferred from a trade, it must be inferred not from the total trade but from that component which was unanticipated (the trade innovation)". Hasbrouck proposed a very simple and general bivariate VAR model (explained in the following section) applied to quote and trade data and extended this work by presenting an explanation of the VAR model for a simple microstructure model (suggested by Glosten). This work was later used by Payne (1999) and Evans (2001) as the basis for application in the FX market (I discuss these papers in the sections below).

Section 8.3: Main applications of VAR models

In most cases VAR models have been used as a macroeconometric tool and only recently have been adopted by finance researchers to examine the linkages and interactions of the stock markets as well as the comovements of stock returns and volatility. In this section I first review the methodologies suggested by Hasbrouck and then review some of the research papers that have used VAR methodologies in different areas of economics and finance.

Section 8.3.1 Impulse responses and variance decompositions

There are normally two different statistics that are computed and reported when VAR models are used as proposed by Hasbrouck (1991a,b). Impulse responses (IMR) and forecast error variance decompositions (VDC).

Impulse responses trace out the responsiveness of the dependent variables in the VAR to shocks to each of the variables (Brooks, 2002). That is, for each variable from each equation separately, a one-unit increase (unit shock) in the current value of one of the VAR errors is applied to examine the effect on the current and future values of each variable over time. The impulse responses show that the "own shock" of each variable has instantaneous effects and the shocks to other variables have lagged effects on each variable. In other words, in the equations in section 8.2 only u_{1t} has immediate effects and u_{2t}, . . ., u_{kt} all have lagged effects on y_{1t} .

The IMR are obtained from the VAR specification as follows: Consider r_t to be the revision in the quote midpoint and x_t an incoming signed order (volume), where t is a transaction-time observation counter:

$$r_t = \alpha_1 r_{t-1} + \alpha_2 r_{t-2} + \ldots + \beta_0 x_t + \beta_1 x_{t-1} + \ldots + \upsilon_{1,t} \quad \text{Eq. 8.4}$$

$$x_t = \gamma_1 r_{t-1} + \gamma_2 r_{t-2} + \ldots + \delta_1 x_t + \delta_2 x_{t-2} + \ldots + \upsilon_{2,t} \quad \text{Eq. 8.5}$$

The equations above can be summarised as:

$$r_t = \sum_{i=1}^{p}\alpha_i r_{t-i} + \sum_{i=1}^{p}\beta_i x_{t-i} + \upsilon_{1t} \qquad \text{Eq. 8.6}$$

$$x_t = \sum_{i=1}^{p}\gamma_i r_{t-i} + \sum_{i=1}^{p}\delta_i x_{t-i} + \upsilon_{2t} \qquad \text{Eq. 8.7}$$

The disturbance in the last equation, $\upsilon_{2t,}$ captures the unanticipated (innovative) component of the trade. If any new information is contained in x_t, it must reside in the innovation u_{2t}, since the remaining component is entirely known (Hasbrouck 1999a).

Equations 8.6 and 8.7 comprise a bivariate VAR model which assumes that the disturbances have zero means and are jointly and serially uncorrelated.

$$E\upsilon_{1t} = E\upsilon_{2t} = 0$$

$$E\upsilon_{1t}\,\upsilon_{1s} = E\upsilon_{2t}\,\upsilon_{2s} = E\upsilon_{1t}\,\upsilon_{2s} = 0, \qquad \text{for } t \neq s. \qquad \text{Eq. 8.8}$$

Inverting the VAR representation yields the following vector moving-average model:

$$\begin{pmatrix} r_t \\ x_t \end{pmatrix} = \begin{pmatrix} a(L) & b(L) \\ c(L) & d(L) \end{pmatrix} \begin{pmatrix} u_{1t} \\ u_{2t} \end{pmatrix} \qquad \text{Eq. 8.9}$$

The impulse response functions implied by the VAR model are the lag polynomials in this representation. Specifically, lag polynomial b(L), captures the impact of order flow information on subsequent prices (Lyons 2001).

If there are g variables in a system, a total g^2 impulse responses could be calculated. Therefore, adding variables to the VAR creates complications due to the increased number of VAR parameters. Three variable VAR models have been widely used due to the relatively easier way to interpret the results. However, small VARs are often unstable and produce poor predictors of the future.

Although impulse response will measure the effect of a unit order flow innovation on the price change it will not show us the share of price movement due to order flow. This can be obtained using **variance decomposition** (Hasbrouck 1991b). As Brooks (2002) explains, a shock to a variable will affect not only that variable but also other variables since its effect will be transmitted in the system through the dynamic structure of VAR. The analysis provides the variance of the forecast error *n* periods ahead and it presents a breakdown of the variance of the forecast error in each variable into components accounted for by innovations in different variables in the VAR. In other words, it explains how much of the n periods ahead forecast error variance of a given variable is explained by innovations to each explanatory variable.

More formally, denote q_t the quote midpoint that is the sum of a random-walk component m_t and a stationary component s_t:

$$q_t = m_t + s_t \qquad \text{Eq. 8.10}$$

where

$m_t = m_{t-1} + w_t$

and $w_t \sim N(0,\sigma^2_w)$, with $E[w_t w_s] = 0$ for $t \neq s$.

The permanent component m_t is “interpreted as the efficient price in the sense of the expected end-of-trading security value conditional on all time-t public information”, as Hasbrouck (1991b) explains. S_t, (transitory component) is a zero-mean nondeterministic stochastic process that is jointly covariance stationary with w_t, and reflects all the transient microstructure imperfections (e.g inventory control) that cause the quote midpoint to deviate from the efficient price (Hasbrouck 1991b).

The next step is to decompose the variance of the permanent component σ^2_v into a part due to public information and a part due to order flow information. By defining $\sigma^2_{\varepsilon 1} = E[\varepsilon^2_{1t}]$ and $\sigma^2_{\varepsilon 2} = E[\varepsilon^2_{2t}]$ from the VAR innovations the permanent component σ^2_v can be written:

$$\sigma^2_v = \left(\sum_{i=0}^{\infty} \alpha_i\right)^2 \sigma^2_{\varepsilon 1} + \left(\sum_{i=0}^{\infty} b_i\right)^2 \sigma^2_{\varepsilon 2} \qquad \text{Eq. 8.11}$$

The share of variance due to order flow innovations can be obtained by estimating the parameters in equation 8.11. Specifically, the second term of the equation reflects the information impounded in price through order flow.

As discussed earlier the ordering of the variables is important in calculating impulse responses and variance decompositions. Ideally, financial theory should suggest the order of the variables in the VAR model. Alternatively, a researcher would re-calculate the results after he has re-ordered the variables. The ordering of data becomes more important when there is high correlation in the residuals from an estimated equation. When residuals are uncorrelated then the ordering will make little difference. In general, both variance decompositions and impulse responses are difficult to interpret accurately (Runkle 1987).

Section 8.3.2: Forecasting and causality tests

The main uses of VAR models are in forecasting and causality tests (Cooley & Leroy,1985). The forecast errors can be obtained from the variance decomposition (VDC) analysis and the causality tests can be made by computing the relevant *F* statistics when excluding the lagged values of a variable from each regression of the model. These *F*-statistics can be used in testing theories of economics and finance, and also in policy analysis. In general, they can show the importance or the lack of it of a variable in the relevant equation of the model.

In their empirical study, Lupoletti and Webb (1984) examine the performance of VAR models for predictive accuracy. They conclude that simplicity of construction, ease of operation, and relative accuracy make the VAR model under consideration a useful benchmark. They find that the VAR model produces forecasts that are competitive with those issued by three well-known commercial forecasters over the period 1970-83. In addition, they argue that forecasts from the unrestricted VAR model are also competitive with those produced by ARIMA techniques and by a more complex Bayesian VAR method.

In contrast, in a more recent paper, Joseph (2001) examines the forecasting accuracy of alternative vector autoregressive models of daily, weekly and monthly foreign exchange (FX) spot rates. The vector autoregressions (VARs) are in non-stationary, stationary and error-correction forms and are estimated using OLS. He finds that the predictive ability of the VARs is very weak.

Section 8.3.3: Comovements in financial markets

The examination of the interdependence among financial markets, and in particular stock markets, was originally motivated by the need for international portfolio diversification (eg. Levy & Samat, 1970; Agmon, 1972). These needs led to a vast number of more recent papers (e.g Jeon & Von Furstenberg, 1990; Fischer & Palasvirta, 1990; Wahab & Lashgari, 1993) that explored the links among the national stock markets. In this part of our study we discuss recent papers that examine the above mentioned relationships using VAR specifications. VAR models have contributed to the study of linkages and interactions of financial markets in general, and to a large extent the interaction of stock markets, at a regional and global level. This field of research on the links between national stock markets has been rapidly growing. Researchers try to identify the differences between periods when markets commove (such as the1987 stock market crash) and those when the correlation between them is low.

Eun and Shim, (1989) use data from nine major stock markets[32] to study empirically the linkages between stock markets and to examine the degree of global capital market integration. They use a VAR specification with nine variables, the daily stock market indices (transformed to daily rates of return)

[32] Australia, Japan, Hong Kong, UK, Switzerland, France, Gremany, Canada, US.

at closing time of the countries under examination for the period from December 1979 to December 1985. To a large degree, their findings support the argument that national stock markets are interrelated with the US stock market to be the most influential market among those examined. In addition, no more than 2 percent of the US error variance can be explained by a single foreign market. Another interesting finding in this work is that the Swiss market is the most interactive one, as innovations in other markets influence it and Swiss innovations are fed into other markets. Similarly, King et al., (1994) use data on sixteen stock markets[33] and apply VAR specifications to study empirically the links between stock markets at a global level. They suggest "a conditional factor model for excess returns, a dynamic model for the asset risk premia in terms of the changing volatility of the factors, an econometric specification of the variation over time in the conditional covariance matrix of returns and a method for generating factors related to measured economic variables that explain the behaviour excess returns". They find global stock markets are not integrated. They argue that although it is commonly accepted that globalization has led to national stock markets moving more closely together, they were unable to find strong evidence in favour of a trend increase in correlations.

In another study, Booth et al., (1997) examine the volatility comovements among three major markets, the US, UK and Japanese for the period from 1988 to 1994. In particular, they use a three-variable VAR model to examine whether the volatility of these markets follows the heat waves and meteor shower hypotheses suggested by Engle et al. (1990). They employ intraday variance figures from the futures contracts on the S&P 500 listed on the Chicago Merchantile Exchange (CME), the FT-SE 100 stock index futures contracts traded on the London International Financial Futures Exchange (LIFFE) and the contracts traded on the Singapore International Monetary Exchange (SIMEX). They find that the volatilities of the US and UK stock index futures market react to shocks from other markets (meteor shower hypothesis) and not only to their own past values. However, the heat wave

[33] Australia, Austria, Belgium, Canada, Denmark, France, Germany, Italy, Japan, Netherlands, Norway, Spain, Sweden, Switzerland, UK and US.

hypothesis (country specific effects) can't be rejected for the Japanese market.

As for the linkages among the European markets, Friedman and Shachmurove (1997) use a VAR model to study whether EC stock markets behave like a single, integrated multi regional market. They say "the VAR model is suitable for the analysis of dynamic linkages among the various markets since it can identify the main channels of interactions and simulates the responses of a given market to innovations in other markets." They examine the relationships in eight EC stock exchanges: namely, Belgium, Britain, Denmark, France, Germany, Italy, Netherlands, and Spain. Specifically, their study comprises time series of daily stock market indices for these markets for the period from January 1988 to December 1994. The results provide evidence of linkages among the markets, such as that the British market is affected by the Netherlands, Spanish, and Italian markets, the French market is influenced by the Netherlands, Belgian, Italian, and Spanish markets, among others. Overall, they find that the most influential markets in the EC are the British, French, Netherlands, Belgian, and Italian. In their paper "Changes in the comovements in the European equity markets", Chelley-Steeley and Steeley (1999) use a vector autoregressive model of daily equity returns to examine the effects of the removal of exchange controls on European stock market integration in the following five European countries: the United Kingdom, Germany, Italy, Switzerland, and France. They find that domestic factors explain less of the variation in equity market returns after the removal of exchange controls.

Emerging markets in the Mediterranean, Asia, South America, Africa or Eastern Europe have been analysed in detail by Harvey (1995), Bekaert and Harvey (1995, 1997, 2000, 2002), Choudhry (1996) and Scheicher (2001). Christofi and Pericli (1999) use a VAR model to examine the lead-lag relationships in five Latin American stock markets. They apply a multivariate VAR-EGARCH model[34] on the daily closing stock price indices of Argentina,

[34] A vector autoregression (VAR) model with errors following a multivariate exponential GARCH process.

Brazil, Chile, Colombia and Mexico for the period between May 1992 and May 1997. The purpose of their research is to examine the asymmetric transmission of volatility among these five major Latin American stock markets. As they report "there is substantial evidence of multidirectional lead–lag relationships and significant volatility transmissions among the major Latin American stock markets". In particular, they find that innovations in Brazil and Chile influence the volatility of all other countries, while the volatility of Columbia's market has only a small influence on the volatility of the other countries. In addition, the results suggest that stock markets are strongly influenced by their own past innovations. In general, results are consistent with the findings of other authors (e.g. Harvey, 1995) who have reported stronger local than global influences on various emerging market returns.

Another application of the VAR model was introduced by Ito (1988) who proposed a new way of testing uncovered interest parity (UIP) using a VAR system on the spot yen/dollar exchange rate, the Japanese domestic interest rate, and the Eurodollar interest rate, to describe the interdependence of the domestic and international financial markets. Uncovered interest parity (UIP) was tested in the proposed VAR system. As Ito explained, UIP is rejected for a period of strict capital controls, 1973-1977, and accepted for the period of free capital mobility, 1981-1985.

Section 8.3.4: Comovements between returns, volatility and trading activity

Theoretical models suggest that the response of security prices to trading activity is a result of asymmetric information. The existence of asymmetric information in the market and the extent to which trades convey this information has been well examined in the finance literature. The foundations of these theoretical approaches were set by the paper of Bagehot (1971) and many theoretical models were developed later by Copeland and Galai (1983) Glosten and Milgrom (1985), Easley and O'Hara (1987) to mention a few. Asymmetric information means that trades will convey information and therefore cause the prices of securities to change. Influential articles by Black

(1976) and Christie (1982) document and attempt to explain the asymmetric volatility property of individual stock returns in the United States. The explanation in these articles is based on leverage. A drop in the value of the stock (negative return) increases financial leverage, which makes the stock riskier and increases its volatility. Since then many research papers have examined these relationships.

Hasbrouck (1991a,b), in his initiative papers, uses a sample of sequenced trades and quoted record from the New York and American Stock Exchanges and the consolidated regional exchanges, over the 62 trading days in the first quarter of 1989. He concludes that the full impact of a trade on a quote revision is felt with a protracted lag and not instantaneously, and that order flow is affected by prior quote revisions. Moreover, he finds that trade informativeness appears to be larger for firms with lower market capitalization, and that trades are more informative in the beginning of the trading day than at other times. He arrives at these conclusions by obtaining the impulse responses of prices to order flow. An informed order flow will have a positive long-run effect on price. In addition, with variance decomposition analysis he finds what portion of the price movement is attributable to order flow.

Following his research a vast number of papers have investigated the comovements of the conditional mean and volatility of stock returns using VAR models, as finance theory suggests that risk and return should be positively related. Researchers have searched for both a positive relation between expected returns and the conditional volatility of returns and a negative relation between unanticipated volatility and realized returns. Whitelaw (1994) uses a VAR model to examine the comovements between the conditional mean and volatility of stock returns. He considers four monthly explanatory variables in estimating the conditional mean and conditional volatility of returns between April 1953 and March 1989. Specifically, he uses the Baa-Aaa corporate bond yield spread, the commercial paper-Treasury yield spread, the one-year Treasury yield, and the divided yield on the S&P 500. He finds evidence of asymmetric relation between volatility and expected returns. As he points out "lagged volatility is positively related to future expected returns but lagged expected returns are negatively related to future volatility". In another paper, Andersen et al., (2003) investigate the daily and lower frequency return volatilities and return distributions of Deutschemark/Dollar and Yen/Dollar spot exchange rates by employing a VAR model. Their examination is based on continuously recorded spot quotes between 1986 and 1999. They find that forecasts from the vector autoregression for the daily realized volatilities perform well and that the VAR volatility forecast produces good quality forecasts of future returns.

Using a VAR model followed by impulse response analysis, Krishnamurti et al.,(2005) address the interrelationship between several market microstructure variables: market depth, volatility, volume and price. Their results show that the impact of the lagged market- depth values in explaining forecast errors of volume is rather low, but it increases for price and volatility. In addition, they find that the shock to volume innovation has a positive impact on volatility in the S&P 500 and Dow Jones stock sample. This finding is in line with both Bessembinder and Seguin (1993) and Karpoff (1987). Bessembinder and Seguin, find a strong positive relation between contemporaneous volume and volatility and that volatility is affected by market depth, while examining the volume, volatility and liquidity relationships in eight futures markets. Karpoff (1987) describes the same positive relationship between volume and the magnitude of price change.

Section 8.3.5: Spillover effects in exchange rates in the FX market

In the FX market research field, VAR methodologies are used to identify the spillover effects of one exchange rate changes on other exchange rates. Engle et al., (1990) in their influential paper "Meteor Showers or Heat Waves? Heteroskedastic Intra-Daily Volatility in the Foreign Exchange Market" use these meteorological terms to examine the volatility spillover effects in the FX market. They use intraday yen/dollar data from October 1985 to September 1986 and find that volatility appears to spillover from one market to another (meteor shower). For example, Tokyo news has large impact on the volatility spillovers of the yen/dollar exchange rate. Samanta (2003) uses a VAR model to identify the spillover effects of one exchange rate change on other exchange rates using monthly data over 1973-1999 period for six OECD countries (Canada, France, Germany, Great Britain, Italy, and Japan). Results suggest strong spillover effects or interdependence among the exchange rates for most of the countries considered in the study.

Section 8.3.6: VAR applications in FX market microstructure

Traditional FX price determination models that use only macroeconomic data are partially successful and only at low frequencies (e.g quarterly) and fail almost entirely to explain exchange rate movements at high frequencies. (e.g daily/hourly). The availability of high frequency data in the FX market has only recently stimulated wide-spread studies of intraday market microstructure variables behaviour. The main focus is on the impact of trading activity in the FX market on the determination of exchange rates. The presumption is that trading activity affects prices since order flow contains information (not necessarily publicly available) and thus trades permanently alter prices. The information contained in these trades can be from two different sources: the private signals that the dealers may receive through order flow from their customers about exchange rate fundamentals[35] (e.g future interest rates from an intervening central bank); and signals that the dealers may receive through order flow due to private portfolio shifts, not related to macroeconomic fundamentals, such as changes in risk aversion, changes in hedging demand, etc.

The latter was originally suggested by Evans and Lyons (1999) and formally tested in Evans and Lyons (2001). In their paper, Evans and Lyons (1999) suggest a new model (portfolio shift model) that uses “order flow”, based on the field of microstructure finance. The model examines the causal link between order flow and price, more accurately from order flow to price[36]. As the authors explain, the portfolio shift model, can explain exchange rate movements since the trades involved are large enough that clearing the

[35] For theoretical and empirical models in this area see Lyons (1995,1996), Perraudin and Vitale (1996), and Lyons (1995, 2007), Yao (1998) respectively.
[36] They find that order flow accounts for about two-thirds of variation in the DM/USD rate.

market requires adjustment of the spot exchange rate. More importantly, the information about these portfolio shifts is not publicly available as they occur, since the orders associated with these shifts are not publicly observable and the market only "learns about the initial portfolio shifts by observing the interdealer trading activity".

Based on this work Evans and Lyons (2001) test a hypothesis that contrasts with their suggested model – that the underlying cause of order flow is portfolio shifts unrelated to macroeconomic information. They actually model the link between order flow and macroeconomic announcements to test whether macroeconomic information causes order flow. They obtain their data from Reuters D 2000-1 system, on USD/DEM exchange rate (May 1 to August 31, 1996). The empirical model includes five parameters[37] that capture the price impact or order flow, the direct effect of announcements on price, the direct effect of announcements on order flow, the component of daily returns unexplained by order flow or announcement and the component of daily order flow unexplained by announcements. The results show that order flow not related to macroeconomic announcements accounts for approximately 30 percent of the price variation. Macroeconomic announcements have an impact on the price directly and indirectly through order flow. The direct effect of macroeconomic announcements explains 10 percent of daily price variation while the indirect effect through order flow explains 20 percent. In a more recent paper, Evans and Lyons (2007) show that the direct impact can account for more than 30 percent of daily price movement. The main reasons for this difference from their earlier study is that they allow for much broader macroeconomic news to affect their model and not just scheduled ones, and they consider that the arrival of news affects prices indirectly through its impact on the volatility of order flow.

Payne (2003) empirically investigates informed trading in the spot foreign exchange market. He adapts the VAR structure introduced in Hasbrouck (1991a,b) and conducts an impulse response and variance decomposition

[37] Parameters are estimated with GMM.

analysis to test for the permanent trading activity effect on price and compute the proportion of all information entering the quotation process via order flow. The data set used is a USD/DEM data set from D2000-2, a closed electronic order driven system, that reflects the interaction of multiple dealers. The results presented in his paper contribute significantly to the notion that asymmetric information contributes significantly in the determination of spreads. Specifically, there is strong evidence that the information content of order flow is responsible for 60% of the spread. Moreover, he examines the relationship between volume and percentage spreads and finds that the trading days with the greatest volume are those with lowest percentage spreads. This was predicted by Admati and Pfleiderer (1988) who argued that high volume periods should be characterised by relatively small price impact from trade. The results from the impulse response functions show that the price response to a trade is relatively low in high volume (liquidity) periods. The return variance decomposition results show that "across the entire trading day, 41 percent of the permanent return variance is attributable to order flow".

In currency futures markets, volatility, volume and market depth have been examined by Fung and Patterson (1999) using VAR based on low frequency hourly data. They generally find that volatility causes volume, and not the converse.

Section 8.4: Variations of VAR models

In their paper "Vector Autoregressions", Stock and Watson (2001) classify VARs in to three categories: reduced form VAR, recursive VAR, and structural VAR. They explain that in **reduced** form, the VAR expresses each variable as a linear function of its own past values, the past values of all other variables in the model and a serially uncorrelated error term.

A **recursive** VAR constructs the error terms in each regression equation to be uncorrelated with the error in the preceding equation. The researcher can use economic theory and thoughtfully add some contemporaneous values as regressors. For example in a two-variable VAR model, ordered as 1) trading activity, 2) volatility, in the first equation of the corresponding recursive VAR, trading activity is the dependent variable and the regressors are lagged values of the two variables (trading activity and volatility). In the second equation, the volatility is the dependent variable and the regressors are the lags of the two variables plus the current value of the trading activity. Estimation of each equation by OLS produces residuals that are uncorrelated across equations. Obviously, the results depend on the order of the variables given that changing the order changes the VAR equations, coefficients, and residuals. There are n! recursive VARs representing all possible orderings.

In a **structural** VAR, economic theory is used to decide the contemporaneous links among the variables (Bernanke, 1986; Blanchard and Watson, 1986; Sims, 1986). Structural VARs allow the researcher to assume the correlation among variables using economic reasoning, and therefore create models that can extend from a single equation (so that only a specific causal link is identified) to the entire VAR. As Stock and Watson (2001) mention "the number of structural VARs is limited only by the inventiveness of the researcher."

Section 8.5: Limitations of VAR models

The use of VARs is controversial in the econometric literature. The main problematic areas are the choice of the appropriate lag length, the fact of assuming causalities (being a-theoretic) and the difficulty of ensuring (jointly) stationarity of all variables included in VAR. However, for an attentive and an inventive researcher, "they can be useful tools to examine the relationships among economic variables in a dynamic context" (Enders,1995). Gujarati (1995) argued that the VAR model, which requires less *a priori* information, has in fact an advantage of treating each variable under the study as an endogenous variable when economic theory cannot offer *a priori* information regarding the variables used in the VAR. Gujarati adds that this makes VAR estimation simpler, and OLS estimation method can be used provided all variables included in the VAR are integrated of the same order.

Section 8.6: VAR results (Daily and Intraday)

This section presents the results from the VAR models based on both daily and intra-day samples focusing on impulse response functions and variance decomposition analysis. Impulse responses can indicate the strength and duration with which a unit shock in one variable is transmitted to another variable. In this part of my study I examine the strength and duration with which a shock in the number of quote revisions, spread, volatility and interest rate differential is transmitted to the spread (quote and relative). The variance decomposition explains how much of the *p* periods ahead forecast error variance of a given variable is explained by innovations to each variable. I examine the effect of trading activity, spread, exchange rate volatility and interest rate differential[38] on the spread for three currency pairs and look for differences and similarities in the variable behaviour between the three different currency pairs in a particular time zone. In addition, I examine whether these relationships are different for a currency pair in different time zones. I begin with results for the daily sample and then discuss results from the intraday sample.

I use an unrestricted "reduced form" VAR with four variables. The number of quote revisions, spread (quoted and relative), exchange rate volatility and interest rate differential are modelled as a four-variable VAR,

$$V_t = \sum_{p=1}^{K} A_p V_{t-p} + e \qquad \text{Eq. 8.12}$$

where, V_t is an 4 x 1 column vector of the four variables, A_p is an 4 x 4 coefficient matrix, *k* is the lag length, and e_t is an 4 x 1 column vector for forecast errors of the best linear predictor of the variables, V_t, using all the past values, V_{t-p}. By construction, e_t is uncorrelated with V_{t-p} for all *p*. Since also e_t is a linear combination of current and past spreads, equation (1), e_t is serially uncorrelated. The *i*,*j*th element of A_p measures the direct effect that a unit change in the *j*th variable has on the *i*th variable in p periods.

[38] As defined in Chapter 8, Section 8.1.1

The equations I use are as follows:

$$NQR_t = \sum_{p=1}^{k}\alpha_i NQR_{t\text{-}i} + \sum_{p=1}^{k}\beta_i S_{t\text{-}i} + \sum_{p=1}^{k}\gamma_i VOL_{t\text{-}i} + \sum_{p=1}^{k}\delta_i IRD_{t\text{-}i} + e_{1t} \qquad \text{Eq. 8.13}$$

$$S_t = \sum_{p=1}^{k}\varepsilon_i S_{t\text{-}i} + \sum_{p=1}^{k}\zeta_i NQR_{t\text{-}i} + \sum_{p=1}^{k}\eta_i VOL_{t\text{-}i} + \sum_{p=1}^{k}\theta_i IRD_{t\text{-}i} + e_{2t} \qquad \text{Eq. 8.14}$$

$$VOL_t = \sum_{p=1}^{k}\iota_i VOL_{t\text{-}i} + \sum_{p=1}^{k}\kappa_i S_{t\text{-}i} + \sum_{p=1}^{k}\lambda_i NQR_{t\text{-}i} + \sum_{p=1}^{k}\mu_i IRD_{t\text{-}i} + e_{3t} \qquad \text{Eq. 8.15}$$

$$IRD_t = \sum_{p=1}^{k}\nu_i IRD_{t\text{-}i} + \sum_{p=1}^{k}\xi_i VOL_{t\text{-}i} + \sum_{p=1}^{k}o_i S_{t\text{-}i} + \sum_{p=1}^{k}\pi_i NQR_{t\text{-}i} + e_{4t} \qquad \text{Eq. 8.16}$$

where
NQR: number of quote revisions
S: spread
VOL: volatility
IRD: interest rate differential
α, β, γ, δ: the coefficients of NQR, S, VOL and IRD, respectively, in the number of quote revisions equation
ε, ζ, η, θ: the coefficients of S, NQR, VOL and IRD, respectively, in the spread equation
ι, κ, λ, μ: the coefficients of VOL, S, NQR and IRD, respectively, in the volatility equation
ν, ξ, ο, π: the coefficients of IRD, VOL, S, and NQR, respectively, in the interest differential equation

The order of the VAR has been chosen by obtaining the first order cross autocorrelations results between the four variables using the full sample. The VAR has been ordered according to which variable leads another. Results from all cross autocorrelations suggest the following order: number of quote revisions, spread (quoted and relative), exchange rate volatility and interest rate differential, with only a couple of exceptions where the leading variable is the spread but the difference is very small. Results are presented in Appendix 7.

In order to determine the appropriate lag lengths for our variables used in all equations, I apply the widely used [(e.g Andersen et al., (2003), King et al., (1994), Friedman (1997), Ito (1988)] multivariate generalisation of Akaike's information criterion (AIC)[39]. The number of lags that minimises the AIC criterion varies across equations and time zones for the daily sample. The table below shows the number of lags where the AIC is minimised[40] in the daily sample. As for the intraday sample, the number of lags that minimises the AIC criterion is ten[41] across all equations and the three time zones.

Table 8.1: Number of lags in VAR model

Daily Sample						
	Quoted Spread			Relative Spread		
	JP/US	GB/US	EU/US	JP/US	GB/US	EU/US
US	10	5	5	8	5	5
UK	8	8	6	8	8	6
ASIA	10	5	5	8	5	6

Section 8.6.1 Daily VAR results

US time zone: Impulse response functions

Panels 8.1-8.3 present the standardised impulse response functions based on the number of quote revisions, spreads (quoted and relative), volatility and interest rate differential variables for the JP/US, GB/US and EU/US currency pairs, in the US time zone for the period from 01.01.1995 to 31.01.2005. The tables in each panel show the impulse response functions that refer to the reaction of the variables listed in the columns of each table to a shock in the variable identified at the head of that table, *p* days later. (*p* = 1, is the reaction at time zero). Panels 8.10-8.12 illustrate plots of those impulse response results.

Results (Panels 8.1-8.3) clearly demonstrate that the innovations to the number of quote revisions have a negative impact on the spread since the impulse response is negative. Our results are in line with the theoretical proposition of Admati and Pfleiderer (1988) that spread should decrease when

[39] Since we use an unrestricted "reduced form" VAR, it is required that the same number of lags of all of the variables is used in all equations.
[40] We re-estimated the VAR model using the same number of lags for all equations, ten, and the results obtained were similar.
[41] We re-estimated the VAR model using twenty lags, and the results obtained were similar.

trading activity increases and the empirical findings of Bollerslev and Domovitz (1993), who show that when orders increase in frequency the spread decreases. The effect of a unit innovation in the number of quote revisions two steps ahead, is transmitted on the spread (quoted and relative) more strongly in the EU/US VAR equations than in the ones of JP/US and GB/US. In particular, a unit shock in the number of quote revisions for the EU/US, will decrease the quoted and relative spread by 0.15 and 0.17 respectively, while for the JP/US the decrease is 0.10 and for the GB/US 0.13. That means that the number of quote revisions is more informative for the EU/US currency pair. As Plots (Panel 8.10-8.12) show, a shock in the number of quote revisions has a long-term effect on the future spread. Although the strongest reaction of the spread to unit shock in the number of quote revisions is observed for the EU/US, the effects do not last as long as for the other two currency pairs.

The remaining results (Panels 8.1-8.3) present how the variables react to shocks that occur in the spread, volatility and interest rate differential respectively. It appears that for all currency pairs (both quoted and relative spread) the spread reacts strongly to own shocks, the effects are long lived and outlast shocks in the volatility and interest rate differential variable. Again, these shocks do not last as long for the EU/US. Regarding the effects of volatility on spread, empirical papers (Bessembinder 1994, Glassman 1987, and Boothe 1987, Bollerslev and Melvin 1994) find a positive and statistically significant relationship. My results show that a unit shock in volatility will change the spreads under consideration between 0.002 and 0.077 but signs (decrease or increase) are mixed. Similarly, mixed signs are found for the impact of our interest rate differential variable on the spread - in line with Becker and Sy (2005), who find that the Eurodollar short-long differential has coefficients with mixed sign[42] - with the exception of the EU/US spread. A unit change in the interest rate differential variable will decrease the EU/US spread by at least 0.055 for up to 20 periods ahead. In contrast, Bessembinder (1994) finds that the coefficient on the Eurodollar based proxy for the opportunity cost

[42] Researching bid-ask spreads for Asian emerging market currencies.

of liquidity is positive for each currency (British pound, Swiss franc, Japanese yen, German mark).

The responses of spread to its own shocks gradually fade in the first five steps followed by a reverse reaction in the sixth step (five days ahead) that is observed for all currency pairs for both the quoted and relative spread. The strongest reaction of the EU/US spread to its own shocks is not observed the next day but five days later as shown in Panel 8.3. It may be that this reverse reaction in the spread is caused by the reverse reaction in volatility one or two days earlier. For the GB/US and EU/US currency pairs, it occurs four steps ahead (three days) while for the JP/US five steps ahead (four days).

UK time zone: Impulse response functions

Panels 8.4-8.6 present the standardised impulse response functions based on the number of quote revisions, spreads (quoted and relative), volatility and interest rate differential variables for the JP/US, GB/US and EU/US currency pairs, in the UK time zone for the period from 01.01.1995 to 31.01.2005. The tables in each panel show the impulse response functions that refer to the reaction of the variables listed in the columns of each table to a shock in the variable identified at the head of that table, p days later. (p = 1, is the reaction at time zero). Panels 8.10-8.12 illustrate plots of the above mentioned impulse response results.

Results suggest that the general pattern of the impulse responses in the UK time zone is similar to the US time zone, but with some important differences.

As expected, the innovations to the number of quote revisions have a negative impact on the spread in the UK time zone too. The effect of a unit innovation in the number of quote revisions on the spread (quoted and relative) two steps ahead, is much weaker in UK time zone for the JP/US and GB/US than the results from the US sample. As with the US sample, the shocks in the number of quote revisions spill over into the spread more strongly in the EU/US VAR equations. That means a unit innovation in the number of quote revisions is more informative (regarding the spread) in the US time zone and in particular for the EU/US currency pair. Concluding, in both time zones, spread is affected by prior trading activity (as this is captured by the number of quote revisions). As Panels 10-12 show, a shock in the number of quote revisions has a long-term effect on the future spread. As with the US time zone, the effects do not last as long in the EU/US VAR specifications as in the JP/US and GB/US.

The remaining results of Panels 10-12, show how the variables react to shocks that occur in the spread, volatility and interest rate differential respectively. As with the US sample, for all currency pairs (both quoted and relative spread) the spread reacts strongly to own shocks, and the effects last longer for shocks in the spread and less for shocks in the volatility variable. As in the US sample, these shocks last less for the EU/US. Moreover, the results show that a shock in the volatility will increase the JP/US spread around 0.02 for up to 20 periods ahead. This finding supports previous empirical papers (Bessembinder 1994, Glassman 1987, and Boothe 1987, Bollerslev and Melvin 1994) that find a positive relationship between volatility and spread. The findings from the interest rate differential variable in the UK time zone are similar to the ones from the US time zone (mixed signs are found for JP/US and GB/US and negative for the EU/US spread). A unit change in the interest rate differential variable will decrease the EU/US quoted spread by at least 0.05 for up to 10 periods ahead.

The reverse reaction in the responses of spread to its own shocks (after the gradual fade in the first days) is also evident in the UK time zone but less significant. In all VAR specifications in the UK time zone, the reaction of the spread to its own shocks two steps ahead (one day after the first shock) is between 10 to 20 percent stronger than the US time zone. That means spread informativeness appears to be larger in the UK time zone, while in the US time zone trading activity appears to be more informative.

ASIA time zone: Impulse response functions

Panels 8.7-8.9 present the standardised impulse response functions based on the number of quote revisions, spreads (quoted and relative), volatility and interest rate differential variables for the JP/US, GB/US and EU/US currency pairs, in the Asia time zone for the period from 01.01.1995 to 31.01.2005. The tables in each panel show the impulse response functions that refer to the reaction of the variables listed in the columns of each table to a shock in the variable identified at the head of that table, *p* days later. (*p* = 1, is the reaction at time zero). Panels 8.10-12 illustrate plots of those impulse response results.

The results suggest that the general pattern of the impulse responses in the Asia time zone is similar to that previously discussed for the UK time zone and almost identical to the one observed in the US time zone. First, the effect of a unit innovation in the number of quote revisions on the spread (quoted and relative) two steps ahead, is significantly similar to the US time zone results (only for the quoted spread) therefore overall the weakest effects among the three time zones are observed in the UK time zone. Moreover, as with the US and UK samples, the shocks in the number of quote revisions spillover into the spread more strongly in the EU/US VAR equations. That means a unit innovation in the number of quote revisions is more informative (regarding the spread) in the US and Asia time zones and in particular for the EU/US currency pair. To sum up, in all three time zones, spread is affected by prior trading activity (as this is captured by the number of quote revisions).

As with the US and UK time zones, for all currency pairs (both quoted and relative spread) the spread reacts strongly to own shocks, and these shocks have long-term effects especially for JP/US and GB/US. In line with the US and UK samples, the effects of a shock in volatility on the spread are generally mixed with the exception of JP/US spread that is affected positively by a change in volatility. In particular, the JP/US will increase by 0.05 one day after a unit shock in volatility. Finally, the effect of the interest rate differential variable on the spread is very similar to those found in the US and UK time zones.

The reverse reaction in the responses of spread to its own shocks (after the gradual fade in the first days) observed in the two other time zones, is again evident in the Asia time zone.

In all VAR specifications in the Asia time zone, the reaction of the spread to its own shocks two steps ahead (one day after the first shock) is between 10 to 20 percent weaker than in the UK time zone. The reaction of spread to shocks in volatility and interest rate differential variable is weak, as in the US and UK sample. That means, overall, spread informativeness appears to be larger in the UK time zone, while in the US and ASIA time zones trading activity appears to be more informative.

US time zone: Variance decompositions

Panels 8.13-8.15 give estimates of the variance decompositions derived from the VAR based on the number of quote revisions, spreads (quoted and relative), volatility and interest rate differential variables for the JP/US, GB/US and EU/US currency pairs, in the US time zone for the period from 01.01.1995 to 31.01.2005[43]. The tables in each panel show the percentage of the forecast error variance shift in the variable listed at the head of that table that is explained by innovations in the variables identified in the columns of each table, up to 200 periods ahead (p = 1, is the reaction at time zero). Panels 8.22-8.24 illustrate plots of those variance decompositions.

By construction, the percentage of the error variance attributable to own shocks in the first step is 100 percent.

Panels 8.13-8.15 show the percentage of the forecast error variance shift in the spread explained by innovations in the number of quote revisions, spread,

[43] For the EU/US the period is from 01.01.2001 to 31.01.2005.

volatility and interest rate differential variable, up to 200 periods ahead (p = 1, is the reaction at time zero).

A very large percentage of the error variance in the spread is attributable to own shocks. However, the tables clearly indicate that the number of quote revisions variable has significant explanatory power on the spread starting from the first days and considerably increasing over the 200 steps for the GB/US and EU/US. Specifically, approximately 10 and 16 percent respectively of the variation in the spread is due to innovations in the number of quote revisions in the first five days (both in quoted and relative spread specifications). By 100 steps ahead, when effects stabilise, for the GB/US it reaches 40 percent, while for the EU/US the effects stabilise much faster (6 steps) at around 17 percent. For the JP/US these effects are much weaker and take much longer to become significant (only 5 percent twenty steps ahead). Payne (2003) finds that the information content of the order flow is 60 percent of the spread; therefore, our results provide additional evidence of the information role of order flow in the determination of spreads. As for the remaining variables, in all cases, volatility and interest rate differential, can explain a very small fraction of the spread variations (in most cases less that one percent) with the exception of the EU/US currency pair (quoted spread) were the interest rate differential 30 steps ahead is responsible for a relatively significant amount of the spread variation (11 percent).

Summarising the findings from the US time zone I can clearly say that trading activity (as captured by our number of quote revisions variable) has strong explanatory power on the spread (7-40 percent). Finally, I further support the well documented two-way causal relationship between spread and trading activity, and I find that overall the number of quote revisions variable has more explanatory power on the spread than the spread has on the number of quote revisions.

UK time zone: Variance decompositions

Panels 8.16-8.18 provide estimates of the variance decompositions derived from the VAR based on the number of quote revisions, spreads (quoted and relative), volatility and interest rate differential variables for the JP/US, GB/US and EU/US currency pairs, in the UK time zone for the period from 01.01.1995 to 31.01.2005[44]. The tables in each panel show the percentage of the forecast error variance shift in the variable listed at the head of that table that is explained by innovations in the variables identified in the columns of each table, up to 200 periods ahead (*p* = 1, is the reaction at time zero). Panels 8.22-8.24 illustrate plots those variance decompositions.

By construction, the percentage of the error variance attributable to own shocks in the first step is 100 percent.

Panels 8.16-8.18, show the percentage of the forecast error variance shift in the spread explained by innovations in the number of quote revisions, spread, volatility and interest rate differential variable, up to 200 periods ahead (*p* = 1, is the reaction at time zero).

A very large percentage of the error variance in the spread is attributable to own shocks. Especially, in the first 5 steps for the JP/US, own shocks explain the variance shifts entirely. The number of quote revisions variable has explanatory power on the spread starting from the first days (apart from the JP/US) but it is not higher that 6 percent in the first 5 steps (up to 17 percent in the US time zone) and does not increase as much as in the US time zone over the 200 (between 5 and 16 percent whereas in the US time zone the percentages range from 15 to 40 percent). Clearly, the number of quote revisions, our proxy for trading activity, is more important in determining the spread in the US time zone. Volatility and interest rate differential cannot explain spread variations (in most cases less than one percent) with the exception of the EU/US currency pair (quoted spread) where the interest rate differential 40 steps ahead is responsible for a relatively significant amount of

[44] For the EU/US the period is from 01.01.2001 to 31.01.2005.

the spread variation (11 percent). This provides additional evidence to that from the US time zone that volatility and interest rate differential variable (inventory cost proxy) are not significant in determining shifts in the spread. It is likely that my inventory cost proxy is unable to capture the effects on the spread since I use Eurodollar rates; that's why the effect is only evident in the EU/US currency pair.

Overall, we can see that the number of quote revisions variable has less impact on the spread in the UK than in the US time zone. The two way causal relationship between the spread and trading activity is observed also in the UK time zone. However, in contrast to the US time zone we find mixed results as to which variable has stronger effect on the other.

ASIA time zone: Variance decompositions

Panels 8.19-8.21 provide estimates of the variance decompositions derived from the VAR based on the number of quote revisions, spreads (quoted and relative), volatility and interest rate differential variables for the JP/US, GB/US and EU/US currency pairs, in the Asia time zone for the period from 01.01.1995 to 31.01.2005[45]. The tables in each panel show the percentage of the forecast error variance shift in the variable listed at the head of that table that is explained by innovations in the variables identified in the columns of each table, up to 200 periods ahead (*p* = 1, is the reaction at time zero). Panels 22-24 illustrate plots of those variance decompositions.

By construction, the percentage of the error variance attributable to own shocks in the first step is 100 percent.

The results from Panels 8.19-8.21 suggest that the general pattern of the variance decompositions in the Asia time zone is very similar to the US time zone, almost identical in many cases for the variance decompositions of spread. This provides strong evidence of the link between trading in two different geographical areas, the markets of New York and Tokyo.

[45] For the EU/US the period is from 01.01.2001 to 31.01.2005.

The number of quote revisions variable is more important in determining the spread in the US and Asia time zones than in the UK time zone. Volatility and interest rate differential, explain only a small fraction of the variation in the spread. Overall, comparing the results from the three time zones I find that trading activity has more impact on the spread in the US and Asia time zones than in the UK time zone. Finally, there is a two way causal relationship between the spread and trading activity in all three time zones, with the trading activity having a stronger effect on the spread in the US and ASIA time zones, while we find mixed results as to which variable has stronger effect on the other in the UK time zone.

Section 8.6.2: Summary of daily VAR results

My results suggest that the general pattern of the impulse responses is similar in all time zones (results for US and Asia time zones are almost identical). The innovations to the number of quote revisions have a negative impact on the spread in line with the theoretical proposition of Admati and Pfleiderer (1988) and the empirical findings of Bollerslev and Domovitz (1993). In particular, a unit innovation in the number of quote revisions is more informative (regarding the spread) in the US time zone and in particular for the EU/US currency pair. In all time zones and for all currency pairs the spread reacts strongly to own shocks, and these shocks have long-term effects especially for JP/US and GB/US. As for the effect of a shock in volatility on the spread, results are mixed. Finally, the effect of the interest rate differential variable on the spread is very similar across major financial markets. Overall, spread informativeness appears to be larger in the UK time zone, while in the US and ASIA time zones trading activity appears to be more informative.

Results from the variance decompositions show that trading activity (as captured by our number of quote revisions variable) has strong explanatory power on the spread. The number of quote revisions variable is more important in determining the spread in the US and Asia time zones than in the UK time zone. Volatility and interest rate differential, explain only a small fraction of the variation in the spread. Concluding, my findings support the well documented two-way causal relationship between spread and trading activity, and show that the number of quote revisions variable has more explanatory power on the spread than the spread has on the number of quote revisions.

Section 8.6.3: Intra-day VAR results

In general intraday results show some differences in the behaviour of our variables at high frequencies compared to the results from the daily sample. In particular, I find more evidence in the intra-day sample than in the daily sample, of the positive impact of volatility on spread. In the sections below, I discuss the results of each time zone and compare them to those from the daily sample.

US time zone: Impulse response functions

Panels 8.25-8.33 present the standardised impulse response functions based on the number of quote revisions, spreads (quoted and relative), volatility and interest rate differential variables for the JP/US, GB/US and EU/US[46] currency pairs, in the US time zone for the period from 01.01.1995 to 31.01.2005. The tables in each panel show the impulse response functions that refer to the reaction of the variables listed in the columns of each table to a shock in the variable identified at the head of that table, *p* periods later. (*p* = 1, is the reaction at time zero, one period: 5 minute interval). Panels 8.34-8.36 illustrate plots of those impulse response results.

The results (Panels 8.25-8.27) show that innovations to the number of quote revisions have a negative impact on the spread since the impulse response is negative. In particular, a unit shock in the number of quote revisions for the JP/US will decrease the quoted and relative spread by 0.0254 and 0.0248 respectively, while for the GB/US the decrease is 0.0266 and 0.0268, and for the EU/US 0.0252 and 0.0296. That means that the number of quote revisions is more informative for the GB/US currency pair; however, the differences are

[46] For the EU/US the period is from 01.01.2001 to 31.01.2005.

not significant. A shock in the number of quote revisions has a long-term effect on the future spread.

Looking at the remaining relationships it appears that the spread (both quoted and relative) reacts to own shocks and the effect is stronger for the GB/US. A unit shock in the spread for the GB/US, will increase the future (5 minutes ahead) quoted spread by 0.1623. This effect is much weaker than in the daily sample. Moreover, the duration of the effect is shorter than that of the number of quote revisions effect. Therefore, we can conclude that a shock in the number of quote revisions has more effect on the spread when short term trading intervals are considered (intra-day) compared to its own shocks. When longer trading intervals are considered (daily) the shocks in the spread have more effect on the future spread. In other words, past trading activity is a more informative about the future spread when intra-day trading is considered while past spread is more informative about the future spread when daily trading is considered. As we will see below, the same behaviour is observed in all time zones.

Regarding the impact of volatility on spread, the results show that a unit shock in volatility will decrease the JP/US spread by 0.0075 and increase the EU/US spread by 0.011 five minutes after the shock is observed. The GB/US spread will also decrease in the second step after the shock in volatility, but in the following steps the signs of the impact are mixed (as in the daily sample). Similarly, mixed signs are found for the impact of the interest rate differential variable on the spread. A unit change in the interest rate differential variable will increase the JP/US spread by approximately 0.001 and decrease the EU/US spread by at least 0.005 for up to 20 periods ahead. The reaction of JP/US spread is in line with Bessembinder (1994), who finds that the coefficient on the Eurodollar based proxy for the opportunity cost of liquidity is positive for each currency (British pound, Swiss franc, Japanese yen, German mark).

UK time zone: Impulse response functions

Panels 8.28-8.30 present the standardised impulse response functions based on the number of quote revisions, spreads (quoted and relative), volatility and interest rate differential variables for the JP/US, GB/US and EU/US[47] currency pairs, in the UK time zone for the period from 01.01.1995 to 31.01.2005. The tables in each panel show the impulse response functions that refer to the reaction of the variables listed in the columns of each table to a shock in the variable identified at the head of that table, *p* periods later. (*p* = 1, is the reaction at time zero, one period: 5 minute interval). Panels 8.34-8.36 illustrate plots of those impulse response results.

The general pattern of the impulse responses in the UK time zone is very similar to those in US time zone. The innovations to the number of quote revisions have a negative impact on the spread in the UK time zone. In particular, a unit shock in the number of quote revisions for the JP/US, will decrease the quoted and relative spread by 0.021, while for the GB/US the decrease is around 0.017, and for the EU/US 0.008 (quoted) and 0.013 (relative). Therefore, it is clear that the impact of the shock is weaker than in the US sample. Similar to the US time zone, a shock in the number of quote revisions has a long-term effect on the future spread.

In line with the findings from the US sample, the spread (both quoted and relative) reacts to own shocks and the effect is stronger for the GB/US. However the effect is weaker than the one in the US sample. As I mentioned earlier, this effect is also much weaker than in the daily sample and fades out faster when compared to the effect from the number of quote revisions; this is also in line with the findings from the US sample.

Regarding the impact of volatility on spread, the results show that a unit shock in volatility has a positive impact on the quoted and relative spreads of all currency pairs under consideration. This finding supports previous empirical

[47] For the EU/US the period is from 01.01.2001 to 31.01.2005.

papers (Bessembinder 1994, Glassman 1987, and Boothe 1987, Bollerslev and Melvin 1994) that find a positive relationship between volatility and spread. In line with my findings from the daily sample, the effects from the shocks last longer for shocks in the spread and less for shocks in the volatility variable. The findings from the interest rate differential variable in the UK ti**me** zone are different from those in the US time zone (mixed signs are found for JP/US, and negative for the GB/US and the EU/US spread).

ASIA time zone: Impulse response functions

Panels 8.31-8.33 present the standardised impulse response functions based on the number of quote revisions, spreads (quoted and relative), volatility and interest rate differential variables for the JP/US, GB/US and EU/US[48] currency pairs, in the UK time zone for the period from 01.01.1995 to 31.01.2005. The tables in each panel show the impulse response functions that refer to the reaction of the variables listed in the columns of each table to a shock in the variable identified at the head of that table, *p* periods later. (*p* = 1, is the reaction at time zero, one period: 5 minute interval). Panels 8.34-8.36 illustrate plots of those impulse response results.

The general pattern of the impulse responses in the Asia time zone is similar to that previously discussed for the UK time zone and almost identical in some cases to the one observed in the US time zone. I arrived at the same conclusion when discussing the results from the daily sample. The findings show that innovations to the number of quote revisions have a negative impact on the spread since the impulse response is negative. In line with the results from the US and UK time zones, a shock in the number of quote revisions has a long-term effect on the future spread.

As in the two other time zones the spread (both quoted and relative) reacts to own shocks and the effect is stronger for the GB/US. The effect is much weaker than in the daily sample and has shorter duration compared to the

[48] For the EU/US the period is from 01.01.2001 to 31.01.2005.

duration than of number of quote revisions effect (as in the US and UK time zones). As for shocks in volatility, the results show that a unit shock in the volatility has a positive impact on the quoted and relative spreads of JP/US and GB/US currency pairs. Two steps ahead (5 minutes after the shock is observed) this effect for the JP/US is stronger in the US time zone and for the GB/US and EU/US stronger in the UK time zone. Finally, its important to note the general pattern of volatility is similar across currency pairs both in the daily and intraday sample. This is in accord with Baillie and Bollerslev (1990), who find that hourly patterns in volatility are remarkably similar across currencies (GB/US, Deutschemark/US, Swiss Frank/US, JP/US). As for the interest rate differential variable it seems that the only similar behaviour across the three time zones is observed for the EU/US exchange rate. In all time zones, a shock in the interest rate differential variable will have a negative impact on the EU/US spread.[49] This result is in contrast to the findings of Bessembinder (1994), who finds that the coefficient on the Eurodollar based proxy for the opportunity cost of liquidity is positive for each currency (British pound, Swiss franc, Japanese yen, German mark).

US time zone: Variance decompositions

Panels 8.37-.8.39 present estimates of the variance decompositions derived from the VAR, based on the number of quote revisions, spreads (quoted and relative), volatility and interest rate differential variables for the JP/US, GB/US and EU/US currency pairs, in the US time zone for the period from 01.01.1995 to 31.01.2005[50]. The tables in each panel show the percentage of the forecast error variance shift in the variable listed at the head of that table that is explained by innovations in the variables identified in the columns of each table, up to 40 periods ahead (p = 1, is the reaction at time zero; Period: 5 minute intervals). Panels 8.46-8.48 illustrate plots of those variance decompositions.

[49] It is possible that the mixed results found for the JP/US and GB/US are due to the fact that we use the Eurodollar rates to determine our variable.
[50] For the EU/US the period is from 01.01.2001 to 31.01.2005.

By construction, the percentage of the error variance attributable to own shocks in the first step is 100 percent.

Panels 8.37-8.39 show the percentage of the forecast error variance shift in the spread that is explained by innovations in the number of quote revisions, spread, volatility and interest rate differential variable, up to 40 periods ahead (p = 1, is the reaction at time zero).

The percentage of shift for the error variance in the spread is explained almost entirely by its own innovations for all three currency pairs (both in quoted and relative spread VARs). Over 93 percent of the error variance in the spread series is attributable to own shocks in the first 40 steps. We can observe some additional significance added due to the number of quote revisions variable (around four percent) on the spread but only after 30 periods ahead. As for the remaining variables, in all cases, volatility and interest rate differential can't explain the spread variations (in all cases the value is close to zero).

Looking at Panels 8.46-8.48 we can see that the behaviour settles down to a steady state faster for the EU/US currency pair. The fact that the EU/US is the most actively traded currency pair (2005 BIS data) is a possible explanation for this finding.

UK time zone: Variance decompositions

Panels 8.40-8.42 present estimates of the variance decompositions derived from the VAR, based on the number of quote revisions, spreads (quoted and relative), volatility and interest rate differential variables for the JP/US, GB/US and EU/US currency pairs, in the UK time zone for the period from 01.01.1995 to 31.01.2005[51]. The tables in each panel show the percentage of the forecast error variance shift in the variable listed at the head of that table that is explained by innovations in the variables identified in the columns of each table, up to 40 periods ahead (p = 1, is the reaction at time zero; Period: 5

[51] For the EU/US the period is from 01.01.2001 to 31.01.2005.

minute intervals). Panels 8.46-8.48 illustrate plots of those variance decompositions.

By construction, the percentage of the error variance attributable to own shocks in the first step is 100 percent.

Panels 8.40-8.42 show the percentage of the forecast error variance shift in the spread that is explained by innovations in the number of quote revisions, spread, volatility and interest rate differential variable, up to 40 periods ahead (p = 1, is the reaction at time zero).

A very large percentage (over 93 percent) of the error variance in the spread is attributable to own shocks. The number of quote revisions variable has some but still very little explanatory power (not more that 5 percent) on the JP/US and GB/US spread but only 30 periods ahead. As for the remaining variables, in all cases volatility and interest rate differential, can't explain the spread variations (in all cases the value is close to zero).

ASIA time zone: Variance decompositions

Panels 8.43-8.45 present estimates of the variance decompositions derived from the VAR, based on the number of quote revisions, spreads (quoted and relative), volatility and interest rate differential variables for the JP/US, GB/US and EU/US currency pairs, in the Asia time zone for the period from 01.01.1995 to 31.01.2005[52]. The tables in each panel show the percentage of the forecast error variance shift in the variable listed at the head of that table that is explained by innovations in the variables identified in the columns of each table, up to 40 periods ahead (p = 1, is the reaction at time zero; Period: 5 minute intervals). Panels 8.46-8.48 illustrate plots of those variance decompositions.

By construction, the percentage of the error variance attributable to own shocks in the first step is 100 percent.

[52] For the EU/US the period is from 01.01.2001 to 31.01.2005.

The general pattern of the variance decompositions in the Asia time zone is very similar to the US time zone, almost identical in many cases. This provides additional evidence of the link between the trading in two different geographical areas, the markets of New York and Tokyo.

As in the US and UK time zones a very large percentage (over 92 percent) of the error variance in the spread is attributable to own shocks. The number of quote revisions variable has slightly higher explanatory power in this time zone but still it doesn't exceed eight percent. As for the remaining variables, in all cases, volatility and interest rate differential, can't explain the spread variations (in all cases the value is close to zero).

Section 8.6.4: Summary of intraday VAR results

Results from the intraday sample show that a shock in the number of quote revisions has more effect on the spread when short term trading intervals are considered (intra-day) compared to its own shocks. When longer trading intervals are considered (daily) the shocks in the spread have more effect on the future spread. In other words, past trading activity is a more informative about the future spread when intra-day trading is considered providing evidence of asymmetric information. Moreover, it's important to note the general pattern of volatility is similar across currency pairs both in the daily and intraday sample. This is in accord with Baillie and Bollerslev (1990), who find that hourly patterns in volatility are remarkably similar across currencies (GB/US, Deutschemark/US, Swiss Frank/US, JP/US).

Finally, findings from the variance decompositions show that across the three financial markets a very large percentage (over 92 percent) of the error variance in the spread is attributable to own shocks. The number of quote revisions variable has slightly higher explanatory power in the Asia time zone but still it doesn't exceed eight percent. As for the remaining variables, in all cases, volatility and interest rate differential, can't explain the spread variations (in all cases the value is close to zero).

Section 8.7: Summary and conclusions

In this chapter I examine the effect of trading activity, exchange rate volatility and inventory holding costs on both quoted and relative spreads using vector autoregression analysis. My results support the presence of asymmetric information in intraday trading. In addition, I find strong evidence of commonality in liquidity across major financial centres as this is documented by the similar general pattern observed for most variables examined in this chapter.

In particular, I find that the general pattern of the impulse responses is similar in all time zones and show that the innovations to the number of quote revisions have a negative impact on the spread in line with the theoretical proposition of Admati and Pfleiderer (1988) and the empirical findings of Bollerslev and Domovitz (1993). Using the daily sample, I find that spread informativeness appears to be larger in the UK time zone, while in the US and ASIA time zones trading activity appears to be more informative. Moreover, results from the variance decompositions support the well documented two-way causal relationship between spread and trading activity, and show that the number of quote revisions variable has more explanatory power on the spread than the spread has on the number of quote revisions. Results from the intraday sample show that past trading activity is a more informative about the future spread when intra-day trading is considered providing evidence of asymmetric information. Moreover, it’s important to note the general pattern of volatility is similar across currency pairs both in the daily and intraday sample.

In the last chapter of this thesis, I summarise the data, the methodology and the main findings of my work and discuss areas for future work resulting from this research.

Panels 8.1 to 8.9: Standardised Impulse Response Functions, Daily Sample

Note to Panels 8.1-8.9: The impulse response functions in this panel illustrate the reaction of the variables listed in the columns of the tables to a shock in the variable identified at the head of each table. These have been estimated using the VAR described in Section 8.6 The VAR is applied on our full daily sample. Variables used in the VAR; The number of quote revisions: mean quote revisions were calculated based on the number of quote revisions recorded in 5-minute intervals, between 8:00am and 5:00pm local time; The daily mean quoted spreads were calculated based on the last recorded bid and ask quotes at 5-minute intervals, between 8:00am and 5pm local time. The daily mean relative spreads were calculated based on the difference of the logarithm of the ask price and the logarithm of the bid price. The logarithmic bid and ask values are based on the last bid-ask quotes recorded at 5-minute intervals, between 8:00am and 5:00pm local time. *Volatility*: the difference between the highest ask price and lowest bid price during a trading day; Interest rate differential (IRD) between Eurodollar overnight deposit rates (short) and Eurodollar one month deposit rate (long). The column headed *p* refers to the number of periods (days) following the shock.

Panel 8.1

Standardized Impulse Response Functions

US Time Zone: JP/US

	Table 1: Number of Quote Revisions				Table 2: Quoted Spread				Table 3: Volatility				Table 4: Interest Rate Differential			
p	NQR	Q. Spread	Volatility	IRD	NQR	Q. Spread	Volatility	IRD	NQR	Q. Spread	Volatility	IRD	NQR	Q. Spread	Volatility	IRD
1	1.0000	0.0000	0.0000	0.0000	-0.1545	0.9880	0.0000	0.0000	0.2571	0.1320	0.9573	0.0000	0.0745	-0.0009	-0.0173	0.9971
2	0.3444	-0.1062	0.0067	0.0485	-0.0316	0.3095	0.0277	-0.0367	0.0897	-0.0096	0.1761	-0.0129	0.0852	-0.0190	-0.0026	0.5893
3	0.1682	-0.0349	-0.0105	0.1480	-0.0275	0.2291	0.0356	-0.0059	0.0348	0.0302	0.1193	0.0081	0.0891	-0.0332	-0.0131	0.3305
4	0.1330	-0.0354	0.0171	0.0386	-0.0174	0.1889	0.0126	-0.0081	0.0253	-0.0027	0.0965	0.0003	0.0558	-0.0004	0.0037	0.3132
5	0.1467	-0.0183	0.0100	0.0454	-0.1068	0.1812	0.0154	-0.0786	-0.0119	0.0341	0.1110	0.0046	-0.0056	0.0078	0.0155	0.2642
6	0.3859	-0.0155	-0.0428	0.0464	-0.0697	0.2147	0.0400	-0.0358	0.0517	0.0653	0.1052	-0.0207	-0.0153	-0.0135	0.0145	0.2121
7	0.1938	-0.0863	-0.0068	0.0355	-0.0196	0.1906	0.0260	-0.0039	-0.0069	-0.0175	0.0899	0.0276	-0.0126	0.0085	0.0189	0.1780
8	0.1565	-0.0115	-0.0079	0.0817	-0.0267	0.1376	0.0334	-0.0179	0.0132	0.0331	0.0807	0.0148	-0.0077	-0.0038	0.0239	0.1772
9	0.1432	-0.0168	-0.0064	-0.0151	-0.0343	0.1348	0.0244	-0.0048	0.0003	-0.0173	0.0790	-0.0175	-0.0119	0.0025	0.0196	0.1870
10	0.1511	-0.0357	-0.0058	-0.0264	-0.0628	0.1632	0.0244	0.0062	-0.0087	0.0001	0.1137	-0.0244	0.0014	-0.0199	0.0018	0.1888
100	0.0328	-0.0466	-0.0145	-0.0138	-0.0357	0.0582	0.0154	0.0043	-0.0065	0.0096	0.0028	0.0007	-0.0026	-0.0039	0.0016	0.0151
150	0.0240	-0.0358	-0.0105	-0.0081	-0.0270	0.0423	0.0117	0.0057	-0.0051	0.0079	0.0022	0.0012	-0.0005	-0.0018	0.0004	0.0047
200	0.0184	-0.0280	-0.0081	-0.0055	-0.0209	0.0323	0.0091	0.0051	-0.0041	0.0063	0.0018	0.0011	0.0001	-0.0010	0.0000	0.0014

	Table 5: Numbner of Quote Revisions				Table 6: Relative Spread				Table 7:Volatility				Table 8: Interest Rate Differential			
p	NQR	R. Spread	Volatility	IRD	NQR	R. Spread	Volatility	IRD	NQR	R. Spread	Volatility	IRD	NQR	R. Spread	Volatility	IRD
1	1.0000	0.0000	0.0000	0.0000	-0.1469	0.9891	0.0000	0.0000	0.2498	0.1500	0.9566	0.0000	0.0763	0.0027	-0.0207	0.9969
2	0.3481	-0.1065	0.0010	0.0512	-0.0257	0.3510	0.0350	-0.0391	0.0834	-0.0028	0.1801	-0.0163	0.0854	-0.0173	-0.0056	0.5917
3	0.1710	-0.0347	-0.0187	0.1515	-0.0150	0.2600	0.0416	-0.0109	0.0294	0.0304	0.1227	0.0058	0.0875	-0.0365	-0.0181	0.3377
4	0.1332	-0.0330	0.0074	0.0433	-0.0004	0.2186	0.0166	-0.0104	0.0214	-0.0023	0.1023	-0.0024	0.0537	-0.0034	-0.0027	0.3204
5	0.1550	-0.0223	-0.0013	0.0507	-0.0959	0.2156	0.0155	-0.0792	-0.0207	0.0263	0.1183	0.0023	0.0017	0.0096	0.0050	0.2725
6	0.3878	-0.0228	-0.0578	0.0525	-0.0648	0.2685	0.0429	-0.0385	0.0475	0.0618	0.1175	-0.0252	-0.0030	-0.0165	0.0008	0.2187
7	0.1991	-0.0933	-0.0260	0.0412	-0.0194	0.2596	0.0216	0.0003	-0.0095	-0.0200	0.1031	0.0215	0.0006	0.0011	0.0043	0.1865
8	0.1601	-0.0299	-0.0285	0.0883	-0.0184	0.2126	0.0241	-0.0136	0.0072	0.0264	0.0990	0.0094	0.0064	-0.0099	0.0058	0.1893
9	0.1508	-0.0425	-0.0299	-0.0090	-0.0352	0.2344	0.0114	-0.0010	-0.0103	-0.0182	0.1098	-0.0332	0.0174	-0.0093	-0.0031	0.2156
10	0.1527	-0.0490	-0.0278	-0.0074	-0.0603	0.2143	0.0256	-0.0078	-0.0289	-0.0026	0.0754	-0.0280	0.0129	-0.0081	-0.0013	0.2127
100	0.0343	-0.0376	-0.0137	-0.0198	-0.0342	0.0516	0.0141	0.0156	-0.0062	0.0026	0.0023	0.0033	-0.0057	-0.0002	0.0021	0.0107
150	0.0229	-0.0273	-0.0092	-0.0135	-0.0253	0.0341	0.0103	0.0134	-0.0033	0.0029	0.0013	0.0022	-0.0030	0.0013	0.0012	0.0035
200	0.0163	-0.0200	-0.0066	-0.0095	-0.0186	0.0239	0.0076	0.0104	-0.0022	0.0024	0.0009	0.0014	-0.0018	0.0014	0.0007	0.0015

Panel 8.2

Standardized Impulse Response Functions

US Time Zone: GB/US

	Table 1: Number of Quote Revisions				Table 2: Quoted Spread				Table 3: Volatility				Table 4: Interest Rate Differential			
p	NQR	Q. Spread	Volatility	IRD	NQR	Q. Spread	Volatility	IRD	NQR	Q. Spread	Volatility	IRD	NQR	Q. Spread	Volatility	IRD
1	1.0000	0.0000	0.0000	0.0000	-0.2938	0.9559	0.0000	0.0000	0.2549	0.1446	0.9561	0.0044	0.0771	0.0154	-0.0288	0.9965
2	0.3180	-0.1292	0.0078	0.0855	-0.1406	0.3277	0.0175	-0.0053	0.0459	0.0118	0.1365	0.0309	0.0661	0.0065	-0.0178	0.6021
3	0.1554	-0.0379	0.0283	0.1756	-0.0851	0.2323	0.0048	-0.0872	-0.0007	-0.0046	0.1164	0.0365	0.0564	-0.0504	-0.0234	0.3562
4	0.1335	-0.0744	0.0529	0.0410	-0.0799	0.2154	0.0038	0.0103	0.0171	-0.0231	0.1465	0.0293	0.0442	-0.0491	-0.0119	0.3425
5	0.1438	-0.0666	0.0414	0.0353	-0.1083	0.2114	0.0151	-0.0501	0.0238	0.0116	0.0807	0.0534	-0.0067	-0.0063	0.0051	0.3013
6	0.3668	-0.0564	-0.0016	0.0122	-0.1629	0.2905	0.0231	-0.0099	0.0692	0.0455	0.1345	0.0325	-0.0092	-0.0152	-0.0044	0.2833
7	0.2299	-0.0993	0.0142	0.0216	-0.1318	0.2236	0.0167	0.0025	0.0279	0.0042	0.0613	0.0715	0.0063	-0.0232	-0.0080	0.2625
8	0.1588	-0.0754	0.0213	0.0643	-0.1107	0.1952	0.0114	-0.0233	0.0067	0.0049	0.0509	0.0861	0.0093	-0.0280	-0.0089	0.2375
9	0.1403	-0.0806	0.0278	0.0316	-0.1040	0.1783	0.0080	-0.0068	0.0063	0.0039	0.0510	0.0861	0.0043	-0.0285	-0.0087	0.2175
10	0.1426	-0.0813	0.0236	0.0161	-0.1142	0.1736	0.0109	-0.0080	0.0118	0.0064	0.0336	0.1306	-0.0108	-0.0222	-0.0050	0.2029
100	0.0362	-0.0290	0.0014	-0.0085	-0.0386	0.0309	-0.0015	0.0091	0.0011	-0.0009	0.0000	-0.0005	-0.0084	0.0062	-0.0004	0.0029
150	0.0214	-0.0171	0.0008	-0.0051	-0.0227	0.0181	-0.0009	0.0054	0.0007	-0.0005	0.0000	-0.0003	-0.0051	0.0040	-0.0002	0.0013
200	0.0129	-0.0103	0.0005	-0.0031	-0.0137	0.0109	-0.0005	0.0033	0.0004	-0.0003	0.0000	-0.0002	-0.0031	0.0025	-0.0001	0.0007

	Table 5: Numbner of Quote Revisions				Table 6: Relative Spread				Table 7:Volatility				Table 8: Interest Rate Differential			
p	NQR	R. Spread	Volatility	IRD	NQR	R. Spread	Volatility	IRD	NQR	R. Spread	Volatility	IRD	NQR	R. Spread	Volatility	IRD
1	1.0000	0.0000	0.0000	0.0000	-0.2790	0.9604	0.0000	0.0000	0.2492	0.1327	0.9593	0.0000	0.0725	0.0097	-0.0298	0.9969
2	0.3188	-0.1303	0.0006	0.0804	-0.1337	0.3348	0.0103	-0.0100	0.0372	0.0021	0.1379	0.0028	0.0581	-0.0037	-0.0194	0.6004
3	0.1551	-0.0370	0.0200	0.1694	-0.0778	0.2448	-0.0028	-0.0871	-0.0119	-0.0156	0.1177	0.0259	0.0455	-0.0637	-0.0259	0.3523
4	0.1319	-0.0731	0.0428	0.0333	-0.0717	0.2306	-0.0073	0.0049	0.0042	-0.0371	0.1490	0.0082	0.0311	-0.0642	-0.0143	0.3379
5	0.1416	-0.0666	0.0305	0.0270	-0.0988	0.2280	0.0026	-0.0558	0.0088	-0.0069	0.0854	0.0380	-0.0228	-0.0244	0.0037	0.2961
6	0.3641	-0.0538	-0.0134	0.0013	-0.1527	0.3010	0.0081	-0.0192	0.0522	0.0202	0.1415	-0.0131	-0.0286	-0.0375	-0.0050	0.2767
7	0.2279	-0.0992	0.0062	0.0102	-0.1227	0.2370	0.0052	-0.0081	0.0139	-0.0152	0.0644	-0.0131	-0.0129	-0.0459	-0.0086	0.2553
8	0.1563	-0.0757	0.0140	0.0529	-0.1016	0.2105	0.0007	-0.0324	-0.0068	-0.0141	0.0539	0.0100	-0.0093	-0.0510	-0.0093	0.2302
9	0.1378	-0.0805	0.0205	0.0203	-0.0948	0.1943	-0.0026	-0.0174	-0.0068	-0.0148	0.0536	-0.0023	-0.0146	-0.0522	-0.0087	0.2105
10	0.1404	-0.0817	0.0164	0.0047	-0.1040	0.1894	0.0010	-0.0185	-0.0010	-0.0124	0.0353	-0.0042	-0.0303	-0.0470	-0.0048	0.1963
90	0.0411	-0.0340	0.0017	-0.0088	-0.0434	0.0367	-0.0017	0.0087	0.0024	-0.0020	0.0001	-0.0005	-0.0067	0.0021	-0.0005	0.0041
100	0.0369	-0.0305	0.0015	-0.0080	-0.0390	0.0327	-0.0016	0.0080	0.0022	-0.0018	0.0001	-0.0005	-0.0057	0.0025	-0.0004	0.0029
150	0.0221	-0.0182	0.0009	-0.0048	-0.0233	0.0192	-0.0010	0.0051	0.0014	-0.0011	0.0001	-0.0003	-0.0030	0.0023	-0.0001	0.0008
200	0.0135	-0.0111	0.0006	-0.0030	-0.0143	0.0117	-0.0006	0.0031	0.0008	-0.0007	0.0000	-0.0002	-0.0018	0.0015	-0.0001	0.0004

Panel 8.3

Standardized Impulse Response Functions

US Time Zone: EU/US

	Table 1: Number of Quote Revisions				Table 2: Quoted Spread				Table 3: Volatility				Table 4: Interest Rate Differential			
p	NQR	Q. Spread	Volatility	IRD	NQR	Q. Spread	Volatility	IRD	NQR	Q. Spread	Volatility	IRD	NQR	Q. Spread	Volatility	IRD
1	1.0000	0.0000	0.0000	0.0000	-0.4081	0.9129	0.0000	0.0000	0.2986	0.1114	0.9478	0.0000	0.0343	-0.0789	0.0007	0.9963
2	0.3017	-0.1512	0.0008	0.0638	-0.1292	0.2688	0.0160	-0.0804	0.0690	-0.0779	-0.0192	0.0272	0.0484	-0.0655	0.0282	0.6515
3	0.1847	-0.0272	0.0160	0.1070	-0.0169	0.0639	-0.0479	-0.1067	0.0636	-0.0727	0.0874	-0.0125	0.0548	-0.0914	-0.0245	0.4710
4	0.1673	0.0076	0.0995	0.0256	0.0129	0.1048	-0.0913	-0.0583	0.0637	-0.0173	0.1224	0.0032	0.0151	-0.0792	0.0011	0.4308
5	0.1379	-0.0061	0.0994	0.0165	-0.0841	0.1523	-0.0649	-0.0201	0.0538	-0.0585	0.0232	-0.0030	-0.0084	-0.0809	-0.0117	0.2955
6	0.3375	-0.0002	0.0255	0.0228	-0.1710	0.2886	0.0359	-0.0426	0.0776	0.0651	0.1121	-0.0153	0.0041	-0.0678	-0.0245	0.2848
7	0.2246	-0.0728	0.0272	0.0307	-0.0953	0.1751	-0.0003	-0.0732	0.0643	-0.0311	0.0204	-0.0042	0.0077	-0.0603	-0.0107	0.2860
8	0.1745	-0.0316	0.0307	0.0611	-0.0434	0.0898	-0.0272	-0.0858	0.0603	-0.0425	0.0226	-0.0080	0.0159	-0.0729	-0.0237	0.2610
9	0.1528	-0.0058	0.0535	0.0457	-0.0270	0.0930	-0.0400	-0.0722	0.0589	-0.0088	0.0311	-0.0044	0.0134	-0.0702	-0.0190	0.2584
10	0.1312	-0.0083	0.0571	0.0361	-0.0624	0.1076	-0.0301	-0.0578	0.0445	-0.0193	0.0147	0.0018	0.0044	-0.0694	-0.0147	0.2417
100	0.0018	-0.0039	-0.0002	0.0087	-0.0011	0.0058	0.0007	-0.0128	0.0006	-0.0008	0.0000	0.0018	0.0006	-0.0081	-0.0012	0.0178
150	0.0002	-0.0013	-0.0001	0.0028	-0.0002	0.0018	0.0002	-0.0040	0.0001	-0.0003	0.0000	0.0006	0.0002	-0.0025	-0.0004	0.0055
200	0.0000	-0.0004	-0.0001	0.0009	0.0000	0.0006	0.0001	-0.0012	0.0000	-0.0001	0.0000	0.0002	0.0001	-0.0008	-0.0001	0.0017

	Table 5: Numbner of Quote Revisions				Table 6: Relative Spread				Table 7:Volatility				Table 8: Interest Rate Differential			
p	NQR	R. Spread	Volatility	IRD	NQR	R. Spread	Volatility	IRD	NQR	R. Spread	Volatility	IRD	NQR	R. Spread	Volatility	IRD
1	1.0000	0.0000	0.0000	0.0000	-0.3938	0.9192	0.0000	0.0000	0.2956	0.1018	0.9499	0.0000	0.0281	-0.0786	-0.0078	0.9965
2	0.2966	-0.1710	-0.0061	0.0557	-0.1236	0.3135	0.0097	-0.0706	0.0604	-0.0715	-0.0315	0.0153	0.0356	-0.0689	0.0174	0.6479
3	0.1776	-0.0461	0.0085	0.0970	-0.0187	0.1462	-0.0527	-0.0903	0.0511	-0.0730	0.0765	-0.0238	0.0384	-0.1020	-0.0375	0.4634
4	0.1581	-0.0119	0.0910	0.0133	-0.0006	0.1819	-0.0935	-0.0449	0.0503	-0.0348	0.1110	-0.0102	-0.0052	-0.0897	-0.0138	0.4224
5	0.1246	-0.0263	0.0910	0.0019	-0.0879	0.2059	-0.0669	-0.0083	0.0338	-0.0677	0.0109	-0.0171	-0.0329	-0.0903	-0.0288	0.2835
6	0.3252	-0.0258	0.0178	0.0029	-0.1552	0.3415	0.0204	-0.0277	0.0586	0.0320	0.1072	-0.0382	-0.0252	-0.0771	-0.0422	0.2692
7	0.2105	-0.1022	0.0186	0.0088	-0.0887	0.2469	-0.0098	-0.0531	0.0491	-0.0436	0.0145	-0.0258	-0.0215	-0.0708	-0.0264	0.2683
8	0.1587	-0.0603	0.0228	0.0389	-0.0455	0.1797	-0.0323	-0.0618	0.0439	-0.0537	0.0195	-0.0280	-0.0126	-0.0848	-0.0389	0.2419
9	0.1365	-0.0370	0.0467	0.0217	-0.0327	0.1796	-0.0437	-0.0512	0.0427	-0.0292	0.0276	-0.0253	-0.0154	-0.0831	-0.0332	0.2390
10	0.1150	-0.0407	0.0512	0.0113	-0.0624	0.1850	-0.0357	-0.0387	0.0308	-0.0391	0.0124	-0.0177	-0.0243	-0.0830	-0.0276	0.2224
100	0.0027	-0.0205	0.0007	0.0113	-0.0038	0.0382	-0.0008	-0.0224	0.0012	-0.0076	0.0004	0.0039	0.0014	-0.0303	0.0000	0.0195
150	0.0010	-0.0111	0.0002	0.0066	-0.0018	0.0204	-0.0003	-0.0122	0.0004	-0.0041	0.0001	0.0024	0.0013	-0.0165	0.0002	0.0101
200	0.0005	-0.0061	0.0001	0.0037	-0.0009	0.0111	-0.0002	-0.0067	0.0002	-0.0023	0.0000	0.0014	0.0007	-0.0090	0.0001	0.0055

Panel 8.4

Standardized Impulse Response Functions

UK Time Zone: JP/US

	Table 1: Number of Quote Revisions				Table 2: Quoted Spread				Table 3: Volatility				Table 4: Interest Rate Differential			
p	NQR	Q. Spread	Volatility	IRD	NQR	Q. Spread	Volatility	IRD	NQR	Q. Spread	Volatility	IRD	NQR	Q. Spread	Volatility	IRD
1	1.0000	0.0000	0.0000	0.0000	-0.0706	0.9975	0.0000	0.0000	0.1915	0.0607	0.9796	0.0000	0.0588	-0.0239	0.0011	0.9980
2	0.2374	-0.0435	0.0428	0.0301	-0.0410	0.3656	0.0207	-0.0205	0.0384	0.0273	0.2164	-0.0074	0.0680	-0.0298	0.0057	0.5930
3	0.1253	0.0008	0.0237	0.1224	-0.0352	0.2696	0.0139	-0.0123	0.0308	0.0378	0.1286	0.0223	0.0559	-0.0285	-0.0030	0.3403
4	0.0993	-0.0395	0.0673	0.0648	-0.0187	0.2235	0.0128	-0.0187	0.0236	0.0224	0.1189	0.0195	0.0139	0.0094	0.0015	0.3218
5	0.1767	-0.0504	0.0504	0.0444	-0.0358	0.2359	0.0383	-0.0334	0.0185	0.0238	0.1325	-0.0040	-0.0230	-0.0022	0.0050	0.2709
6	0.3491	-0.1032	0.0171	0.0738	-0.0332	0.2430	0.0125	-0.0329	0.0604	0.0179	0.1243	-0.0014	-0.0257	-0.0146	-0.0007	0.2173
7	0.1396	-0.0562	0.0195	0.0594	-0.0450	0.2232	0.0383	-0.0011	0.0163	0.0142	0.1305	0.0159	-0.0121	0.0038	-0.0011	0.1864
8	0.1124	-0.0332	0.0367	0.1392	-0.0433	0.2089	0.0295	-0.0017	0.0356	0.0516	0.0984	0.0496	-0.0182	-0.0049	0.0161	0.1882
9	0.1122	-0.0612	0.0340	-0.0187	-0.0649	0.2294	0.0410	-0.0099	0.0186	0.0193	0.0984	-0.0192	-0.0048	-0.0169	0.0159	0.2163
10	0.1314	-0.0735	0.0294	-0.0279	-0.0571	0.2088	0.0339	-0.0118	0.0153	0.0252	0.0745	-0.0200	-0.0076	-0.0165	0.0134	0.2087
100	0.0277	-0.0483	-0.0072	-0.0125	-0.0337	0.0605	0.0088	0.0114	-0.0049	0.0097	0.0013	-0.0002	-0.0033	0.0016	0.0008	0.0108
150	0.0204	-0.0358	-0.0053	-0.0088	-0.0244	0.0432	0.0064	0.0098	-0.0041	0.0074	0.0011	0.0012	-0.0018	0.0022	0.0005	0.0029
200	0.0155	-0.0272	-0.0040	-0.0066	-0.0183	0.0323	0.0048	0.0077	-0.0032	0.0057	0.0008	0.0013	-0.0012	0.0019	0.0003	0.0010

	Table 5: Numbner of Quote Revisions				Table 6: Relative Spread				Table 7:Volatility				Table 8: Interest Rate Differential			
p	NQR	R. Spread	Volatility	IRD	NQR	R. Spread	Volatility	IRD	NQR	R. Spread	Volatility	IRD	NQR	R. Spread	Volatility	IRD
1	1.0000	0.0000	0.0000	0.0000	-0.0411	0.9992	0.0000	0.0000	0.1795	0.0719	0.9811	0.0000	-0.0181	0.0000	-0.0016	0.2717
2	0.2414	-0.0448	0.0305	0.0320	-0.0530	0.3806	0.0398	-0.0158	0.0242	0.0318	0.2203	-0.0086	-0.0203	-0.0107	-0.0078	0.2183
3	0.1295	0.0045	0.0077	0.1243	-0.0274	0.2883	0.0245	-0.0104	0.0153	0.0314	0.1341	0.0205	-0.0062	0.0062	-0.0089	0.1876
4	0.1031	-0.0300	0.0496	0.0677	-0.0157	0.2361	0.0169	-0.0131	0.0068	0.0141	0.1257	0.0171	-0.0122	0.0013	0.0075	0.1896
5	0.1800	-0.0374	0.0322	0.0478	-0.0302	0.2436	0.0381	-0.0329	-0.0020	0.0136	0.1410	-0.0065	0.0014	-0.0104	0.0068	0.2180
6	0.3526	-0.0986	-0.0018	0.0771	-0.0211	0.2481	0.0160	-0.0295	0.0369	0.0019	0.1355	-0.0040	-0.0010	-0.0110	0.0048	0.2106
7	0.1444	-0.0522	-0.0054	0.0639	-0.0348	0.2346	0.0389	0.0035	-0.0091	-0.0045	0.1427	0.0129	-0.0038	-0.0095	0.0046	0.1901
8	0.1169	-0.0258	0.0087	0.1440	-0.0389	0.2194	0.0294	0.0067	0.0077	0.0302	0.1126	0.0459	-0.0042	-0.0080	0.0049	0.1800
9	0.1164	-0.0513	0.0028	-0.0107	-0.0523	0.2388	0.0342	-0.0012	-0.0130	-0.0037	0.1159	-0.0243	-0.0087	-0.0075	0.0053	0.1732
10	0.1349	-0.0640	0.0045	-0.0198	-0.0480	0.2180	0.0337	-0.0002	-0.0121	0.0051	0.0860	-0.0256	-0.0079	-0.0084	0.0048	0.1645
100	0.0262	-0.0469	-0.0109	-0.0155	-0.0330	0.0599	0.0137	0.0173	-0.0026	0.0050	0.0011	0.0007	-0.0033	0.0027	0.0012	0.0092
150	0.0194	-0.0346	-0.0080	-0.0117	-0.0238	0.0426	0.0099	0.0139	-0.0021	0.0038	0.0009	0.0011	-0.0020	0.0029	0.0008	0.0028
200	0.0147	-0.0262	-0.0061	-0.0089	-0.0178	0.0317	0.0074	0.0107	-0.0017	0.0030	0.0007	0.0010	-0.0011	0.0017	0.0003	0.0010

Panel 8.5

Standardized Impulse Response Functions

UK Time Zone: GB/US

	Table 1: Number of Quote Revisions				Table 2: Quoted Spread				Table 3: Volatility				Table 4: Interest Rate Differential			
p	NQR	Q. Spread	Volatility	IRD	NQR	Q. Spread	Volatility	IRD	NQR	Q. Spread	Volatility	IRD	NQR	Q. Spread	Volatility	IRD
1	1.0000	0.0000	0.0000	0.0000	-0.1767	0.9843	0.0000	0.0000	0.2511	0.0485	0.9667	0.0000	0.0690	0.0305	-0.0103	0.9971
2	0.2864	-0.0562	0.0123	0.0694	-0.0955	0.3859	0.0205	-0.0224	0.0202	0.0080	0.1510	0.0053	0.0596	0.0203	-0.0087	0.5940
3	0.1306	0.0038	0.0121	0.1261	-0.0766	0.2523	0.0088	-0.0165	0.0168	-0.0060	0.1224	0.0380	0.0535	-0.0083	-0.0316	0.3404
4	0.0887	-0.0329	0.0660	0.0857	-0.0455	0.2346	-0.0126	0.0179	0.0039	-0.0166	0.1000	0.0238	0.0306	-0.0076	-0.0064	0.3211
5	0.1561	-0.0001	0.0545	0.0625	-0.0490	0.2259	-0.0036	-0.0345	0.0024	0.0075	0.0815	-0.0070	-0.0237	-0.0048	0.0020	0.2728
6	0.3530	-0.0591	0.0195	0.0862	-0.0355	0.2046	0.0001	-0.0290	0.0564	0.0070	0.1534	0.0045	-0.0262	-0.0161	-0.0111	0.2180
7	0.1521	-0.0827	0.0285	0.0677	-0.0454	0.2693	0.0237	0.0211	0.0407	-0.0032	0.1000	-0.0321	-0.0110	-0.0073	-0.0082	0.1862
8	0.1342	-0.0307	-0.0160	0.1382	-0.0223	0.2323	0.0268	0.0111	0.0456	0.0116	0.0821	0.0216	-0.0097	-0.0109	-0.0110	0.1888
9	0.1326	-0.0358	0.0409	-0.0039	-0.0766	0.2400	-0.0043	-0.0005	0.0401	0.0080	0.1281	0.0135	0.0062	-0.0041	-0.0160	0.2162
10	0.1441	-0.0428	0.0328	-0.0179	-0.0629	0.2209	0.0050	0.0053	0.0220	0.0043	0.0705	0.0063	-0.0023	-0.0004	-0.0152	0.2098
100	0.0197	-0.0449	0.0014	-0.0108	-0.0251	0.0615	-0.0010	0.0112	0.0030	-0.0066	0.0002	-0.0012	-0.0045	0.0049	-0.0016	0.0100
150	0.0137	-0.0324	0.0008	-0.0073	-0.0177	0.0424	-0.0009	0.0087	0.0021	-0.0050	0.0001	-0.0011	-0.0025	0.0046	-0.0004	0.0029
200	0.0100	-0.0238	0.0006	-0.0052	-0.0128	0.0305	-0.0007	0.0065	0.0016	-0.0038	0.0001	-0.0008	-0.0017	0.0037	-0.0002	0.0012

	Table 5: Numbner of Quote Revisions				Table 6: Relative Spread				Table 7:Volatility				Table 8: Interest Rate Differential			
p	NQR	R. Spread	Volatility	IRD	NQR	R. Spread	Volatility	IRD	NQR	R. Spread	Volatility	IRD	NQR	R. Spread	Volatility	IRD
1	1.0000	0.0000	0.0000	0.0000	-0.1760	0.9844	0.0000	0.0000	0.2472	0.0495	0.0000	0.0000	0.0649	0.0261	-0.0100	0.9975
2	0.2821	-0.0613	0.0091	0.0654	-0.0950	0.3890	0.0192	-0.0244	0.0156	0.0066	0.0042	0.0042	0.0536	0.0137	-0.0084	0.5937
3	0.1247	0.0005	0.0077	0.1212	-0.0752	0.2570	0.0081	-0.0170	0.0112	-0.0054	0.0365	0.0365	0.0464	-0.0150	-0.0317	0.3390
4	0.0816	-0.0368	0.0614	0.0799	-0.0431	0.2416	-0.0077	0.0152	-0.0019	-0.0199	0.0222	0.0222	0.0226	-0.0147	-0.0066	0.3193
5	0.1481	-0.0057	0.0495	0.0560	-0.0483	0.2286	-0.0046	-0.0350	-0.0044	-0.0003	-0.0084	-0.0084	-0.0332	-0.0129	0.0018	0.2704
6	0.3454	-0.0653	0.0143	0.0801	-0.0361	0.1998	0.0020	-0.0302	0.0486	-0.0031	0.0033	0.0033	-0.0370	-0.0254	-0.0112	0.2154
7	0.1408	-0.0984	0.0224	0.0601	-0.0470	0.2697	0.0208	0.0190	0.0323	-0.0126	-0.0336	-0.0336	-0.0228	-0.0175	-0.0079	0.1835
8	0.1211	-0.0415	-0.0237	0.1312	-0.0261	0.2325	0.0253	0.0067	0.0363	0.0040	0.0199	0.0199	-0.0226	-0.0231	-0.0105	0.1860
9	0.1173	-0.0499	0.0337	-0.0147	-0.0827	0.2363	-0.0039	-0.0038	0.0292	0.0003	0.0109	0.0109	-0.0084	-0.0177	-0.0150	0.2130
10	0.1311	-0.0562	0.0263	-0.0299	-0.0673	0.2191	0.0049	0.0021	0.0123	-0.0038	0.0036	0.0036	-0.0164	-0.0139	-0.0145	0.2061
100	0.0228	-0.0460	0.0013	-0.0112	-0.0280	0.0596	-0.0011	0.0106	0.0042	-0.0095	-0.0010	-0.0010	-0.0040	-0.0007	-0.0017	0.0111
150	0.0160	-0.0327	0.0008	-0.0075	-0.0196	0.0407	-0.0009	0.0085	0.0033	-0.0070	-0.0013	-0.0013	-0.0014	0.0007	-0.0004	0.0029
200	0.0116	-0.0237	0.0006	-0.0054	-0.0141	0.0291	-0.0007	0.0064	0.0025	-0.0051	-0.0011	-0.0011	-0.0007	0.0009	-0.0001	0.0009

Panel 8.6

Standardized Impulse Response Functions

UK Time Zone: EU/US

	Table 1: Number of Quote Revisions				Table 2: Quoted Spread				Table 3: Volatility				Table 4: Interest Rate Differential			
p	NQR	Q. Spread	Volatility	IRD	NQR	Q. Spread	Volatility	IRD	NQR	Q. Spread	Volatility	IRD	NQR	Q. Spread	Volatility	IRD
1	1.0000	0.0000	0.0000	0.0000	-0.2391	0.9710	0.0000	0.0000	0.2230	-0.0200	0.9746	0.0000	0.0346	-0.0576	-0.0128	0.9976
2	0.2675	-0.1596	0.0187	0.0544	-0.1206	0.3821	0.0008	-0.0430	0.0252	-0.0524	0.0242	-0.0152	0.0302	-0.0874	0.0158	0.6366
3	0.1652	-0.0302	0.0365	0.0013	-0.0024	0.1751	-0.0306	-0.0890	0.0655	-0.0344	0.0675	-0.0303	0.0178	-0.0827	-0.0031	0.4692
4	0.1581	-0.0121	0.0689	0.0270	-0.0241	0.1976	-0.0469	-0.0678	0.0671	-0.0016	0.0993	0.0216	0.0122	-0.0730	0.0195	0.4227
5	0.1844	-0.0403	0.0935	0.0225	-0.0825	0.1884	-0.0226	0.0075	0.0364	-0.0876	0.0684	0.0011	-0.0266	-0.0669	0.0175	0.2808
6	0.3499	0.0009	0.0566	0.0196	-0.0572	0.2199	0.0008	-0.0347	0.1128	-0.0125	0.1498	0.0161	-0.0106	-0.0579	-0.0042	0.2133
7	0.1897	-0.0969	-0.0108	0.0171	-0.0370	0.1994	-0.0191	-0.0483	0.0615	-0.0262	0.0520	0.0004	-0.0067	-0.0541	-0.0048	0.2505
8	0.1615	-0.0583	0.0411	0.0131	-0.0186	0.1587	-0.0167	-0.0459	0.0586	-0.0347	0.0432	-0.0092	-0.0119	-0.0578	-0.0064	0.2467
9	0.1486	-0.0393	0.0508	0.0192	-0.0261	0.1359	-0.0232	-0.0644	0.0659	-0.0238	0.0434	-0.0089	-0.0083	-0.0580	-0.0083	0.2474
10	0.1523	-0.0454	0.0543	0.0195	-0.0366	0.1254	-0.0199	-0.0637	0.0469	-0.0380	0.0349	-0.0043	-0.0145	-0.0580	-0.0035	0.2542
100	-0.0012	-0.0027	-0.0003	0.0081	0.0057	0.0027	0.0015	-0.0140	-0.0002	-0.0010	0.0000	0.0026	-0.0101	-0.0043	-0.0026	0.0239
150	-0.0011	-0.0006	-0.0003	0.0030	0.0022	0.0008	0.0006	-0.0049	-0.0004	-0.0002	-0.0001	0.0010	-0.0037	-0.0013	-0.0010	0.0082
200	-0.0005	-0.0002	-0.0001	0.0011	0.0008	0.0003	0.0002	-0.0017	-0.0002	-0.0001	0.0000	0.0004	-0.0013	-0.0004	-0.0003	0.0028

	Table 5: Numbner of Quote Revisions				Table 6: Relative Spread				Table 7:Volatility				Table 8: Interest Rate Differential			
p	NQR	R. Spread	Volatility	IRD	NQR	R. Spread	Volatility	IRD	NQR	R. Spread	Volatility	IRD	NQR	R. Spread	Volatility	IRD
1	1.0000	0.0000	0.0000	0.0000	-0.2196	0.9756	0.0000	0.0000	0.2183	-0.0212	0.9756	0.0000	0.0294	-0.0531	-0.0194	0.9980
2	0.2651	-0.1682	0.0129	0.0507	-0.1058	0.3915	0.0003	-0.0387	0.0210	-0.0635	0.0143	-0.0237	0.0242	-0.0868	0.0066	0.6341
3	0.1624	-0.0275	0.0316	-0.0038	0.0078	0.2124	-0.0251	-0.0746	0.0570	-0.0331	0.0600	-0.0391	0.0092	-0.0807	-0.0154	0.4639
4	0.1513	-0.0030	0.0607	0.0201	-0.0228	0.2455	-0.0344	-0.0574	0.0607	-0.0193	0.0897	0.0125	0.0013	-0.0740	0.0054	0.4162
5	0.1769	-0.0444	0.0845	0.0138	-0.0776	0.2308	-0.0188	0.0181	0.0236	-0.0808	0.0576	-0.0091	-0.0403	-0.0699	0.0011	0.2706
6	0.3429	-0.0049	0.0458	0.0100	-0.0480	0.2774	0.0063	-0.0183	0.1013	-0.0297	0.1389	0.0045	-0.0277	-0.0613	-0.0228	0.2005
7	0.1787	-0.1005	-0.0244	0.0035	-0.0342	0.2842	-0.0112	-0.0287	0.0491	-0.0336	0.0381	-0.0170	-0.0260	-0.0634	-0.0251	0.2355
8	0.1515	-0.0641	0.0310	-0.0003	-0.0158	0.2358	-0.0102	-0.0265	0.0476	-0.0430	0.0343	-0.0260	-0.0309	-0.0697	-0.0256	0.2297
9	0.1378	-0.0418	0.0402	0.0036	-0.0205	0.2118	-0.0165	-0.0446	0.0541	-0.0355	0.0346	-0.0241	-0.0277	-0.0707	-0.0266	0.2300
10	0.1404	-0.0512	0.0423	0.0027	-0.0316	0.2061	-0.0141	-0.0428	0.0351	-0.0469	0.0261	-0.0221	-0.0343	-0.0725	-0.0210	0.2364
100	-0.0043	-0.0166	-0.0009	0.0096	0.0135	0.0286	0.0033	-0.0242	-0.0018	-0.0081	-0.0003	0.0042	-0.0147	-0.0213	-0.0038	0.0242
150	-0.0035	-0.0072	-0.0008	0.0062	0.0074	0.0127	0.0019	-0.0125	-0.0016	-0.0035	-0.0004	0.0029	-0.0067	-0.0100	-0.0018	0.0111
200	-0.0019	-0.0033	-0.0005	0.0032	0.0037	0.0059	0.0009	-0.0062	-0.0009	-0.0016	-0.0002	0.0015	-0.0031	-0.0047	-0.0008	0.0052

Panel 8.7

Standardized Impulse Response Functions

ASIA Time Zone: JP/US

	Table 1: Number of Quote Revisions				Table 2: Quoted Spread				Table 3: Volatility				Table 4: Interest Rate Differential			
p	NQR	Q. Spread	Volatility	IRD	NQR	Q. Spread	Volatility	IRD	NQR	Q. Spread	Volatility	IRD	NQR	Q. Spread	Volatility	IRD
1	1.0000	0.0000	0.0000	0.0000	-0.1576	0.9875	0.0000	0.0000	0.0968	0.0344	0.9947	0.0000	0.0768	0.0039	-0.0051	0.9970
2	0.3446	-0.1026	0.0054	0.0451	-0.0323	0.3087	-0.0016	-0.0377	0.0324	0.0510	0.1626	0.0381	0.0854	-0.0159	-0.0108	0.5906
3	0.1665	-0.0325	0.0358	0.1464	-0.0295	0.2293	0.0041	-0.0098	0.0762	0.0768	0.1610	-0.0010	0.0894	-0.0277	0.0138	0.3315
4	0.1338	-0.0341	-0.0017	0.0387	-0.0208	0.1892	0.0066	-0.0089	0.0127	0.0076	0.1414	0.0056	0.0586	0.0054	0.0236	0.3131
5	0.1480	-0.0164	0.0123	0.0425	-0.1050	0.1822	0.0576	-0.0780	0.0031	0.0233	0.1015	0.0241	-0.0028	0.0092	-0.0100	0.2656
6	0.3873	-0.0151	-0.0208	0.0469	-0.0705	0.2150	0.0386	-0.0365	0.0411	0.0269	0.1084	0.0425	-0.0111	-0.0118	-0.0205	0.2123
7	0.1975	-0.0840	-0.0180	0.0340	-0.0199	0.1903	-0.0074	-0.0041	0.0482	0.0020	0.0859	0.0125	-0.0113	0.0096	-0.0143	0.1767
8	0.1568	-0.0100	-0.0042	0.0792	-0.0258	0.1363	0.0118	-0.0181	-0.0054	0.0187	0.0992	0.0104	-0.0065	-0.0034	-0.0365	0.1768
9	0.1446	-0.0160	-0.0385	-0.0161	-0.0353	0.1334	0.0058	-0.0050	0.0127	0.0430	0.1092	0.0067	-0.0099	0.0025	0.0128	0.1864
10	0.1541	-0.0348	-0.0036	-0.0286	-0.0621	0.1623	0.0136	0.0067	-0.0122	0.0005	0.0932	0.0008	0.0020	-0.0198	0.0079	0.1886
100	0.0333	-0.0468	-0.0143	-0.0129	-0.0364	0.0584	0.0148	0.0037	-0.0090	0.0135	0.0037	-0.0001	-0.0030	-0.0040	0.0025	0.0150
150	0.0246	-0.0362	-0.0104	-0.0073	-0.0276	0.0428	0.0115	0.0050	-0.0071	0.0110	0.0029	0.0011	-0.0008	-0.0017	0.0007	0.0047
200	0.0190	-0.0285	-0.0080	-0.0049	-0.0215	0.0329	0.0090	0.0046	-0.0058	0.0089	0.0024	0.0012	-0.0001	-0.0008	0.0001	0.0015

	Table 5: Numbner of Quote Revisions				Table 6: Relative Spread				Table 7:Volatility				Table 8: Interest Rate Differential			
p	NQR	R. Spread	Volatility	IRD	NQR	R. Spread	Volatility	IRD	NQR	R. Spread	Volatility	IRD	NQR	R. Spread	Volatility	IRD
1	1.0000	0.0000	0.0000	0.0000	-0.1386	0.9904	0.0000	0.0000	0.0876	0.2348	0.9681	0.0000	0.0754	-0.0215	-0.0044	0.9969
2	0.3478	-0.0453	0.0079	0.0476	-0.1188	0.3413	0.0451	0.0031	0.0217	0.0665	0.1614	0.0356	0.0871	-0.0477	-0.0051	0.5905
3	0.1712	-0.0135	0.0307	0.1458	-0.0449	0.2605	0.0217	-0.0375	0.0647	0.0655	0.1656	0.0015	0.0845	-0.0071	0.0091	0.3365
4	0.1360	-0.0279	-0.0026	0.0384	-0.0216	0.2211	-0.0085	-0.0221	0.0050	0.0402	0.1516	-0.0036	0.0512	-0.0130	0.0179	0.3181
5	0.1584	-0.0376	0.0089	0.0446	-0.0103	0.2168	0.0078	-0.0160	-0.0157	0.0017	0.1196	0.0176	0.0023	-0.0215	-0.0161	0.2718
6	0.3983	-0.0514	-0.0226	0.0476	-0.0757	0.2751	0.0145	-0.0494	0.0189	0.0148	0.1270	0.0365	-0.0056	-0.0058	-0.0305	0.2167
7	0.2061	-0.0423	-0.0233	0.0358	-0.0626	0.2461	0.0284	-0.0451	0.0254	0.0294	0.1062	0.0004	-0.0037	-0.0167	-0.0216	0.1830
8	0.1665	-0.0236	-0.0131	0.0816	-0.0520	0.2211	0.0365	0.0107	-0.0320	0.0177	0.1299	0.0019	0.0008	-0.0237	-0.0451	0.1858
9	0.1624	-0.0421	-0.0483	-0.0139	-0.0460	0.2347	-0.0117	0.0029	-0.0189	0.0314	0.1454	-0.0152	0.0110	-0.0207	0.0028	0.2124
10	0.1586	-0.0444	-0.0274	-0.0132	-0.0373	0.2149	0.0146	-0.0033	-0.0226	0.0171	0.0929	-0.0160	0.0035	-0.0212	0.0047	0.2086
100	0.0389	-0.0275	-0.0133	-0.0228	-0.0356	0.0502	0.0100	0.0189	-0.0091	0.0027	0.0035	0.0038	-0.0082	-0.0116	0.0041	0.0105
150	0.0252	-0.0189	-0.0085	-0.0154	-0.0273	0.0307	0.0083	0.0156	-0.0052	0.0025	0.0019	0.0031	-0.0025	-0.0063	0.0015	0.0029
200	0.0171	-0.0132	-0.0057	-0.0105	-0.0203	0.0199	0.0064	0.0119	-0.0033	0.0020	0.0012	0.0021	-0.0001	-0.0036	0.0004	0.0005

Panel 8.8

Standardized Impulse Response Functions

ASIA Time Zone: GB/US

	Table 1: Number of Quote Revisions				Table 2: Quoted Spread				Table 3: Volatility				Table 4: Interest Rate Differential			
p	NQR	Q. Spread	Volatility	IRD	NQR	Q. Spread	Volatility	IRD	NQR	Q. Spread	Volatility	IRD	NQR	Q. Spread	Volatility	IRD
1	1.0000	0.0000	0.0000	0.0000	-0.2922	0.9563	0.0000	0.0000	0.0413	0.0136	0.9991	0.0000	0.0774	0.0159	-0.0031	0.9969
2	0.3176	-0.1280	0.0220	0.0838	-0.1395	0.3287	0.0021	-0.0044	0.0192	0.0529	0.1864	0.0050	0.0677	0.0072	0.0115	0.6021
3	0.1538	-0.0356	0.0427	0.1736	-0.0847	0.2322	-0.0238	-0.0869	0.0229	0.0093	0.1875	0.0131	0.0585	-0.0495	0.0065	0.3561
4	0.1314	-0.0721	0.0472	0.0400	-0.0799	0.2160	-0.0035	0.0106	-0.0061	0.0309	0.1421	0.0114	0.0462	-0.0479	0.0079	0.3424
5	0.1423	-0.0645	0.0320	0.0347	-0.1094	0.2114	-0.0124	-0.0503	0.0270	0.0115	0.2022	0.0153	-0.0050	-0.0051	0.0007	0.3011
6	0.3659	-0.0535	0.0055	0.0128	-0.1643	0.2900	0.0148	-0.0107	0.0206	0.0030	0.1641	-0.0054	-0.0074	-0.0141	-0.0111	0.2838
7	0.2290	-0.0966	0.0168	0.0197	-0.1321	0.2253	0.0024	0.0029	0.0182	0.0156	0.1124	0.0054	0.0083	-0.0218	-0.0110	0.2633
8	0.1571	-0.0743	0.0270	0.0613	-0.1099	0.1967	-0.0028	-0.0228	0.0143	0.0103	0.0955	0.0050	0.0113	-0.0264	-0.0115	0.2372
9	0.1397	-0.0810	0.0288	0.0303	-0.1043	0.1803	-0.0023	-0.0068	0.0080	0.0114	0.0877	0.0045	0.0063	-0.0277	-0.0127	0.2164
10	0.1422	-0.0806	0.0212	0.0168	-0.1140	0.1748	0.0003	-0.0080	0.0172	0.0063	0.0778	0.0039	-0.0089	-0.0217	-0.0121	0.2024
100	0.0360	-0.0295	0.0035	-0.0086	-0.0381	0.0312	-0.0037	0.0092	0.0029	-0.0024	0.0003	-0.0007	-0.0083	0.0063	-0.0010	0.0029
150	0.0213	-0.0174	0.0021	-0.0052	-0.0225	0.0184	-0.0022	0.0055	0.0018	-0.0015	0.0002	-0.0004	-0.0050	0.0041	-0.0005	0.0013
200	0.0129	-0.0105	0.0013	-0.0032	-0.0136	0.0111	-0.0013	0.0033	0.0011	-0.0009	0.0001	-0.0003	-0.0031	0.0025	-0.0003	0.0008

	Table 5: Numbner of Quote Revisions				Table 6: Relative Spread				Table 7:Volatility				Table 8: Interest Rate Differential			
p	NQR	R. Spread	Volatility	IRD	NQR	R. Spread	Volatility	IRD	NQR	R. Spread	Volatility	IRD	NQR	R. Spread	Volatility	IRD
1	1.0000	0.0000	0.0000	0.0000	-0.1953	0.9807	0.0000	0.0000	0.0300	0.0679	0.9973	0.0000	0.0703	-0.0493	-0.0029	0.9963
2	0.3248	-0.0819	0.0210	0.0746	-0.1257	0.3063	-0.0029	-0.0436	0.0102	0.0349	0.1829	0.0010	0.0647	-0.0548	0.0069	0.5963
3	0.1683	-0.0424	0.0330	0.1634	-0.0886	0.2587	0.0281	-0.0517	0.0087	-0.0115	0.1883	0.0079	0.0538	-0.0424	-0.0021	0.3450
4	0.1462	-0.0249	0.0350	0.0253	-0.1009	0.2408	-0.0192	-0.0462	-0.0196	-0.0246	0.1429	0.0060	0.0330	-0.0491	0.0010	0.3313
5	0.1557	-0.0552	0.0203	0.0201	-0.0641	0.2595	-0.0178	-0.0063	0.0154	-0.0192	0.2012	0.0082	-0.0195	-0.0614	-0.0073	0.2884
6	0.3798	-0.0444	-0.0087	-0.0123	-0.1065	0.2911	-0.0071	-0.0239	0.0038	0.0019	0.1618	-0.0097	-0.0244	-0.0671	-0.0210	0.2671
7	0.2415	-0.0711	0.0082	0.0037	-0.1044	0.2300	-0.0035	-0.0285	0.0037	-0.0120	0.1100	-0.0058	-0.0084	-0.0676	-0.0207	0.2447
8	0.1725	-0.0604	0.0161	0.0449	-0.0945	0.2140	-0.0053	-0.0321	-0.0006	-0.0197	0.0957	-0.0051	-0.0044	-0.0679	-0.0202	0.2172
9	0.1563	-0.0529	0.0180	0.0089	-0.0963	0.2006	-0.0116	-0.0290	-0.0070	-0.0223	0.0866	-0.0041	-0.0106	-0.0684	-0.0200	0.1996
10	0.1589	-0.0614	0.0114	-0.0016	-0.0841	0.1954	-0.0118	-0.0245	0.0039	-0.0185	0.0760	-0.0057	-0.0267	-0.0695	-0.0192	0.1853
100	0.0368	-0.0225	0.0039	-0.0069	-0.0331	0.0230	-0.0034	0.0046	0.0045	-0.0032	0.0005	-0.0006	-0.0059	-0.0012	-0.0008	0.0039
150	0.0202	-0.0124	0.0021	-0.0037	-0.0187	0.0119	-0.0020	0.0032	0.0026	-0.0017	0.0003	-0.0004	-0.0027	0.0009	-0.0003	0.0009
200	0.0113	-0.0070	0.0012	-0.0021	-0.0105	0.0066	-0.0011	0.0019	0.0015	-0.0009	0.0002	-0.0003	-0.0014	0.0007	-0.0002	0.0003

Panel 8.9

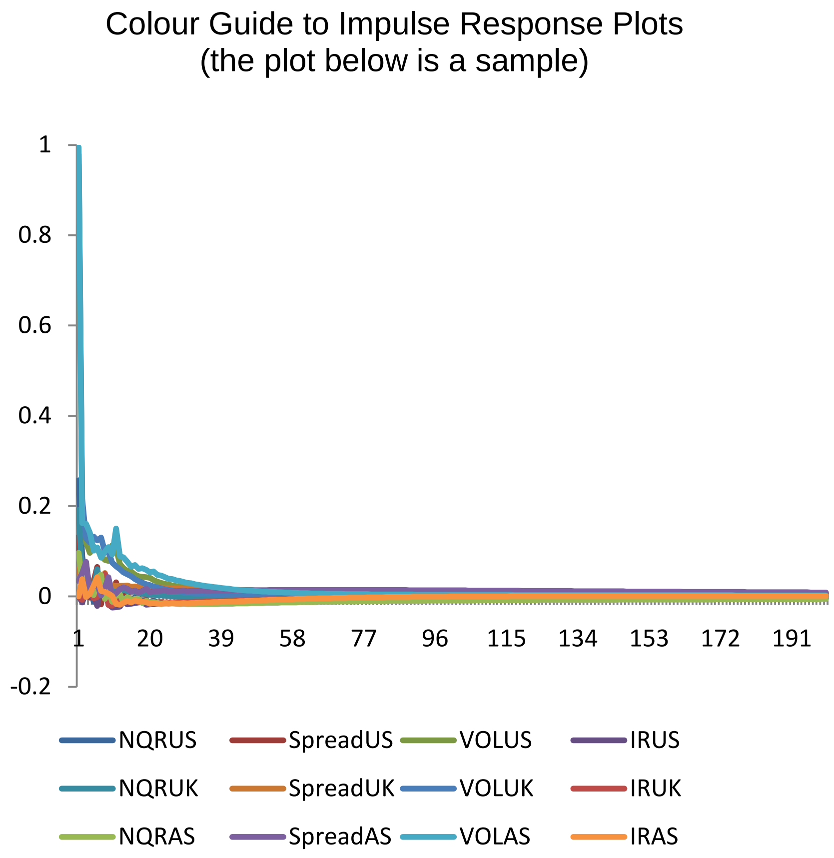
Standardized Impulse Response Functions

ASIA Time Zone: EU/US

	Table 1: Number of Quote Revisions				Table 2: Quoted Spread				Table 3: Volatility				Table 4: Interest Rate Differential			
p	NQR	Q. Spread	Volatility	IRD	NQR	Q. Spread	Volatility	IRD	NQR	Q. Spread	Volatility	IRD	NQR	Q. Spread	Volatility	IRD
1	1.0000	0.0000	0.0000	0.0000	-0.4151	0.9098	0.0000	0.0000	0.0822	-0.0966	0.9919	0.0000	0.0367	-0.0731	0.0041	0.9966
2	0.2959	-0.1629	0.0462	0.0642	-0.1298	0.2744	0.0184	-0.0812	-0.0354	-0.0138	0.0826	0.0442	0.0494	-0.0619	-0.0270	0.6505
3	0.1725	-0.0347	0.0781	0.1071	-0.0109	0.0638	-0.0282	-0.1045	-0.0009	0.0184	0.1609	0.0709	0.0562	-0.0856	-0.0156	0.4716
4	0.1529	0.0044	0.0620	0.0328	0.0170	0.1010	-0.0011	-0.0652	0.0553	0.0108	0.1312	-0.0016	0.0177	-0.0743	-0.0196	0.4326
5	0.1229	-0.0094	0.0725	0.0216	-0.0817	0.1498	-0.0241	-0.0208	0.0153	-0.0378	0.1659	0.0420	-0.0046	-0.0758	-0.0022	0.2944
6	0.3274	-0.0046	0.0666	0.0284	-0.1739	0.2901	-0.0075	-0.0411	0.0940	-0.0386	0.0898	-0.0041	0.0083	-0.0610	-0.0270	0.2856
7	0.2145	-0.0783	0.0653	0.0390	-0.0898	0.1752	-0.0066	-0.0785	0.0306	-0.0234	0.0743	-0.0050	0.0129	-0.0594	-0.0261	0.2865
8	0.1629	-0.0343	0.0652	0.0652	-0.0389	0.0889	-0.0130	-0.0841	0.0295	0.0024	0.0645	0.0102	0.0211	-0.0694	-0.0240	0.2589
9	0.1427	-0.0111	0.0639	0.0514	-0.0246	0.0944	-0.0108	-0.0750	0.0439	-0.0062	0.0590	-0.0087	0.0173	-0.0685	-0.0266	0.2586
10	0.1238	-0.0177	0.0626	0.0415	-0.0642	0.1133	-0.0133	-0.0600	0.0445	-0.0207	0.0452	-0.0057	0.0091	-0.0682	-0.0239	0.2400
100	0.0022	-0.0040	-0.0003	0.0086	-0.0009	0.0059	0.0016	-0.0129	0.0009	-0.0006	0.0002	0.0013	-0.0001	-0.0081	-0.0028	0.0180
150	0.0002	-0.0013	-0.0003	0.0028	-0.0001	0.0018	0.0006	-0.0041	0.0001	-0.0002	0.0000	0.0005	-0.0001	-0.0025	-0.0009	0.0056
200	0.0000	-0.0004	-0.0001	0.0009	0.0000	0.0006	0.0002	-0.0013	0.0000	-0.0001	0.0000	0.0001	0.0000	-0.0008	-0.0003	0.0017

	Table 5: Numbner of Quote Revisions				Table 6: Relative Spread				Table 7:Volatility				Table 8: Interest Rate Differential			
p	NQR	R. Spread	Volatility	IRD	NQR	R. Spread	Volatility	IRD	NQR	R. Spread	Volatility	IRD	NQR	R. Spread	Volatility	IRD
1	1.0000	0.0000	0.0000	0.0000	-0.2060	0.9785	0.0000	0.0000	0.0764	-0.0838	0.9935	0.0000	0.0329	-0.0444	-0.0065	0.9984
2	0.3236	-0.0904	0.0575	0.0735	-0.1122	0.2910	-0.0503	-0.0321	-0.0380	-0.0445	0.0765	0.0333	0.0543	-0.0651	-0.0363	0.6313
3	0.1769	-0.0641	0.0464	0.0985	-0.0763	0.1952	0.0003	-0.0708	-0.0133	-0.0169	0.1488	0.0536	0.0532	-0.0518	-0.0211	0.4595
4	0.1543	0.0000	0.0433	0.0089	-0.0267	0.1674	-0.0219	-0.0805	0.0458	-0.0005	0.1144	-0.0183	0.0170	-0.0505	-0.0286	0.4125
5	0.1137	-0.0374	0.0597	0.0042	0.0255	0.2319	-0.0013	-0.0237	0.0116	-0.0823	0.1466	0.0265	-0.0108	-0.0525	-0.0124	0.2615
6	0.3808	0.0092	0.0497	0.0137	-0.1648	0.3076	0.0026	-0.0172	0.0729	-0.0228	0.0726	-0.0147	-0.0192	-0.0421	-0.0480	0.1891
7	0.1607	-0.0865	0.0631	0.0136	-0.1001	0.2539	-0.0017	-0.0348	-0.0006	-0.0464	0.1005	-0.0353	-0.0269	-0.0652	-0.0470	0.2202
8	0.1250	-0.0655	0.0505	0.0338	-0.0727	0.2075	-0.0057	-0.0500	0.0101	-0.0282	0.0518	-0.0194	-0.0202	-0.0695	-0.0466	0.2125
9	0.1192	-0.0359	0.0473	0.0176	-0.0478	0.1843	0.0007	-0.0492	0.0251	-0.0283	0.0541	-0.0272	-0.0230	-0.0717	-0.0496	0.2149
10	0.1014	-0.0471	0.0513	0.0148	-0.0297	0.1993	-0.0011	-0.0459	0.0263	-0.0396	0.0410	-0.0292	-0.0264	-0.0722	-0.0483	0.2228
100	0.0073	-0.0254	-0.0021	0.0131	-0.0126	0.0490	0.0052	-0.0274	0.0031	-0.0083	-0.0002	0.0035	0.0078	-0.0406	-0.0062	0.0260
150	0.0042	-0.0166	-0.0018	0.0094	-0.0076	0.0312	0.0036	-0.0180	0.0014	-0.0054	-0.0005	0.0029	0.0062	-0.0268	-0.0034	0.0159
200	0.0027	-0.0111	-0.0013	0.0064	-0.0050	0.0206	0.0024	-0.0119	0.0009	-0.0036	-0.0004	0.0021	0.0042	-0.0179	-0.0021	0.0104

Panel 8.10 to 8.12: Impulse Response Plots, Daily Sample

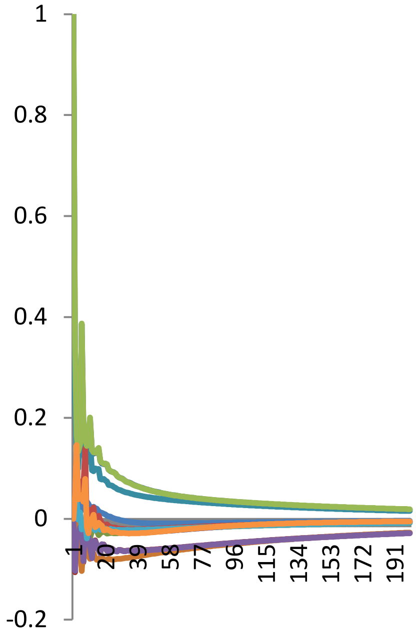


Note for Panels 8.10-18.12: Plot 1 shows the impact that a shock in the number of quote revisions (NQR) has on the number of quote revisions (own shock), quoted spread, exchange rate volatility, and interest rate differential, up to 200 periods ahead. (one period is equal to one trading day). Plot 2-4: Defined as Plot 1 but for quoted spread, exchange rate volatility and interest rate differential respectively. Plot 5 shows the impact that a shock in the number of quote revisions (NQR) has on the number of quote revisions (own shock), relative spread, exchange rate volatility, and interest rate differential, up to 200 periods ahead. (one period is equal to one trading day). Plot 6-8: Defined as Plot 1 but for Relative spread, exchange rate volatility and interest rate differential respectively. The impulse response results are obtained from the VAR models described in section 8.6 applied on our full daily sample. Variables used in the VAR; The number of quote revisions: mean quote revisions were calculated based on the number of quote revisions recorded in 5-minute intervals, between 8:00am and 5:00pm local time; The daily mean quoted spreads were calculated based on the last recorded bid and ask quotes at 5-minute intervals, between 8:00am and 5pm local time. The daily mean relative spreads were calculated based on the difference of the logarithm of the ask price and the logarithm of the bid price. The logarithmic bid and ask values are based on the last bid-ask quotes recorded at 5-minute intervals, between 8:00am and 5:00pm local time. *Volatility*: the difference between the highest ask price and lowest bid price during a trading day; Interest rate differential (IRD) between Eurodollar overnight deposit rates (short) and Eurodollar one month deposit rate (long). The x-axis values give the number of periods (forecast horizon in days) since the shock was first felt

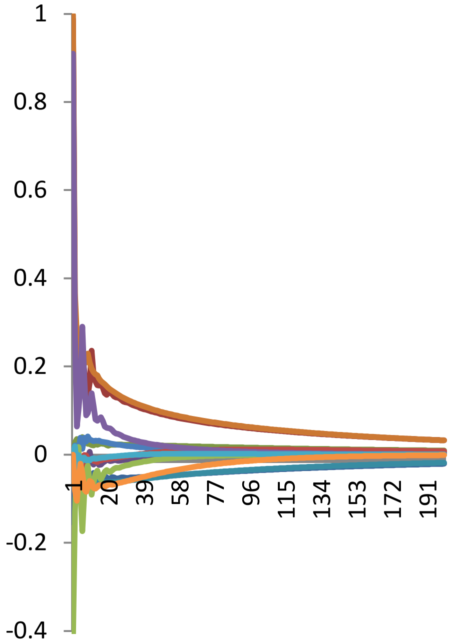
Panel 8.10: Impulse Response, JP/US (US, UK, ASIA time zones)

Quoted Spread

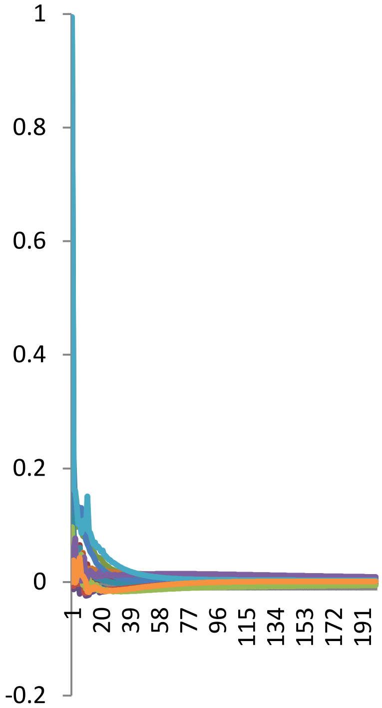
Plot 1
Number of Quote Revisions



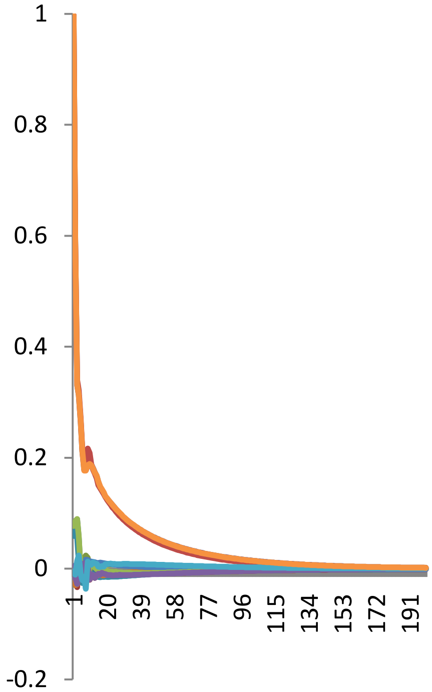
Plot 2
Quoted Spread



Plot 3
Volatility

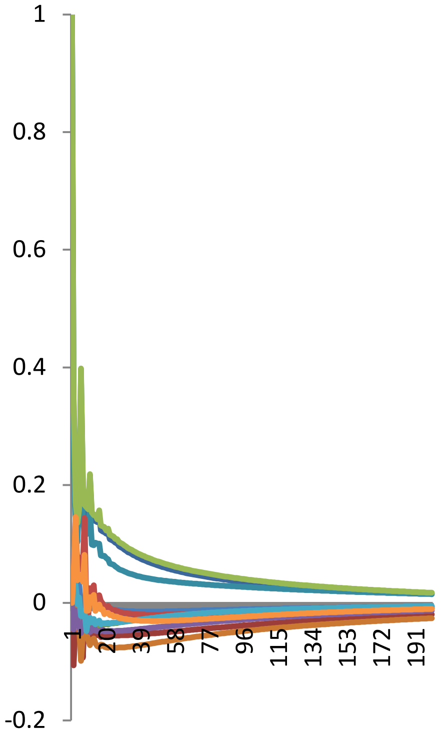


Plot 4
Interest Rate Differential

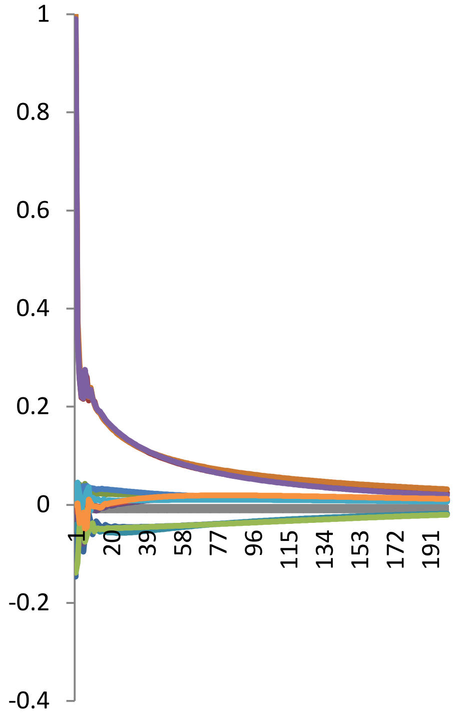


Relative Spread

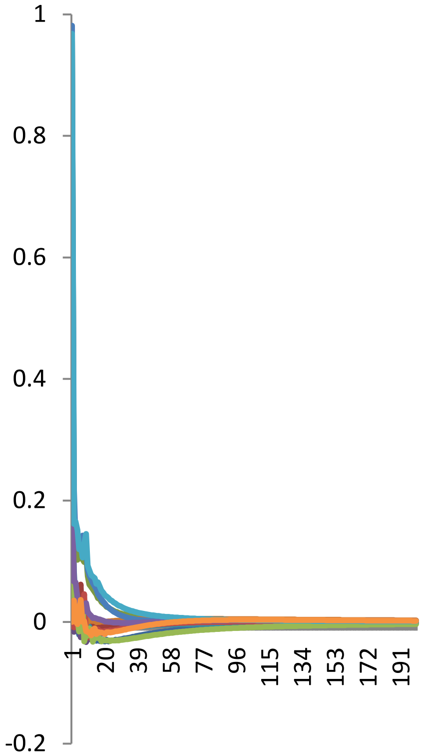
Plot 5
Number of Quote Revisions



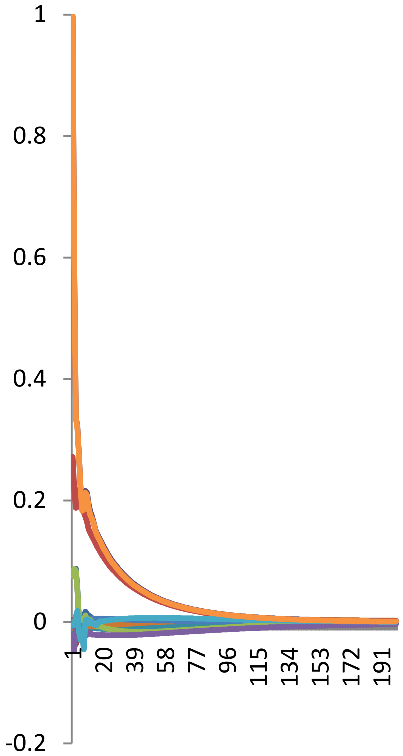
Plot 6
Relative Spread



Plot 7
Volatility

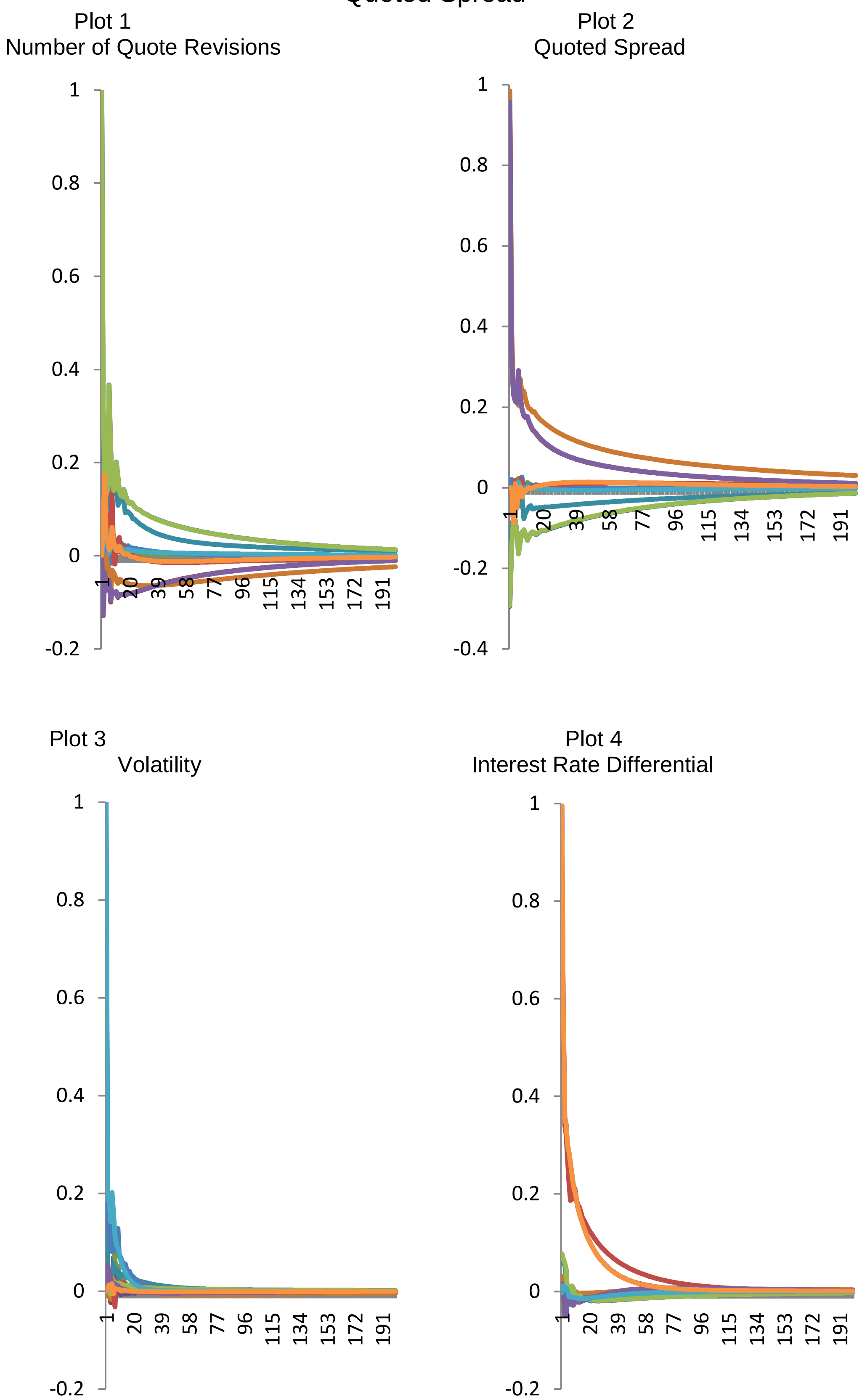


Plot 8
Interest Rate Differential



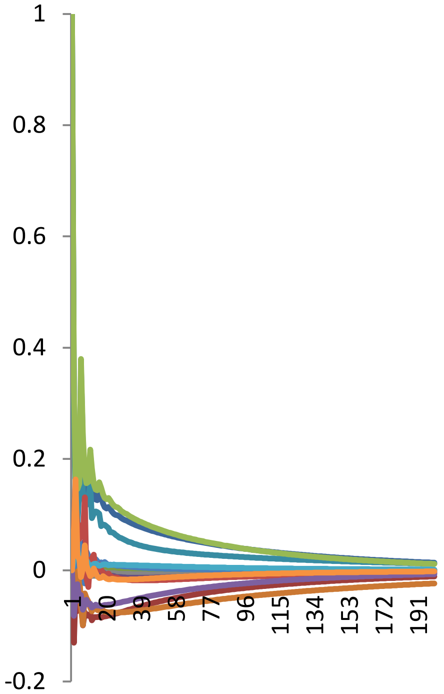
Panel 8.11: Impulse Response, GB/US (US, UK, ASIA time zones)

Quoted Spread

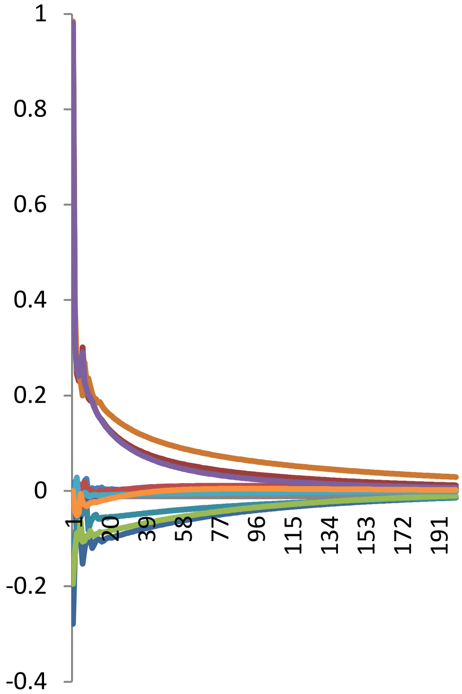


Relative Spread

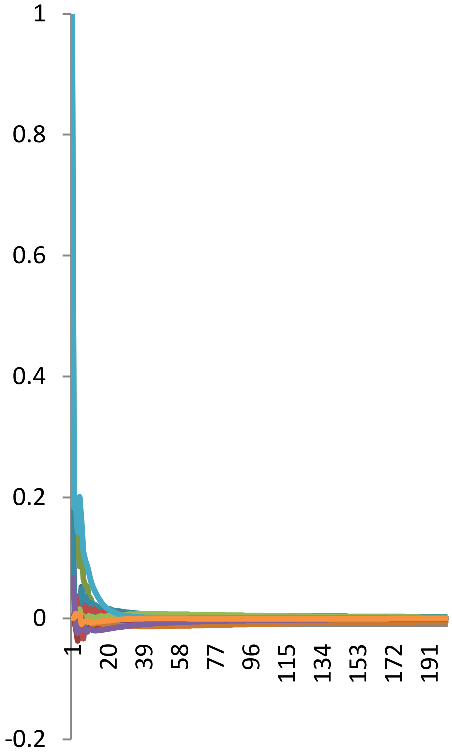
Plot 5
Number of Quote Revisions



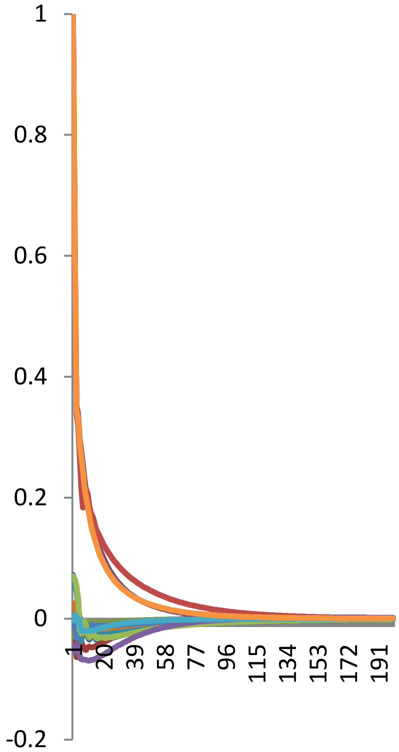
Plot 6
Relative Spread



Plot 7
Volatility



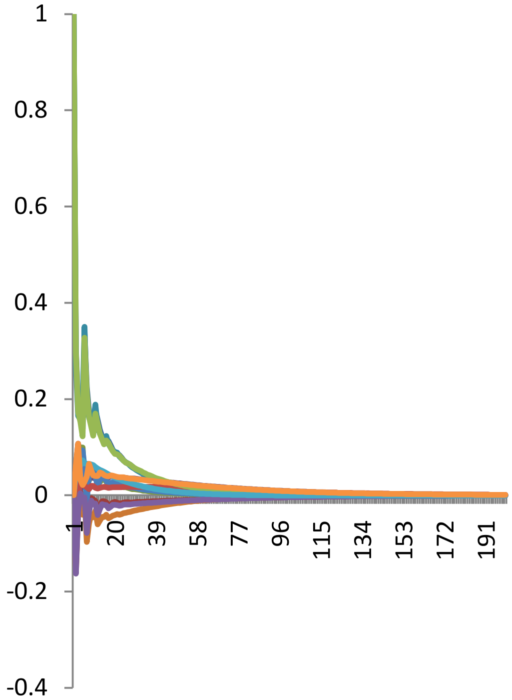
Plot 8
Interest Rate Differential



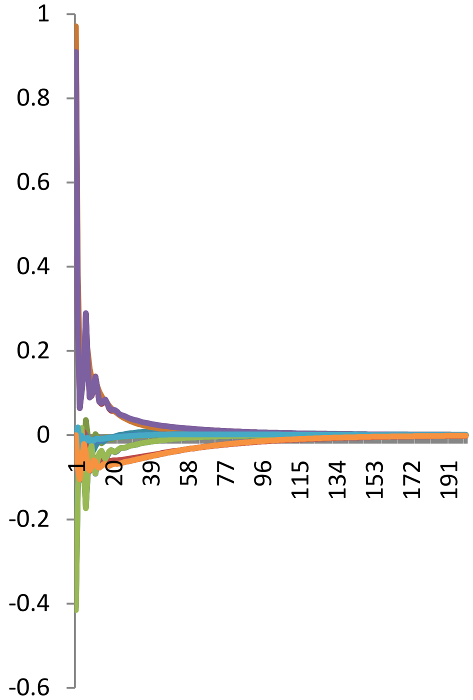
Panel 8.12: Impulse Response, EU/US (US, UK, ASIA time zones)

Quoted Spread

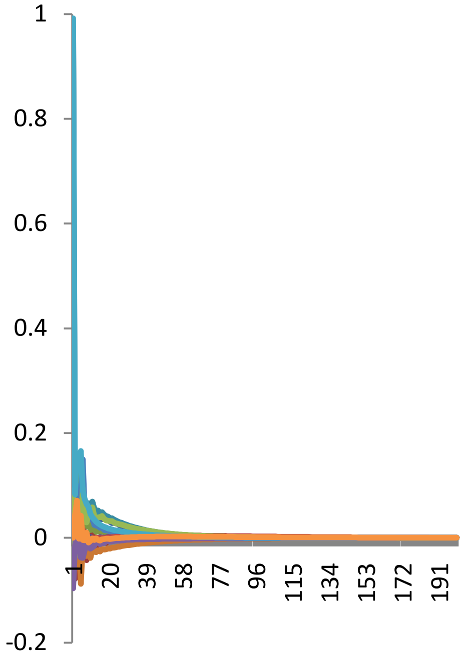
Plot 1
Number of Quote Revisions



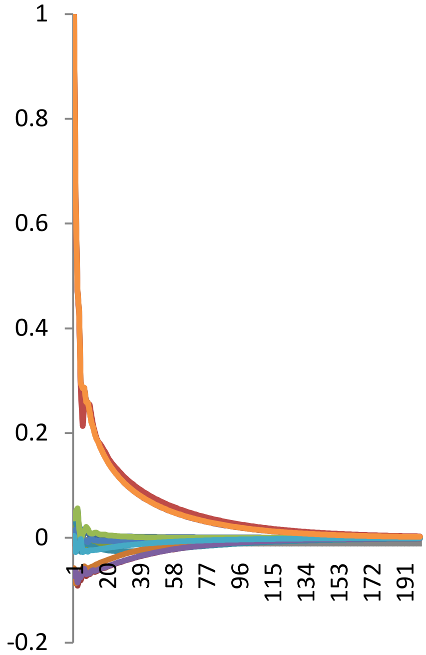
Plot 2
Quoted Spread



Plot 3
Volatility

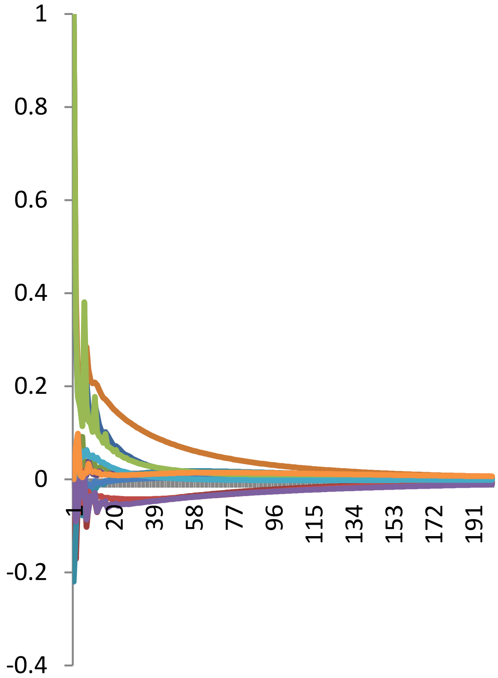


Plot 4
Interest Rate Differential

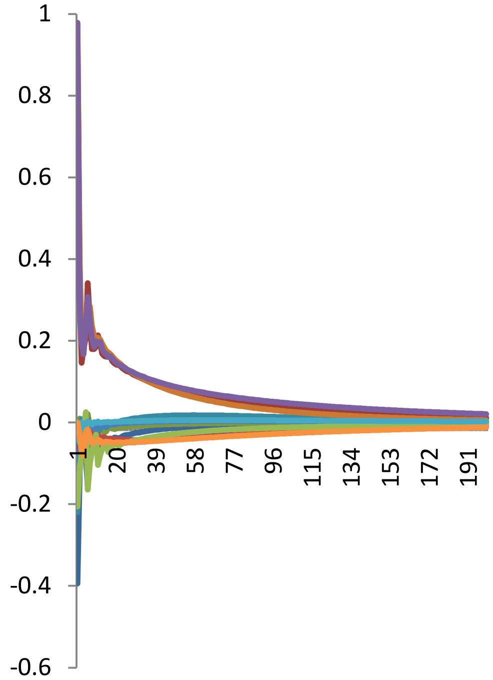


Relative Spread

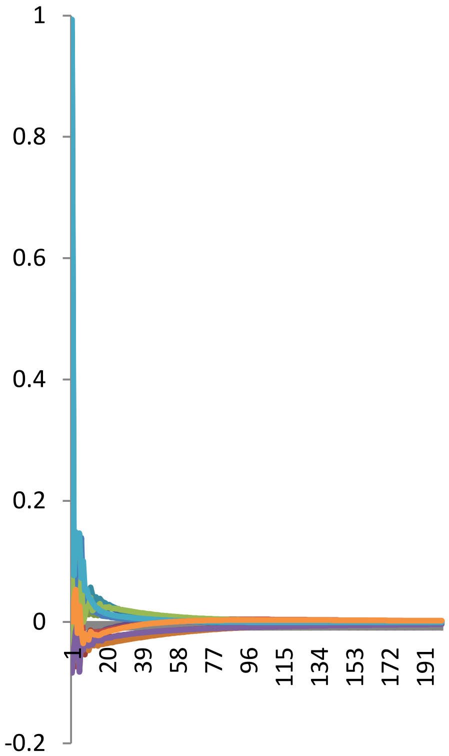
Plot 5
Number of Quote Revisions



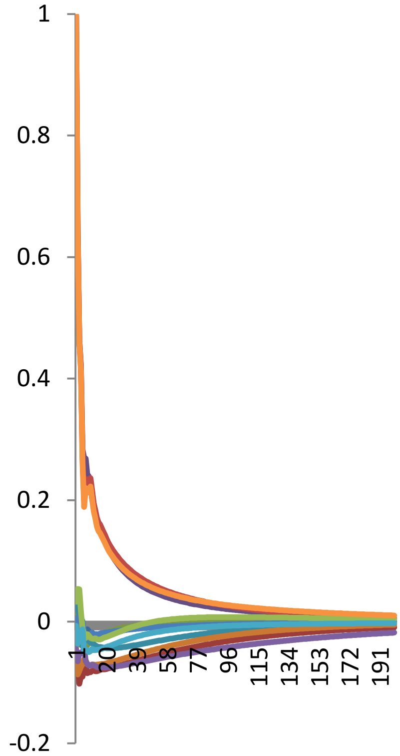
Plot 6
Relative Spread



Plot 7
Volatility



Plot 8
Interest Rate Differential



Panels 8.13 to 8.21: Variance Decompositions, Daily Sample

Note for Panels 8.13-8.21: Table 1 shows the percentage of the forecast error variance shift of the number of quote revisions (NQR) that is explained by innovations in the number of quote revisions (own shock), quoted spread, exchange rate volatility, and interest rate differential, up to 200 periods ahead. (one period is equal to one trading day). Table 2-4: Defined as Table 1 but for quoted spread, exchange rate volatility and interest rate differential respectively. Table 5 shows the percentage of the forecast error variance shift of the number of quote revisions (NQR) that is explained by innovations in the number of quote revisions (own shock), relative spread, exchange rate volatility, and interest rate differential, up to 200 periods ahead. (one period is equal to one trading day). Table 6-8: Defined as Table 1 but for Relative spread, exchange rate volatility and interest rate differential respectively. The variance decompositions results are obtained from the VAR models described in section 8.6 applied on our full daily sample. Variables used in the VAR; The number of quote revisions: mean quote revisions were calculated based on the number of quote revisions recorded in 5-minute intervals, between 8:00am and 5:00pm local time; The daily mean quoted spreads were calculated based on the last recorded bid and ask quotes at 5-minute intervals, between 8:00am and 5pm local time. The daily mean relative spreads were calculated based on the difference of the logarithm of the ask price and the logarithm of the bid price. The logarithmic bid and ask values are based on the last bid-ask quotes recorded at 5-minute intervals, between 8:00am and 5:00pm local time. *Volatility*: the difference between the highest ask price and lowest bid price during a trading day; Interest rate differential (IRD) between Eurodollar overnight deposit rates (short) and Eurodollar one month deposit rate (long).

Panel 8.13

Variance Decompositions

US Time Zone: JP/US

Innovation in

	Table 1: Number of Quote Revisions				Table 2: Quoted Spread				Table 3: Volatility				Table 4: Interest Rate Differential			
p	NQR	Q. Spread	Volatility	IRD	NQR	Q. Spread	Volatility	IRD	NQR	Q. Spread	Volatility	IRD	NQR	Q. Spread	Volatility	IRD
1	100.0000	0.0000	0.0000	0.0000	2.3872	97.6128	0.0000	0.0000	6.6084	1.7436	91.6479	0.0000	0.5549	0.0001	0.0298	99.4153
2	98.6325	1.1278	0.0046	0.2352	2.2513	97.5371	0.0768	0.1349	7.1529	1.6843	91.1461	0.0167	1.0839	0.0361	0.0199	98.8602
3	96.3787	1.1916	0.0153	2.4144	2.2040	97.4656	0.1994	0.1310	7.1565	1.7479	91.0726	0.0230	1.7498	0.1420	0.0346	98.0736
4	96.1505	1.2924	0.0440	2.5131	2.1544	97.5046	0.2081	0.1329	7.1490	1.7312	91.0970	0.0228	1.8835	0.1276	0.0325	97.9564
5	95.9936	1.2949	0.0530	2.6585	3.1852	95.8501	0.2213	0.7435	7.0656	1.8238	91.0861	0.0246	1.7545	0.1248	0.0541	98.0666
6	96.1845	1.1206	0.2281	2.4669	3.4993	95.3000	0.3692	0.8315	7.2031	2.2166	90.5132	0.0672	1.6979	0.1374	0.0728	98.0919
7	95.4860	1.8130	0.2222	2.4788	3.4071	95.3681	0.4229	0.8019	7.1415	2.2267	90.4893	0.1425	1.6591	0.1401	0.1061	98.0947
8	94.9408	1.7695	0.2214	3.0683	3.4063	95.2510	0.5256	0.8171	7.1018	2.3184	90.4167	0.1632	1.6118	0.1371	0.1599	98.0912
9	94.9922	1.7604	0.2208	3.0266	3.4561	95.1661	0.5748	0.8031	7.0532	2.3325	90.4216	0.1927	1.5687	0.1329	0.1926	98.1058
10	94.9163	1.8440	0.2187	3.0209	3.7452	94.9152	0.5573	0.7823	6.9649	2.3008	90.4847	0.2495	1.5124	0.1679	0.1860	98.1338
100	69.2412	22.9956	3.2872	4.4761	14.0866	82.8312	2.5336	0.5486	7.4679	3.0239	88.6088	0.8994	1.1908	0.6754	0.3037	97.8301
150	64.0966	27.8974	3.5793	4.4266	16.1644	80.3066	2.9413	0.5877	7.5891	3.3876	88.1236	0.8998	1.1961	0.7103	0.3068	97.7868
200	61.3684	30.6127	3.7169	4.3021	17.2606	78.9070	3.1605	0.6719	7.6652	3.6244	87.8078	0.9027	1.1958	0.7194	0.3068	97.7780

	Table 5: Numbner of Quote Revisions				Table 6: Relative Spread				Table 7:Volatility				Table 8: Interest Rate Differential			
p	NQR	R. Spread	Volatility	IRD	NQR	R. Spread	Volatility	IRD	NQR	R. Spread	Volatility	IRD	NQR	R. Spread	Volatility	IRD
1	100.0000	0.0000	0.0000	0.0000	2.1569	97.8431	0.0000	0.0000	6.2389	2.2507	91.5104	0.0000	0.5819	0.0007	0.0431	99.3743
2	98.6031	1.1346	0.0001	0.2622	1.9497	97.7749	0.1228	0.1526	6.6876	2.1622	91.1237	0.0266	1.1033	0.0303	0.0307	98.8356
3	96.2280	1.1941	0.0349	2.5430	1.8362	97.7227	0.2871	0.1539	6.6610	2.2183	91.0913	0.0295	1.7329	0.1599	0.0597	98.0475
4	96.0045	1.2782	0.0397	2.6775	1.7478	97.7941	0.3007	0.1574	6.6340	2.1945	91.1418	0.0297	1.8386	0.1442	0.0541	97.9631
5	95.8057	1.2935	0.0388	2.8621	2.5590	96.3600	0.3059	0.7751	6.5765	2.2303	91.1634	0.0298	1.7021	0.1427	0.0526	98.1026
6	95.8024	1.1424	0.3664	2.6888	2.7757	95.8971	0.4653	0.8619	6.6676	2.5665	90.6734	0.0925	1.6211	0.1632	0.0501	98.1656
7	94.9067	1.9551	0.4155	2.7226	2.6238	96.0929	0.4803	0.8031	6.5993	2.5768	90.6861	0.1379	1.5647	0.1576	0.0502	98.2275
8	94.1347	1.9757	0.4824	3.4072	2.5361	96.1634	0.5163	0.7843	6.5343	2.6189	90.7016	0.1452	1.5125	0.1617	0.0518	98.2740
9	94.0065	2.1059	0.5592	3.3284	2.5168	96.2428	0.5002	0.7402	6.4561	2.6164	90.6743	0.2532	1.4718	0.1627	0.0504	98.3152
10	93.8425	2.2902	0.6217	3.2456	2.7545	95.9958	0.5407	0.7091	6.4926	2.5980	90.5798	0.3296	1.4215	0.1619	0.0482	98.3684
100	73.8831	17.0918	4.1795	4.8457	11.6083	84.8583	2.2300	1.3033	9.1448	2.5997	87.3358	0.9197	1.3096	0.2889	0.1085	98.2931
150	69.8308	20.2111	4.3380	5.6201	14.0668	81.2025	2.6040	2.1268	9.2292	2.6358	87.1783	0.9567	1.3958	0.2915	0.1211	98.1917
200	67.8602	21.7943	4.3998	5.9457	15.3377	79.2195	2.7935	2.6492	9.2569	2.6680	87.1037	0.9715	1.4225	0.3011	0.1251	98.1513

Panel 8.14

Variance Decompositions

US Time Zone: GB/US

Innovation in

	Table 1: Number of Quote Revisions				Table 2: Quoted Spread				Table 3: Volatility				Table 4: Interest Rate Differential			
p	NQR	Q. Spread	Volatility	IRD	NQR	Q. Spread	Volatility	IRD	NQR	Q. Spread	Volatility	IRD	NQR	Q. Spread	Volatility	IRD
1	100.0000	0.0000	0.0000	0.0000	8.6319	91.3682	0.0000	0.0000	6.4972	2.0921	91.4107	0.0000	0.5939	0.0237	0.0827	99.2997
2	97.5940	1.6685	0.0061	0.7315	9.5071	90.4595	0.0306	0.0028	6.5720	2.0623	91.3625	0.0032	0.8131	0.0193	0.0840	99.0837
3	94.4254	1.7163	0.0860	3.7723	9.5760	89.6298	0.0308	0.7634	6.4772	2.0347	91.3993	0.0888	1.0234	0.2703	0.1274	98.5790
4	93.5802	2.2216	0.3629	3.8353	9.7070	89.5288	0.0307	0.7336	6.3612	2.0423	91.4961	0.1004	1.0945	0.4781	0.1260	98.3015
5	93.0218	2.6023	0.5239	3.8521	10.3047	88.7024	0.0516	0.9413	6.3612	2.0376	91.3342	0.2670	0.9995	0.4386	0.1171	98.4448
6	93.6510	2.5613	0.4519	3.3358	11.8092	87.2458	0.0990	0.8460	6.6813	2.1939	90.8560	0.2689	0.9275	0.4265	0.1097	98.5363
7	93.0004	3.3854	0.4433	3.1710	12.7478	86.3425	0.1203	0.7894	6.7284	2.1855	90.8111	0.2751	0.8670	0.4506	0.1085	98.5739
8	92.2221	3.8336	0.4728	3.4715	13.3237	85.7457	0.1272	0.8034	6.7138	2.1817	90.8126	0.2919	0.8260	0.5034	0.1102	98.5604
9	91.6125	4.3763	0.5369	3.4744	13.8371	85.2611	0.1281	0.7738	6.6999	2.1774	90.8316	0.2911	0.7880	0.5604	0.1124	98.5391
10	91.1037	4.9151	0.5775	3.4037	14.5407	84.5782	0.1345	0.7466	6.7049	2.1787	90.8252	0.2913	0.7668	0.5863	0.1103	98.5366
100	75.2394	22.1519	0.3511	2.2576	38.5458	60.1788	0.0918	1.1836	6.8396	2.2017	90.6387	0.3201	2.3260	1.0302	0.1871	96.4568
150	74.1735	23.1644	0.3339	2.3283	40.0511	58.5149	0.0916	1.3424	6.8430	2.2039	90.6329	0.3203	2.5362	1.1561	0.1868	96.1209
200	73.8109	23.5074	0.3280	2.3536	40.5587	57.9525	0.0915	1.3973	6.8442	2.2047	90.6307	0.3204	2.6134	1.2055	0.1867	95.9944

	Table 5: Numbner of Quote Revisions				Table 6: Relative Spread				Table 7:Volatility				Table 8: Interest Rate Differential			
p	NQR	R. Spread	Volatility	IRD	NQR	R. Spread	Volatility	IRD	NQR	R. Spread	Volatility	IRD	NQR	R. Spread	Volatility	IRD
1	100.0000	0.0000	0.0000	0.0000	7.7814	92.2187	0.0000	0.0000	6.2085	1.7597	92.0318	0.0000	0.5254	0.0095	0.0888	99.3764
2	97.6551	1.6981	0.0000	0.6468	8.5554	91.4241	0.0106	0.0100	6.2204	1.7243	92.0546	0.0008	0.6710	0.0074	0.0942	99.2275
3	94.7372	1.7424	0.0399	3.4804	8.5318	90.6899	0.0106	0.7677	6.1419	1.7228	92.0673	0.0679	0.7905	0.4127	0.1488	98.6481
4	94.0436	2.2326	0.2221	3.5017	8.5473	90.7121	0.0153	0.7253	5.9984	1.8200	92.1087	0.0730	0.7925	0.7758	0.1515	98.2802
5	93.5903	2.6177	0.3091	3.4828	8.9683	90.0272	0.0150	0.9895	5.9530	1.8086	92.0221	0.2164	0.7740	0.7665	0.1394	98.3200
6	94.1523	2.5521	0.2851	3.0105	10.2747	88.7924	0.0199	0.9131	6.0864	1.8071	91.8779	0.2285	0.7946	0.8465	0.1310	98.2280
7	93.5157	3.3785	0.2713	2.8346	11.0475	88.0769	0.0212	0.8545	6.0770	1.8215	91.8569	0.2445	0.7575	1.0000	0.1296	98.1129
8	92.8579	3.8397	0.2818	3.0206	11.4637	87.6042	0.0201	0.9121	6.0620	1.8356	91.8488	0.2537	0.7240	1.2042	0.1310	97.9408
9	92.3152	4.3861	0.3165	2.9822	11.8230	87.2578	0.0198	0.8994	6.0475	1.8517	91.8474	0.2534	0.7112	1.4198	0.1325	97.7367
10	91.8240	4.9363	0.3348	2.9049	12.3490	86.7406	0.0189	0.8915	6.0391	1.8644	91.8418	0.2548	0.7735	1.5815	0.1293	97.5158
100	74.6156	23.0853	0.2130	2.0861	34.4237	64.7244	0.0329	0.8191	6.0910	2.0493	91.5719	0.2878	3.7850	4.1738	0.1656	91.8757
150	73.4454	24.2188	0.2049	2.1309	36.2298	62.7748	0.0377	0.9578	6.1048	2.0592	91.5475	0.2885	3.8669	4.2015	0.1656	91.7659
200	73.0400	24.6105	0.2020	2.1475	36.8599	62.0909	0.0394	1.0098	6.1101	2.0630	91.5381	0.2887	3.8938	4.2173	0.1656	91.7233

Panel 8.15

Variance Decompositions

US Time Zone: EU/US

Innovation in

Table 1: Number of Quote Revisions

p	NQR	Q. Spread	Volatility	IRD
1	100.0000	0.0000	0.0000	0.0000
2	97.3061	2.2873	0.0001	0.4065
3	96.1873	2.2547	0.0256	1.5323
4	95.2727	2.1734	1.0152	1.5387
5	94.3909	2.1136	1.9745	1.5210
6	94.9196	1.8704	1.8120	1.3980
7	94.5130	2.2933	1.7818	1.4119
8	94.1441	2.3103	1.8116	1.7340
9	93.8120	2.2481	2.0460	1.8939
10	93.4836	2.2058	2.3276	1.9830
100	87.8622	2.6542	2.7043	6.7793
150	87.7092	2.6789	2.6996	6.9123
200	87.6937	2.6814	2.6992	6.9257

Table 2: Quoted Spread

p	NQR	Q. Spread	Volatility	IRD
1	16.6549	83.3451	0.0000	0.0000
2	16.7313	82.5967	0.0256	0.6464
3	16.4579	81.5153	0.2544	1.7724
4	16.0977	80.7477	1.0827	2.0719
5	16.2442	80.2490	1.4667	2.0400
6	17.2887	79.2997	1.4262	1.9854
7	17.4178	78.7890	1.3619	2.4314
8	17.2917	78.1730	1.4115	3.1238
9	17.0849	77.7720	1.5488	3.5944
10	17.1378	77.3955	1.6088	3.8579
100	15.9219	64.8727	1.2619	17.9436
150	15.8633	64.6922	1.2581	18.1864
200	15.8576	64.6747	1.2578	18.2100

Table 3: Volatility

p	NQR	Q. Spread	Volatility	IRD
1	8.9181	1.2410	89.8409	0.0000
2	9.2882	1.8328	88.8053	0.0738
3	9.5338	2.3301	88.0479	0.0882
4	9.7547	2.3150	87.8428	0.0875
5	9.9773	2.6416	87.2932	0.0878
6	10.3500	3.0047	86.5362	0.1091
7	10.7061	3.0850	86.0986	0.1103
8	11.0051	3.2474	85.6315	0.1160
9	11.3025	3.2404	85.3398	0.1174
10	11.4718	3.2691	85.1416	0.1174
100	13.6552	3.3025	82.8164	0.2260
150	13.6544	3.3035	82.8094	0.2327
200	13.6543	3.3036	82.8087	0.2334

Table 4: Interest Rate Differential

p	NQR	Q. Spread	Volatility	IRD
1	0.1177	0.6233	0.0000	99.2589
2	0.3015	0.7830	0.0794	98.8362
3	0.5316	1.4358	0.1209	97.9118
4	0.4523	1.7874	0.0978	97.6625
5	0.4169	2.2735	0.1023	97.2073
6	0.3826	2.5369	0.1535	96.9271
7	0.3557	2.6835	0.1517	96.8092
8	0.3545	3.0154	0.1965	96.4336
9	0.3467	3.2905	0.2184	96.1444
10	0.3267	3.5633	0.2261	95.8839
100	0.1817	8.8864	0.3306	90.6013
150	0.1811	8.9458	0.3308	90.5424
200	0.1810	8.9515	0.3308	90.5368

Table 5: Numbner of Quote Revisions

p	NQR	R. Spread	Volatility	IRD
1	100.0000	0.0000	0.0000	0.0000
2	96.7602	2.9256	0.0038	0.3105
3	95.7384	3.0120	0.0108	1.2388
4	95.0221	2.9251	0.8380	1.2148
5	94.2462	2.9224	1.6460	1.1854
6	94.7612	2.6773	1.5019	1.0597
7	93.9631	3.5743	1.4535	1.0091
8	93.5818	3.8280	1.4608	1.1294
9	93.3261	3.8779	1.6454	1.1507
10	93.0036	3.9750	1.8783	1.1432
100	80.2891	15.2750	2.1425	2.2934
150	79.0257	16.2167	2.1093	2.6483
200	78.6460	16.4925	2.0992	2.7624

Table 6: Relative Spread

p	NQR	R. Spread	Volatility	IRD
1	15.5060	84.4940	0.0000	0.0000
2	15.1949	84.2972	0.0094	0.4985
3	14.7339	83.6819	0.2871	1.2971
4	14.0879	83.3221	1.1479	1.4421
5	14.0903	83.0062	1.5332	1.3702
6	14.5005	82.8896	1.3574	1.2526
7	14.2475	83.0380	1.2697	1.4448
8	13.8958	83.0098	1.3243	1.7701
9	13.4772	83.0930	1.4649	1.9649
10	13.3154	83.1174	1.5327	2.0345
100	7.5521	81.0649	0.8434	10.5397
150	7.1778	80.6509	0.7993	11.3721
200	7.0703	80.5270	0.7867	11.6160

Table 7:Volatility

p	NQR	R. Spread	Volatility	IRD
1	8.7372	1.0373	90.2255	0.0000
2	9.0147	1.5386	89.4234	0.0234
3	9.1466	2.0496	88.7240	0.0798
4	9.2522	2.1375	88.5214	0.0890
5	9.3099	2.5822	87.9905	0.1175
6	9.4916	2.6398	87.6072	0.2615
7	9.6836	2.8160	87.1739	0.3266
8	9.8185	3.0878	86.6907	0.4030
9	9.9609	3.1604	86.4131	0.4656
10	10.0266	3.3036	86.1744	0.4954
100	11.0884	5.5768	82.4341	0.9008
150	11.0672	5.7273	82.2566	0.9489
200	11.0603	5.7720	82.2023	0.9654

Table 8: Interest Rate Differential

p	NQR	R. Spread	Volatility	IRD
1	0.0789	0.6170	0.0061	99.2980
2	0.1721	0.8282	0.0336	98.9661
3	0.2804	1.6807	0.1664	97.8725
4	0.2308	2.1720	0.1543	97.4428
5	0.3181	2.7908	0.2236	96.6676
6	0.3559	3.1599	0.3840	96.1003
7	0.3742	3.4144	0.4239	95.7876
8	0.3648	3.9032	0.5465	95.1855
9	0.3646	4.3388	0.6211	94.6755
10	0.4024	4.7772	0.6615	94.1589
100	0.8300	24.2032	0.7431	74.2238
150	0.8108	25.9048	0.7166	72.5678
200	0.8070	26.4046	0.7091	72.0793

Panel 8.16

Variance Decompositions

UK Time Zone: JP/US

Innovation in

Table 1: Number of Quote Revisions

p	NQR	Q. Spread	Volatility	IRD
1	100.0000	0.0000	0.0000	0.0000
2	99.5369	0.1890	0.1834	0.0907
3	97.9982	0.1832	0.2337	1.5849
4	97.0098	0.3358	0.6816	1.9729
5	96.4191	0.5770	0.9092	2.0947
6	95.2745	1.5626	0.8126	2.3503
7	94.6932	1.8365	0.8290	2.6413
8	92.6931	1.8834	0.9352	4.4884
9	92.2982	2.2246	1.0340	4.4433
10	91.7806	2.7108	1.0955	4.4131
100	62.9875	31.5996	1.1442	4.2687
150	58.3875	36.1245	1.1938	4.2942
200	56.0400	38.4478	1.2191	4.2931

Table 2: Quoted Spread

p	NQR	Q. Spread	Volatility	IRD
1	0.4983	99.5017	0.0000	0.0000
2	0.5987	99.3163	0.0428	0.0422
3	0.6778	99.2091	0.0589	0.0542
4	0.6784	99.1626	0.0724	0.0866
5	0.7666	98.8261	0.2144	0.1929
6	0.8295	98.6646	0.2169	0.2891
7	0.9876	98.3870	0.3517	0.2738
8	1.1294	98.1869	0.4223	0.2614
9	1.4839	97.6947	0.5656	0.2559
10	1.7387	97.3502	0.6535	0.2576
100	14.0499	83.8060	1.5191	0.6250
150	15.5032	81.9167	1.5265	1.0535
200	16.2012	80.9504	1.5306	1.3178

Table 3: Volatility

p	NQR	Q. Spread	Volatility	IRD
1	3.6682	0.3686	95.9633	0.0000
2	3.6355	0.4252	95.9339	0.0055
3	3.6598	0.5596	95.7254	0.0551
4	3.6584	0.6012	95.6481	0.0923
5	3.6249	0.6465	95.6364	0.0922
6	3.9193	0.6661	95.3241	0.0906
7	3.8761	0.6743	95.3354	0.1142
8	3.9407	0.9297	94.7710	0.3587
9	3.9329	0.9569	94.7185	0.3916
10	3.9294	1.0141	94.6273	0.4291
100	4.0131	2.8842	92.1616	0.9411
150	4.0955	3.2275	91.7368	0.9402
200	4.1497	3.4305	91.4741	0.9457

Table 4: Interest Rate Differential

p	NQR	Q. Spread	Volatility	IRD
1	0.3454	0.0572	0.0001	99.5973
2	0.6849	0.1255	0.0034	99.1862
3	0.9153	0.1915	0.0038	98.8894
4	0.8397	0.1804	0.0037	98.9763
5	0.8307	0.1675	0.0059	98.9959
6	0.8568	0.1807	0.0057	98.9568
7	0.8416	0.1758	0.0056	98.9770
8	0.8442	0.1719	0.0312	98.9527
9	0.8066	0.1923	0.0550	98.9462
10	0.7768	0.2110	0.0706	98.9416
100	1.1786	0.3671	0.1963	98.2581
150	1.2057	0.3874	0.1976	98.2093
200	1.2160	0.4090	0.1982	98.1769

Table 5: Numbner of Quote Revisions

p	NQR	R. Spread	Volatility	IRD
1	100.0000	0.0000	0.0000	0.0000
2	99.6041	0.2003	0.0933	0.1023
3	98.0630	0.1959	0.0962	1.6449
4	97.3039	0.2825	0.3409	2.0727
5	96.9314	0.4123	0.4322	2.2241
6	95.7940	1.3262	0.3721	2.5078
7	95.2276	1.5615	0.3646	2.8462
8	93.2463	1.5734	0.3594	4.8209
9	93.0805	1.8114	0.3543	4.7538
10	92.7868	2.1799	0.3483	4.6851
100	64.4523	29.4461	1.3605	4.7411
150	59.5459	33.7691	1.6204	5.0646
200	57.0409	35.9669	1.7532	5.2390

Table 6: Relative Spread

p	NQR	R. Spread	Volatility	IRD
1	0.1691	99.8309	0.0000	0.0000
2	0.4250	99.3919	0.1583	0.0249
3	0.4642	99.2974	0.2049	0.0335
4	0.4626	99.2668	0.2219	0.0487
5	0.5248	98.9682	0.3531	0.1539
6	0.5361	98.8762	0.3566	0.2311
7	0.6264	98.6675	0.4871	0.2190
8	0.7462	98.4926	0.5488	0.2124
9	0.9745	98.1934	0.6325	0.1996
10	1.1555	97.9411	0.7140	0.1894
100	12.7414	82.9784	2.7433	1.5369
150	14.1721	80.5339	2.8977	2.3963
200	14.8453	79.3072	2.9695	2.8781

Table 7:Volatility

p	NQR	R. Spread	Volatility	IRD
1	3.2230	0.5175	96.2596	0.0000
2	3.1199	0.5928	96.2799	0.0074
3	3.0821	0.6796	96.1890	0.0494
4	3.0363	0.6884	96.1973	0.0780
5	2.9756	0.6930	96.2508	0.0806
6	3.0528	0.6797	96.1869	0.0806
7	2.9980	0.6677	96.2387	0.0955
8	2.9567	0.7486	95.9900	0.3048
9	2.9316	0.7393	95.9698	0.3593
10	2.9222	0.7358	95.9204	0.4217
100	3.3787	0.9091	94.8364	0.8758
150	3.4017	1.0027	94.7161	0.8795
200	3.4164	1.0588	94.6407	0.8841

Table 8: Interest Rate Differential

p	NQR	R. Spread	Volatility	IRD
1	0.3663	0.0526	0.0000	99.5811
2	0.7355	0.1251	0.0012	99.1381
3	1.0014	0.1984	0.0059	98.7943
4	0.9306	0.1830	0.0071	98.8793
5	0.8943	0.1694	0.0068	98.9294
6	0.8923	0.1727	0.0126	98.9224
7	0.8647	0.1704	0.0202	98.9448
8	0.8482	0.1644	0.0251	98.9623
9	0.8080	0.1674	0.0285	98.9962
10	0.7721	0.1719	0.0295	99.0265
100	0.9845	0.2091	0.1098	98.6966
150	1.0179	0.2505	0.1147	98.6169
200	1.0321	0.2863	0.1171	98.5645

Panel 8.17

Variance Decompositions

UK Time Zone: GB/US

Innovation in

	Table 1: Number of Quote Revisions				Table 2: Quoted Spread				Table 3: Volatility				Table 4: Interest Rate Differential			
p	NQR	Q. Spread	Volatility	IRD	NQR	Q. Spread	Volatility	IRD	NQR	Q. Spread	Volatility	IRD	NQR	Q. Spread	Volatility	IRD
1	100.0000	0.0000	0.0000	0.0000	3.1226	96.8774	0.0000	0.0000	6.3034	0.2352	93.4614	0.0000	0.4760	0.0928	0.0106	99.4207
2	99.1877	0.3153	0.0150	0.4819	3.5375	96.3700	0.0422	0.0503	6.1973	0.2360	93.5638	0.0028	0.6610	0.1008	0.0143	99.2240
3	97.6095	0.3064	0.0292	2.0550	3.8776	96.0015	0.0470	0.0739	6.1217	0.2356	93.4956	0.1471	0.8678	0.0956	0.1127	98.9239
4	96.3800	0.4083	0.4640	2.7477	3.8611	95.9769	0.0602	0.1018	6.0568	0.2605	93.4809	0.2019	0.8709	0.0914	0.1051	98.9327
5	95.8055	0.3956	0.7464	3.0525	3.8901	95.8363	0.0582	0.2154	6.0165	0.2643	93.5138	0.2054	0.8616	0.0869	0.0976	98.9539
6	95.2450	0.6915	0.6831	3.3804	3.8451	95.8094	0.0556	0.2899	6.1738	0.2621	93.3622	0.2019	0.8885	0.1087	0.1053	98.8976
7	94.1906	1.3509	0.7400	3.7185	3.7603	95.8197	0.1074	0.3126	6.2607	0.2598	93.1774	0.3021	0.8695	0.1103	0.1082	98.9120
8	92.3847	1.3931	0.7374	5.4848	3.6023	95.9169	0.1731	0.3078	6.4097	0.2708	92.9735	0.3461	0.8477	0.1183	0.1165	98.9176
9	92.2442	1.4926	0.8896	5.3737	3.9608	95.5871	0.1639	0.2882	6.4535	0.2723	92.9162	0.3580	0.8116	0.1144	0.1365	98.9375
10	92.1069	1.6403	0.9759	5.2770	4.1475	95.4189	0.1577	0.2759	6.4665	0.2727	92.9008	0.3600	0.7762	0.1093	0.1535	98.9609
100	69.6504	24.8992	1.1213	4.3291	9.1052	90.0113	0.0627	0.8208	7.7507	0.6001	90.9683	0.6809	1.0651	0.1635	0.4842	98.2871
150	64.8819	29.7584	1.0291	4.3306	9.8427	88.9364	0.0581	1.1628	7.7662	0.7674	90.7803	0.6861	1.1184	0.2830	0.4870	98.1117
200	62.5320	32.1715	0.9833	4.3132	10.1853	88.4102	0.0567	1.3478	7.7740	0.8621	90.6743	0.6896	1.1380	0.3699	0.4867	98.0054

	Table 5: Numbner of Quote Revisions				Table 6: Relative Spread				Table 7:Volatility				Table 8: Interest Rate Differential			
p	NQR	R. Spread	Volatility	IRD	NQR	R. Spread	Volatility	IRD	NQR	R. Spread	Volatility	IRD	NQR	R. Spread	Volatility	IRD
1	100.0000	0.0000	0.0000	0.0000	3.0979	96.9021	0.0000	0.0000	6.1100	0.2449	93.6451	0.0000	0.4215	0.0679	0.0100	99.5006
2	99.1884	0.3754	0.0083	0.4278	3.5011	96.4027	0.0368	0.0594	5.9919	0.2436	93.7628	0.0017	0.5593	0.0625	0.0135	99.3647
3	97.7381	0.3641	0.0139	1.8839	3.8138	96.0616	0.0407	0.0839	5.9050	0.2425	93.7176	0.1350	0.7082	0.0775	0.1122	99.1021
4	96.6281	0.4932	0.3911	2.4876	3.7686	96.0853	0.0442	0.1019	5.8400	0.2794	93.6978	0.1828	0.6865	0.0912	0.1050	99.1173
5	96.1595	0.4828	0.6253	2.7323	3.7917	95.9457	0.0438	0.2187	5.8014	0.2775	93.7326	0.1886	0.7456	0.1010	0.0975	99.0559
6	95.5711	0.8463	0.5643	3.0184	3.7624	95.8942	0.0424	0.3010	5.8841	0.2711	93.6602	0.1846	0.8466	0.1606	0.1052	98.8876
7	94.3398	1.7868	0.5956	3.2779	3.6982	95.9053	0.0824	0.3141	5.9135	0.2835	93.5082	0.2949	0.8695	0.1856	0.1078	98.8371
8	92.5841	1.8982	0.6313	4.8864	3.5612	95.9956	0.1420	0.3012	5.9930	0.2826	93.3923	0.3321	0.8897	0.2324	0.1150	98.7629
9	92.3311	2.1134	0.7335	4.8220	4.0217	95.5599	0.1346	0.2838	5.9702	0.2775	93.4143	0.3381	0.8558	0.2530	0.1323	98.7589
10	92.0253	2.3824	0.7867	4.8056	4.2636	95.3372	0.1299	0.2693	5.9536	0.2774	93.4315	0.3375	0.8459	0.2613	0.1477	98.7452
100	65.0500	30.0433	0.6658	4.2409	11.2602	88.0604	0.0512	0.6282	6.4373	1.4444	91.5524	0.5659	2.0470	0.8122	0.4946	96.6462
150	60.7034	34.4436	0.6086	4.2444	12.2215	86.7608	0.0486	0.9692	6.4812	1.7727	91.1752	0.5709	2.0741	0.8113	0.4982	96.6165
200	58.6286	36.5568	0.5811	4.2336	12.6708	86.1190	0.0482	1.1621	6.5076	1.9489	90.9669	0.5767	2.0786	0.8146	0.4985	96.6084

Panel 8.18

Variance Decompositions

UK Time Zone: EU/US

Innovation in

	Table 1: Number of Quote Revisions				Table 2: Quoted Spread				Table 3: Volatility				Table 4: Interest Rate Differential			
p	NQR	Q. Spread	Volatility	IRD	NQR	Q. Spread	Volatility	IRD	NQR	Q. Spread	Volatility	IRD	NQR	Q. Spread	Volatility	IRD
1	100.0000	0.0000	0.0000	0.0000	5.7183	94.2817	0.0000	0.0000	4.9750	0.0401	94.9849	0.0000	0.1198	0.3316	0.0165	99.5321
2	97.1227	2.5466	0.0350	0.2957	6.2442	93.5709	0.0001	0.1849	5.0177	0.3143	94.6448	0.0232	0.1614	0.9588	0.0347	98.8452
3	96.9831	2.5627	0.1671	0.2871	5.9978	92.9382	0.0940	0.9700	5.3913	0.4292	94.0646	0.1149	0.1563	1.4251	0.0278	98.3908
4	96.5139	2.4989	0.6362	0.3511	5.7773	92.5289	0.3095	1.3843	5.7616	0.4231	93.6556	0.1597	0.1424	1.6955	0.0605	98.1016
5	95.5840	2.5489	1.4812	0.3858	6.2095	92.1126	0.3473	1.3307	5.8150	1.1842	92.8431	0.1577	0.2014	2.0001	0.0860	97.7125
6	95.7816	2.2277	1.6151	0.3756	6.2082	92.0818	0.3290	1.3811	6.8813	1.1577	91.7831	0.1780	0.2028	2.2374	0.0836	97.4763
7	94.9949	3.0648	1.5528	0.3876	6.0729	92.0219	0.3512	1.5541	7.2101	1.2180	91.3952	0.1767	0.1939	2.3826	0.0803	97.3432
8	94.6256	3.3089	1.6730	0.3925	5.9380	91.9709	0.3693	1.7218	7.5058	1.3306	90.9796	0.1840	0.1955	2.5628	0.0792	97.1625
9	94.3190	3.3752	1.8867	0.4191	5.8645	91.6253	0.4145	2.0957	7.8886	1.3783	90.5424	0.1907	0.1897	2.7332	0.0810	96.9961
10	93.9425	3.4846	2.1277	0.4451	5.8719	91.2267	0.4450	2.4564	8.0702	1.5162	90.2220	0.1916	0.1977	2.8831	0.0767	96.8425
100	88.2132	6.7696	2.8162	2.2009	5.1689	79.4307	0.4452	14.9552	11.3340	2.4508	85.9206	0.2946	2.9911	4.5574	0.2156	92.2360
150	88.0795	6.7694	2.8122	2.3389	5.2161	79.0551	0.4479	15.2810	11.3327	2.4519	85.9057	0.3097	3.1676	4.5277	0.2272	92.0775
200	88.0626	6.7685	2.8118	2.3571	5.2228	79.0094	0.4483	15.3195	11.3328	2.4519	85.9036	0.3117	3.1907	4.5236	0.2288	92.0569

	Table 5: Numbner of Quote Revisions				Table 6: Relative Spread				Table 7:Volatility				Table 8: Interest Rate Differential			
p	NQR	R. Spread	Volatility	IRD	NQR	R. Spread	Volatility	IRD	NQR	R. Spread	Volatility	IRD	NQR	R. Spread	Volatility	IRD
1	100.0000	0.0000	0.0000	0.0000	4.8222	95.1778	0.0000	0.0000	4.7670	0.0450	95.1881	0.0000	0.0866	0.2823	0.0376	99.5936
2	96.8970	2.8294	0.0168	0.2568	5.1410	94.7096	0.0000	0.1494	4.7862	0.4481	94.7098	0.0560	0.1096	0.9207	0.0265	98.9433
3	96.8074	2.8256	0.1160	0.2510	4.8830	94.3552	0.0631	0.6987	5.0656	0.5534	94.1724	0.2086	0.0937	1.3673	0.0442	98.4948
4	96.4834	2.7502	0.4819	0.2845	4.6163	94.2244	0.1771	0.9822	5.3717	0.5841	93.8227	0.2216	0.0772	1.6700	0.0392	98.2137
5	95.6967	2.8356	1.1757	0.2920	4.9422	93.8999	0.2018	0.9560	5.3711	1.2312	93.1702	0.2275	0.2337	2.0249	0.0362	97.7052
6	95.9903	2.4983	1.2444	0.2670	4.7793	94.1174	0.1898	0.9135	6.2334	1.2819	92.2621	0.2226	0.2996	2.3090	0.0865	97.3049
7	95.0896	3.4027	1.2509	0.2568	4.5003	94.3931	0.1866	0.9201	6.4413	1.3878	91.9205	0.2504	0.3491	2.5704	0.1445	96.9360
8	94.7198	3.7188	1.3117	0.2496	4.2702	94.6053	0.1865	0.9381	6.6297	1.5645	91.4893	0.3165	0.4238	2.9043	0.2013	96.4706
9	94.5000	3.8108	1.4440	0.2453	4.1091	94.5938	0.2049	1.0922	6.8827	1.6810	91.0637	0.3727	0.4755	3.2324	0.2603	96.0319
10	94.1911	3.9804	1.5884	0.2401	4.0222	94.5366	0.2156	1.2256	6.9741	1.8928	90.7135	0.4197	0.5632	3.5548	0.2879	95.5941
100	81.5347	16.1627	1.6968	0.6058	3.3108	86.6825	0.1767	9.8299	8.6343	6.1279	84.4243	0.8135	6.8446	15.8570	0.8237	76.4748
150	80.7544	16.6421	1.6833	0.9202	3.6989	85.0742	0.2020	11.0249	8.6308	6.2654	84.2256	0.8783	7.1557	16.4975	0.8337	75.5131
200	80.5694	16.7245	1.6809	1.0252	3.8082	84.6500	0.2096	11.3323	8.6332	6.2910	84.1743	0.9016	7.2205	16.6399	0.8357	75.3040

Panel 8.19

Variance Decompositions

ASIA Time Zone: JP/US

Innovation in

Table 1: Number of Quote Revisions

p	NQR	Q. Spread	Volatility	IRD
1	100.0000	0.0000	0.0000	0.0000
2	98.7404	1.0534	0.0029	0.2032
3	96.4274	1.1050	0.1312	2.3365
4	96.2347	1.1983	0.1288	2.4383
5	96.1031	1.1962	0.1409	2.5598
6	96.4125	1.0360	0.1628	2.3886
7	95.7297	1.6921	0.1876	2.3907
8	95.2229	1.6496	0.1836	2.9439
9	95.1326	1.6374	0.3279	2.9022
10	95.0536	1.7163	0.3207	2.9094
100	69.7168	23.2007	2.5965	4.4861
150	64.5319	28.1633	2.9569	4.3479
200	61.7509	30.9397	3.1281	4.1813

Table 2: Quoted Spread

p	NQR	Q. Spread	Volatility	IRD
1	2.4840	97.5161	0.0000	0.0000
2	2.3452	97.5127	0.0003	0.1418
3	2.3069	97.5473	0.0019	0.1438
4	2.2663	97.5811	0.0062	0.1464
5	3.2478	95.6675	0.3382	0.7465
6	3.5694	95.1219	0.4692	0.8395
7	3.4779	95.2543	0.4574	0.8104
8	3.4759	95.2346	0.4622	0.8273
9	3.5342	95.1950	0.4568	0.8140
10	3.8121	94.9328	0.4614	0.7937
100	14.5642	82.6979	2.2007	0.5372
150	16.7124	80.1283	2.6108	0.5486
200	17.8518	78.7048	2.8370	0.6065

Table 3: Volatility

p	NQR	Q. Spread	Volatility	IRD
1	0.9379	0.1183	98.9439	0.0000
2	1.0130	0.3743	98.4676	0.1451
3	1.5553	0.9495	97.3555	0.1398
4	1.5398	0.9361	97.3841	0.1401
5	1.5232	0.9796	97.3006	0.1967
6	1.6677	1.0365	96.9218	0.3740
7	1.8838	1.0267	96.7036	0.3859
8	1.8672	1.0512	96.6890	0.3927
9	1.8572	1.2214	96.5298	0.3917
10	1.8557	1.2106	96.5455	0.3883
100	3.0463	2.7021	93.1734	1.0782
150	3.3265	3.4170	92.1873	1.0693
200	3.5078	3.8800	91.5437	1.0685

Table 4: Interest Rate Differential

p	NQR	Q. Spread	Volatility	IRD
1	0.5893	0.0015	0.0026	99.4066
2	1.1087	0.0261	0.0133	98.8519
3	1.7758	0.1000	0.0308	98.0934
4	1.9383	0.0927	0.0832	97.8858
5	1.8019	0.0945	0.0873	98.0163
6	1.7317	0.1041	0.1254	98.0388
7	1.6896	0.1099	0.1418	98.0587
8	1.6387	0.1075	0.2700	97.9839
9	1.5911	0.1044	0.2769	98.0277
10	1.5341	0.1396	0.2731	98.0531
100	1.2100	0.6940	0.4718	97.6242
150	1.2201	0.7274	0.4806	97.5718
200	1.2203	0.7343	0.4812	97.5642

Table 5: Numbner of Quote Revisions

p	NQR	R. Spread	Volatility	IRD
1	100.0000	0.0000	0.0000	0.0000
2	99.5625	0.2049	0.0062	0.2265
3	97.3468	0.2125	0.1000	2.3407
4	97.1760	0.2860	0.0986	2.4394
5	96.9085	0.4191	0.1037	2.5686
6	96.8745	0.6142	0.1378	2.3735
7	96.6579	0.7645	0.1856	2.3920
8	96.0359	0.7933	0.1963	2.9744
9	95.7272	0.9466	0.4238	2.9024
10	95.5572	1.1173	0.4870	2.8385
100	78.9993	10.8101	3.9461	6.2445
150	76.2339	12.2961	4.1145	7.3555
200	75.0107	12.9859	4.1738	7.8296

Table 6: Relative Spread

p	NQR	R. Spread	Volatility	IRD
1	1.9204	98.0796	0.0000	0.0000
2	3.0768	96.7190	0.2032	0.0010
3	3.0573	96.5650	0.2359	0.1418
4	2.9515	96.6336	0.2314	0.1835
5	2.8222	96.7509	0.2265	0.2004
6	3.1581	96.1862	0.2284	0.4273
7	3.3376	95.7670	0.2936	0.6018
8	3.4307	95.5765	0.4116	0.5812
9	3.4458	95.6039	0.4016	0.5488
10	3.4199	95.6527	0.4038	0.5236
100	12.3295	84.9225	0.7439	2.0040
150	15.2462	80.5753	1.0387	3.1397
200	16.9108	78.0217	1.2294	3.8382

Table 7:Volatility

p	NQR	R. Spread	Volatility	IRD
1	0.7669	5.5138	93.7193	0.0000
2	0.7895	5.7789	93.3052	0.1264
3	1.1803	6.0000	92.6976	0.1221
4	1.1537	6.0136	92.7123	0.1204
5	1.1612	5.9245	92.7648	0.1496
6	1.1759	5.8396	92.7044	0.2802
7	1.2252	5.8512	92.6470	0.2767
8	1.3051	5.7759	92.6470	0.2720
9	1.3112	5.7431	92.6568	0.2889
10	1.3498	5.7168	92.6217	0.3118
100	4.8901	5.2079	88.9460	0.9560
150	5.1125	5.2252	88.6455	1.0169
200	5.1919	5.2426	88.5174	1.0480

Table 8: Interest Rate Differential

p	NQR	R. Spread	Volatility	IRD
1	0.5688	0.0463	0.0019	99.3830
2	1.1237	0.2574	0.0039	98.6151
3	1.7017	0.2314	0.0117	98.0552
4	1.7860	0.2243	0.0426	97.9472
5	1.6533	0.2537	0.0653	98.0277
6	1.5771	0.2449	0.1553	98.0227
7	1.5245	0.2643	0.1967	98.0145
8	1.4679	0.3108	0.3933	97.8280
9	1.4129	0.3393	0.3761	97.8718
10	1.3519	0.3691	0.3617	97.9173
100	2.2414	2.9457	0.4759	94.3371
150	2.3586	3.3071	0.5101	93.8242
200	2.3634	3.4201	0.5135	93.7030

Panel 8.20

Variance Decompositions

ASIA Time Zone: GB/US

Innovation in

Table 1: Number of Quote Revisions

p	NQR	Q. Spread	Volatility	IRD
1	100.0000	0.0000	0.0000	0.0000
2	97.6097	1.6397	0.0486	0.7020
3	94.4226	1.6735	0.2277	3.6762
4	93.6661	2.1499	0.4443	3.7398
5	93.1958	2.5089	0.5347	3.7607
6	93.8220	2.4514	0.4645	3.2621
7	93.2071	3.2321	0.4636	3.0973
8	92.4414	3.6723	0.5203	3.3661
9	91.8206	4.2266	0.5889	3.3640
10	91.3224	4.7600	0.6179	3.2998
100	74.7446	22.4360	0.6012	2.2183
150	73.6057	23.5004	0.5979	2.2962
200	73.2171	23.8620	0.5968	2.3241

Table 2: Quoted Spread

p	NQR	Q. Spread	Volatility	IRD
1	8.5406	91.4594	0.0000	0.0000
2	9.3981	90.5996	0.0004	0.0019
3	9.4650	89.7217	0.0571	0.7562
4	9.5995	89.6180	0.0553	0.7272
5	10.2256	88.7699	0.0675	0.9370
6	11.7870	87.2870	0.0820	0.8440
7	12.7265	86.4093	0.0770	0.7873
8	13.2807	85.8467	0.0738	0.7987
9	13.7915	85.3687	0.0712	0.7687
10	14.4891	84.7012	0.0681	0.7417
100	37.6891	60.8841	0.1957	1.2312
150	39.1547	59.2323	0.2219	1.3911
200	39.6507	58.6719	0.2309	1.4465

Table 3: Volatility

p	NQR	Q. Spread	Volatility	IRD
1	0.1702	0.0186	99.8112	0.0000
2	0.2008	0.2973	99.4994	0.0025
3	0.2458	0.2953	99.4392	0.0197
4	0.2443	0.3843	99.3392	0.0322
5	0.3071	0.3815	99.2571	0.0543
6	0.3411	0.3719	99.2312	0.0558
7	0.3698	0.3914	99.1808	0.0580
8	0.3866	0.3982	99.1552	0.0599
9	0.3900	0.4080	99.1405	0.0615
10	0.4170	0.4094	99.1110	0.0627
100	0.7597	0.4872	98.6843	0.0687
150	0.7860	0.5047	98.6391	0.0702
200	0.7958	0.5113	98.6221	0.0708

Table 4: Interest Rate Differential

p	NQR	Q. Spread	Volatility	IRD
1	0.5993	0.0254	0.0010	99.3744
2	0.8371	0.0212	0.0138	99.1280
3	1.0678	0.2632	0.0161	98.6529
4	1.1510	0.4609	0.0204	98.3678
5	1.0490	0.4217	0.0186	98.5107
6	0.9697	0.4075	0.0293	98.5935
7	0.9087	0.4265	0.0394	98.6253
8	0.8694	0.4716	0.0504	98.6086
9	0.8318	0.5260	0.0642	98.5780
10	0.8051	0.5511	0.0762	98.5676
100	2.2123	0.9906	0.4865	96.3107
150	2.4202	1.1216	0.4872	95.9710
200	2.4970	1.1732	0.4873	95.8425

Table 5: Numbner of Quote Revisions

p	NQR	R. Spread	Volatility	IRD
1	100.0000	0.0000	0.0000	0.0000
2	98.7288	0.6706	0.0442	0.5564
3	95.8431	0.8119	0.1506	3.1943
4	95.6939	0.8547	0.2692	3.1822
5	95.4291	1.1351	0.3027	3.1332
6	95.8791	1.1656	0.2659	2.6894
7	95.6265	1.5978	0.2557	2.5200
8	95.1903	1.9058	0.2725	2.6314
9	95.0028	2.1333	0.2973	2.5666
10	94.7583	2.4481	0.3016	2.4920
100	83.9991	13.4270	0.4781	2.0958
150	83.2645	14.1272	0.4948	2.1136
200	83.0435	14.3386	0.4997	2.1182

Table 6: Relative Spread

p	NQR	R. Spread	Volatility	IRD
1	3.8158	96.1842	0.0000	0.0000
2	4.9712	94.8381	0.0008	0.1899
3	5.3666	94.1111	0.0797	0.4426
4	6.0053	93.2587	0.1111	0.6249
5	5.9855	93.2957	0.1348	0.5840
6	6.5414	92.7473	0.1268	0.5845
7	7.2087	92.0434	0.1198	0.6281
8	7.6988	91.4895	0.1160	0.6958
9	8.2374	90.8945	0.1235	0.7447
10	8.5663	90.5315	0.1318	0.7704
100	27.9303	71.0359	0.2936	0.7402
150	29.7800	69.1227	0.3141	0.7832
200	30.3616	68.5142	0.3208	0.8035

Table 7:Volatility

p	NQR	R. Spread	Volatility	IRD
1	0.0897	0.4607	99.4496	0.0000
2	0.0971	0.5667	99.3361	0.0001
3	0.1011	0.5597	99.3328	0.0063
4	0.1373	0.6084	99.2445	0.0099
5	0.1553	0.6201	99.2086	0.0161
6	0.1526	0.6041	99.2182	0.0251
7	0.1521	0.6110	99.2088	0.0282
8	0.1507	0.6438	99.1750	0.0305
9	0.1543	0.6886	99.1252	0.0319
10	0.1549	0.7185	99.0917	0.0349
100	0.4621	1.5922	97.8772	0.0686
150	0.5241	1.6191	97.7868	0.0700
200	0.5446	1.6268	97.7581	0.0706

Table 8: Interest Rate Differential

p	NQR	R. Spread	Volatility	IRD
1	0.4944	0.2433	0.0009	99.2615
2	0.7331	0.4549	0.0052	98.8068
3	0.9314	0.5783	0.0050	98.4853
4	0.9347	0.7541	0.0045	98.3066
5	0.8909	1.0650	0.0095	98.0346
6	0.8817	1.4334	0.0527	97.6321
7	0.8315	1.7979	0.0920	97.2786
8	0.7901	2.1649	0.1280	96.9170
9	0.7658	2.5355	0.1621	96.5367
10	0.8065	2.9165	0.1926	96.0844
100	3.6930	9.8493	0.5669	85.8909
150	3.7712	9.8406	0.5676	85.8206
200	3.7896	9.8418	0.5677	85.8009

Panel 8.21

Variance Decompositions

ASIA Time Zone: EU/US

Innovation in

Table 1: Number of Quote Revisions

p	NQR	Q. Spread	Volatility	IRD
1	100.0000	0.0000	0.0000	0.0000
2	96.7203	2.6538	0.2138	0.4122
3	95.0011	2.6455	0.8136	1.5399
4	94.6488	2.5725	1.1749	1.6039
5	94.1792	2.5275	1.6764	1.6169
6	94.3079	2.2453	1.9310	1.5159
7	93.4459	2.7284	2.2457	1.5800
8	92.7158	2.7470	2.5898	1.9475
9	92.2295	2.6846	2.9270	2.1589
10	91.7998	2.6586	3.2567	2.2848
100	84.3440	3.4096	5.2451	7.0014
150	84.1957	3.4341	5.2363	7.1339
200	84.1802	3.4366	5.2356	7.1476

Table 2: Quoted Spread

p	NQR	Q. Spread	Volatility	IRD
1	17.2315	82.7685	0.0000	0.0000
2	17.2096	82.0972	0.0337	0.6595
3	16.9478	81.1983	0.1130	1.7410
4	16.7270	81.0217	0.1114	2.1399
5	16.8912	80.8243	0.1660	2.1186
6	17.9535	79.8526	0.1523	2.0416
7	17.9529	79.3316	0.1498	2.5657
8	17.8052	78.7994	0.1644	3.2310
9	17.5941	78.4880	0.1736	3.7443
10	17.6413	78.1449	0.1877	4.0261
100	16.1021	65.5882	0.2120	18.0978
150	16.0406	65.3992	0.2168	18.3435
200	16.0344	65.3806	0.2174	18.3676

Table 3: Volatility

p	NQR	Q. Spread	Volatility	IRD
1	0.6751	0.9333	98.3916	0.0000
2	0.7935	0.9429	98.0682	0.1954
3	0.7688	0.9472	97.5920	0.6920
4	1.0589	0.9397	97.3233	0.6781
5	1.0497	1.0537	97.0628	0.8339
6	1.9138	1.1830	96.0830	0.8203
7	1.9941	1.2292	95.9597	0.8170
8	2.0712	1.2235	95.8822	0.8231
9	2.2524	1.2206	95.7008	0.8263
10	2.4400	1.2580	95.4763	0.8257
100	5.0028	1.3625	92.8031	0.8317
150	5.0033	1.3632	92.7983	0.8351
200	5.0033	1.3633	92.7978	0.8355

Table 4: Interest Rate Differential

p	NQR	Q. Spread	Volatility	IRD
1	0.1348	0.5344	0.0017	99.3291
2	0.3211	0.6875	0.0740	98.9174
3	0.5618	1.2598	0.0811	98.0973
4	0.4846	1.5676	0.1038	97.8441
5	0.4419	1.9975	0.0946	97.4660
6	0.4107	2.1982	0.1596	97.2315
7	0.3918	2.3607	0.2137	97.0338
8	0.4076	2.6701	0.2556	96.6667
9	0.4080	2.9462	0.3078	96.3381
10	0.3906	3.2254	0.3455	96.0385
100	0.2210	8.5089	1.0132	90.2569
150	0.2194	8.5685	1.0211	90.1911
200	0.2192	8.5742	1.0218	90.1847

Table 5: Numbner of Quote Revisions

p	NQR	R. Spread	Volatility	IRD
1	100.0000	0.0000	0.0000	0.0000
2	98.3115	0.8174	0.3306	0.5406
3	96.7944	1.1901	0.5299	1.4856
4	96.6812	1.1594	0.7041	1.4553
5	96.2426	1.2784	1.0479	1.4311
6	96.5241	1.0979	1.1397	1.2383
7	95.4889	1.8056	1.4953	1.2103
8	94.7981	2.1914	1.7148	1.2957
9	94.5082	2.2810	1.9077	1.3031
10	94.0851	2.4682	2.1418	1.3050
100	79.1952	15.6596	2.8089	2.3363
150	77.0407	17.3154	2.7475	2.8964
200	76.0865	18.0249	2.7235	3.1651

Table 6: Relative Spread

p	NQR	R. Spread	Volatility	IRD
1	4.2456	95.7544	0.0000	0.0000
2	5.0755	94.5685	0.2529	0.1031
3	5.4099	93.7502	0.2405	0.5994
4	5.2880	93.2056	0.2798	1.2266
5	5.0621	93.4582	0.2646	1.2152
6	7.1610	91.5097	0.2330	1.0963
7	7.6218	91.0285	0.2156	1.1342
8	7.7626	90.7034	0.2079	1.3261
9	7.6911	90.5917	0.1999	1.5173
10	7.4508	90.6945	0.1915	1.6632
100	8.3384	80.9328	0.2415	10.4874
150	7.9368	79.9685	0.3074	11.7872
200	7.7669	79.5723	0.3368	12.3241

Table 7:Volatility

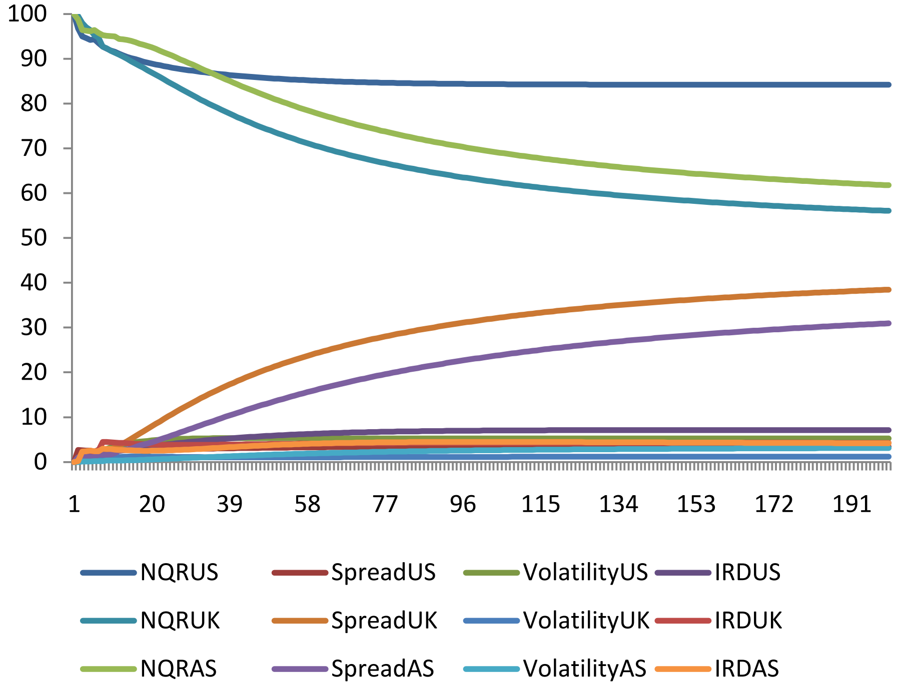
p	NQR	R. Spread	Volatility	IRD
1	0.5838	0.7024	98.7139	0.0000
2	0.7221	0.8927	98.2743	0.1109
3	0.7214	0.8984	97.9847	0.3955
4	0.9204	0.8845	97.7723	0.4228
5	0.9070	1.5355	97.0767	0.4808
6	1.4276	1.5703	96.5051	0.4971
7	1.4084	1.7643	96.2124	0.6149
8	1.4131	1.8370	96.0999	0.6500
9	1.4691	1.9076	95.9026	0.7207
10	1.5314	2.0554	95.6107	0.8025
100	3.1646	4.5421	90.9645	1.3289
150	3.1773	4.7532	90.6910	1.3785
200	3.1794	4.8447	90.5687	1.4073

Table 8: Interest Rate Differential

p	NQR	R. Spread	Volatility	IRD
1	0.1083	0.1967	0.0042	99.6908
2	0.3586	0.5411	0.1340	98.9664
3	0.5642	0.6919	0.1496	98.5943
4	0.4950	0.8266	0.2057	98.4729
5	0.4712	1.0434	0.2064	98.2791
6	0.4891	1.1789	0.4284	97.9036
7	0.5341	1.5385	0.6259	97.3015
8	0.5468	1.9401	0.8102	96.7029
9	0.5702	2.3487	1.0126	96.0686
10	0.6069	2.7347	1.1869	95.4715
100	1.1067	25.4507	3.6230	69.8196
150	1.2649	28.8319	3.4443	66.4588
200	1.3535	30.2536	3.3630	65.0299

Panel 8.22 to 8.24: Variance Decompositions Plots, Daily Sample

Colour Guide to Variance Decompositions Plots
(the plot below is a sample)

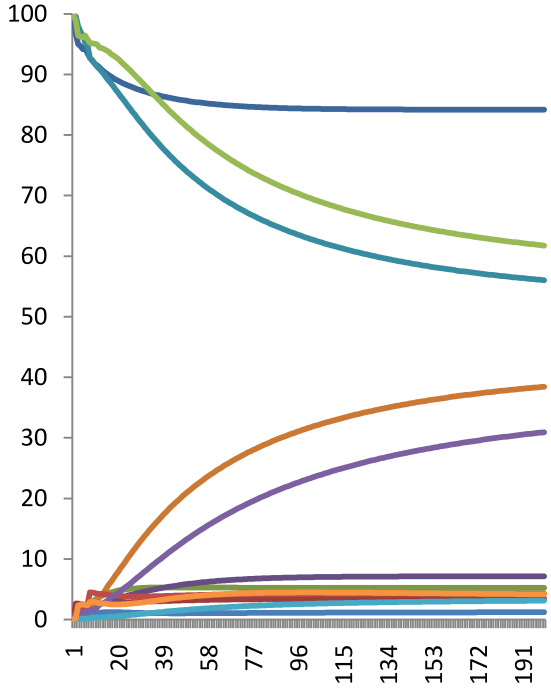


Note for Panels 8.22-8.24: Plot 1 shows the percentage of the forecast error variance shift of the number of quote revisions (NQR) that is explained by innovations in the number of quote revisions (own shock), quoted spread, exchange rate volatility, and interest rate differential, up to 200 periods ahead. (one period is equal to one trading day). Plot 2-4: Defined as Plot 1 but for quoted spread, exchange rate volatility and interest rate differential respectively. Plot 5 shows the percentage of the forecast error variance shift of the number of quote revisions (NQR) that is explained by innovations in the number of quote revisions (own shock), relative spread, exchange rate volatility, and interest rate differential, up to 200 periods ahead. (one period is equal to one trading day). Plot 6-8: Defined as Plot 1 but for Relative spread, exchange rate volatility and interest rate differential respectively. The variance decompositions results are obtained from the VAR models described in section 8.6 applied on our full daily sample. Variables used in the VAR; The number of quote revisions: mean quote revisions were calculated based on the number of quote revisions recorded in 5-minute intervals, between 8:00am and 5:00pm local time; The daily mean quoted spreads were calculated based on the last recorded bid and ask quotes at 5-minute intervals, between 8:00am and 5pm local time. The daily mean relative spreads were calculated based on the difference of the logarithm of the ask price and the logarithm of the bid price. The logarithmic bid and ask values are based on the last bid-ask quotes recorded at 5-minute intervals, between 8:00am and 5:00pm local time. *Volatility*: the difference between the highest ask price and lowest bid price during a trading day; Interest rate differential (IRD) between Eurodollar overnight deposit rates (short) and Eurodollar one month deposit rate (long). The x-axis values give the number of periods (forecast horizon in days) since the shock was first felt.

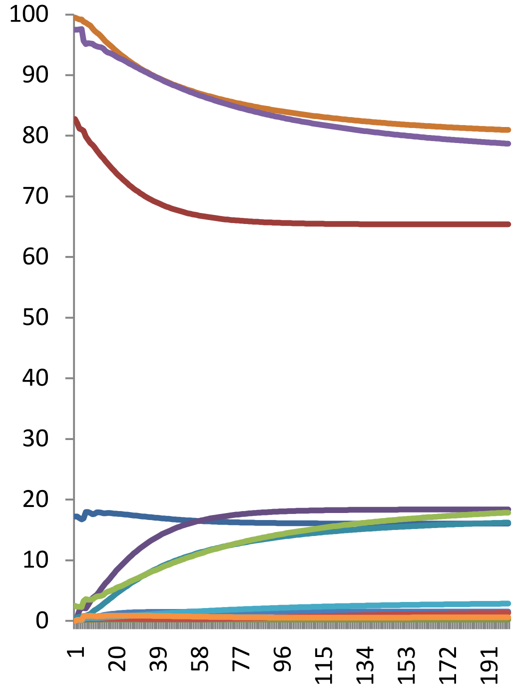
Panel 8.22: Variance Decompositions, JP/US (US, UK, ASIA time zones)

Quoted Spread

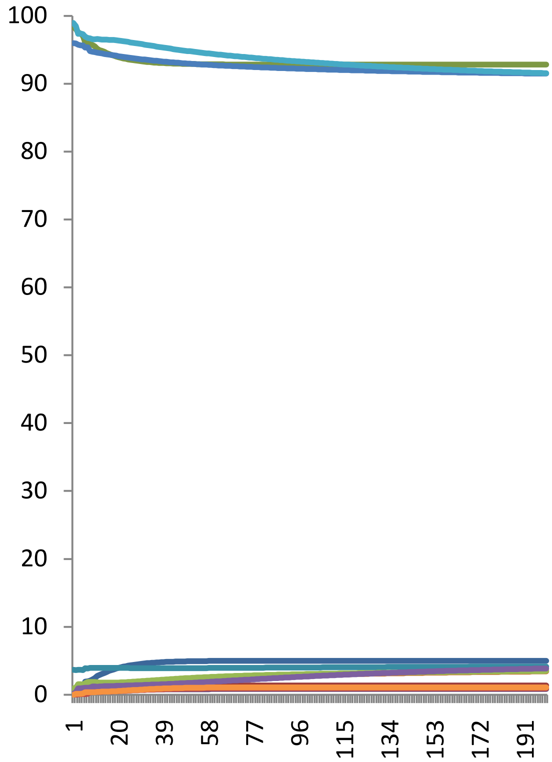
Plot 1
Number of Quote Revisions



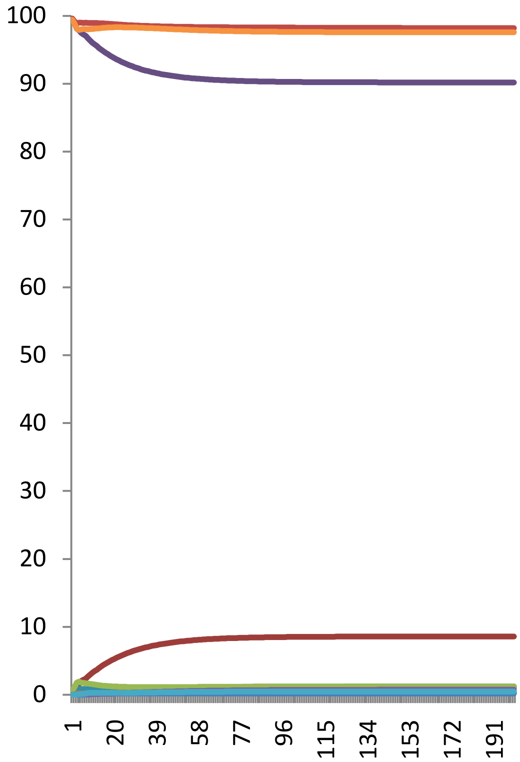
Plot 2
Quoted Spread



Plot 3
Volatility

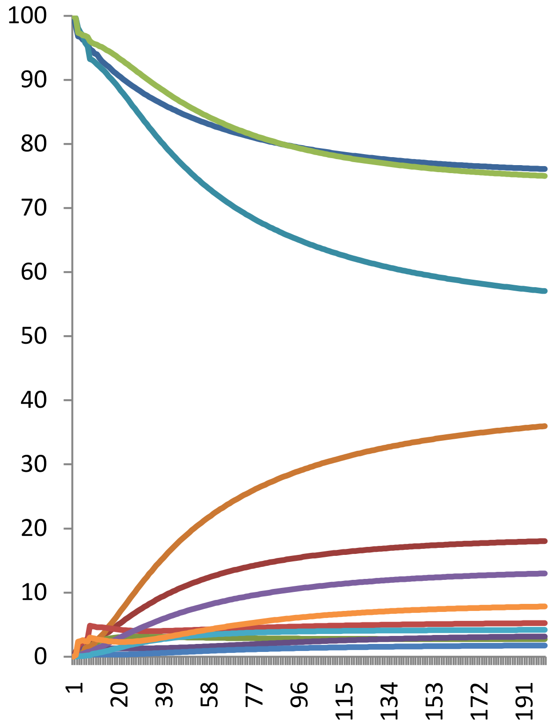


Plot 4
Interest Rate Differential

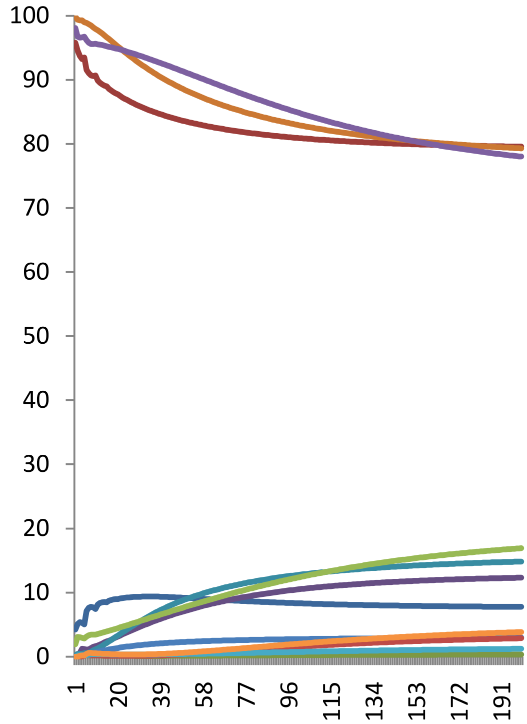


Relative Spread

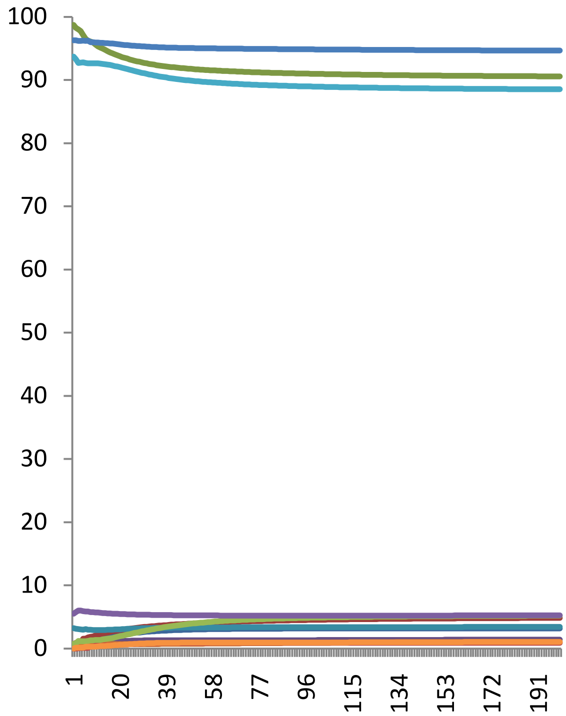
Plot 5
Number of Quote Revisions



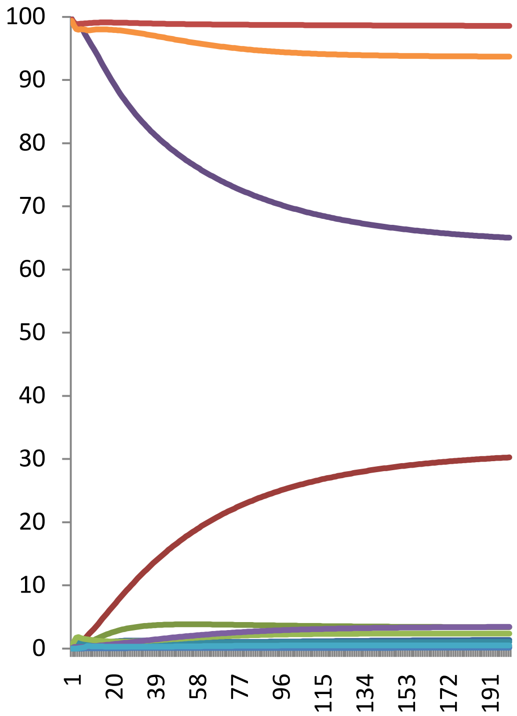
Plot 6
Relative Spread



Plot 7
Volatility



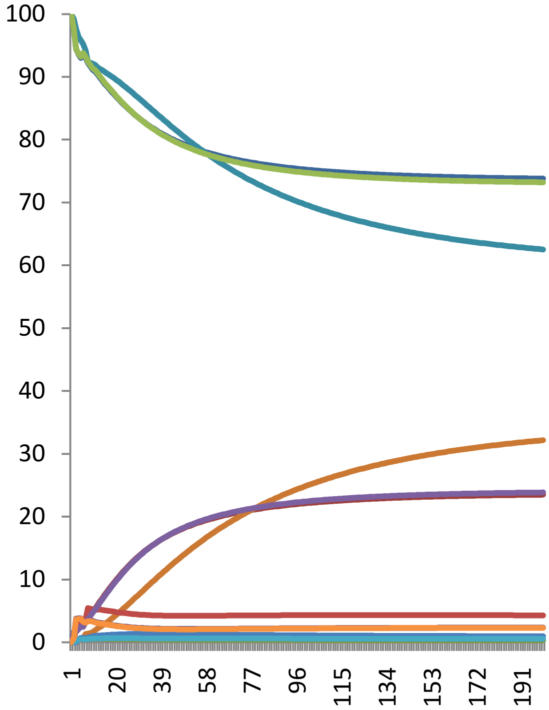
Plot 8
Interest Rate Differential



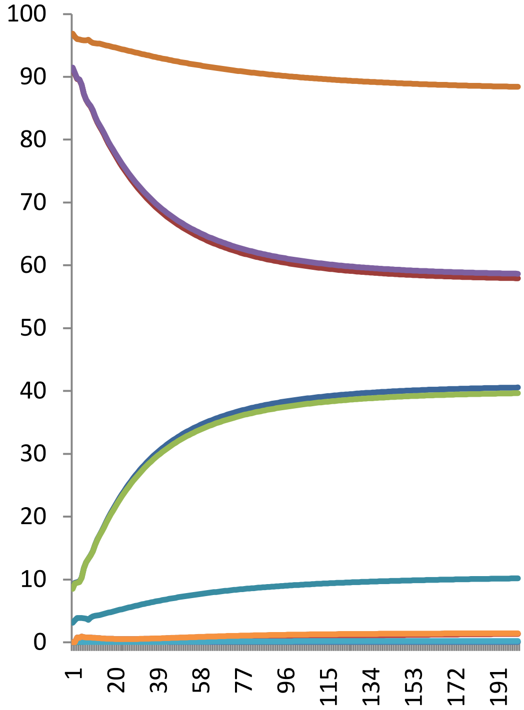
Panel 8.23: Variance Decompositions, GB/US (US, UK, ASIA time zones)

Quoted Spread

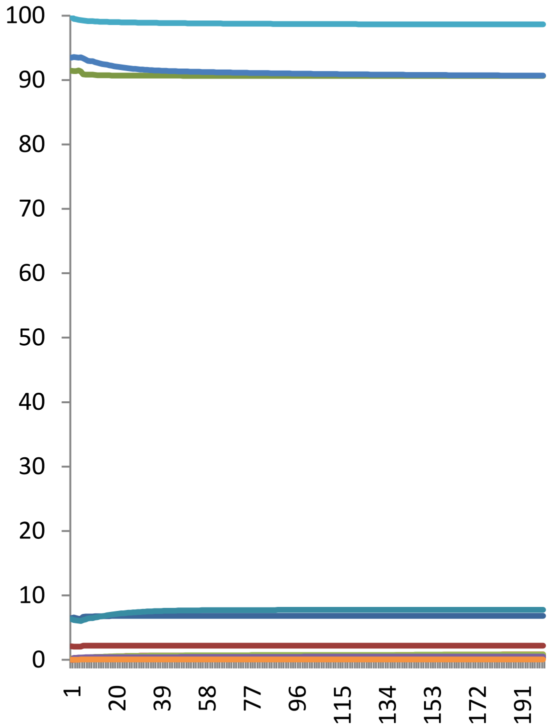
Plot 1
Number of Quote Revisions



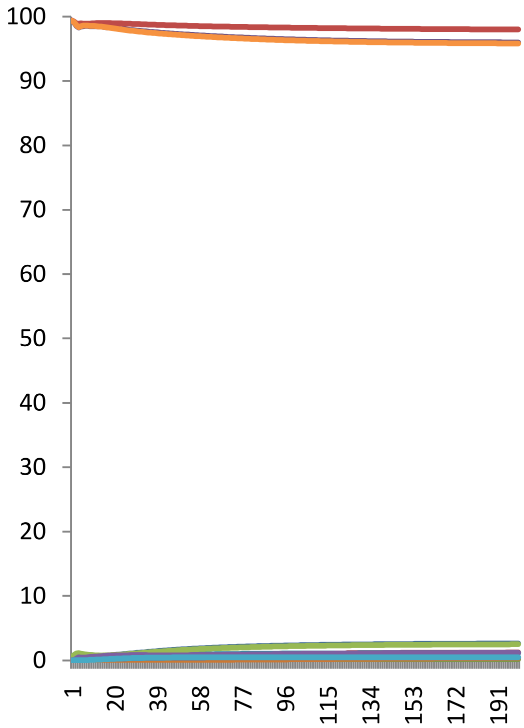
Plot 2
Quoted Spread



Plot 3
Volatility

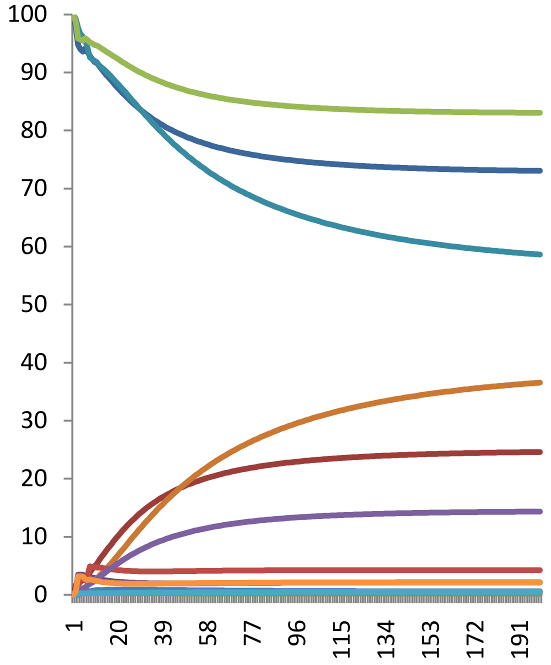


Plot 4
Interest Rate Differential

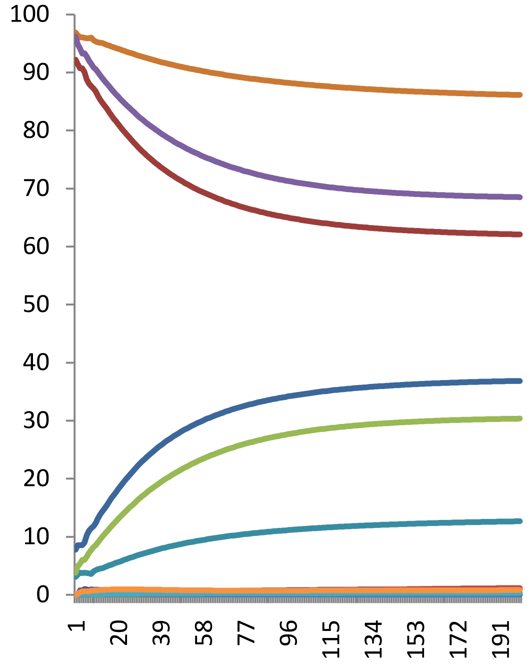


Relative Spread

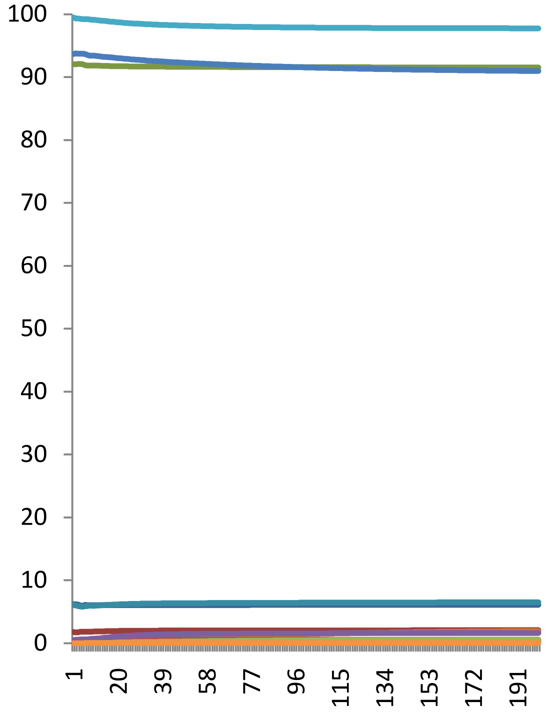
Plot 5
Number of Quote Revisions



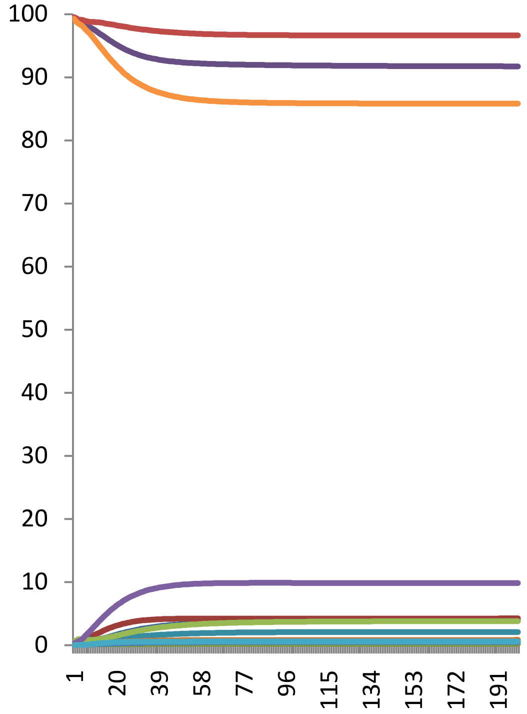
Plot 6
Relative Spread



Plot 7
Volatility



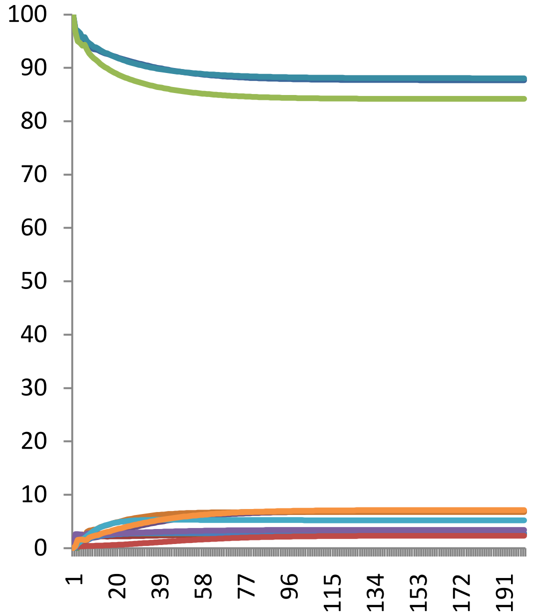
Plot 8
Interest Rate Differential



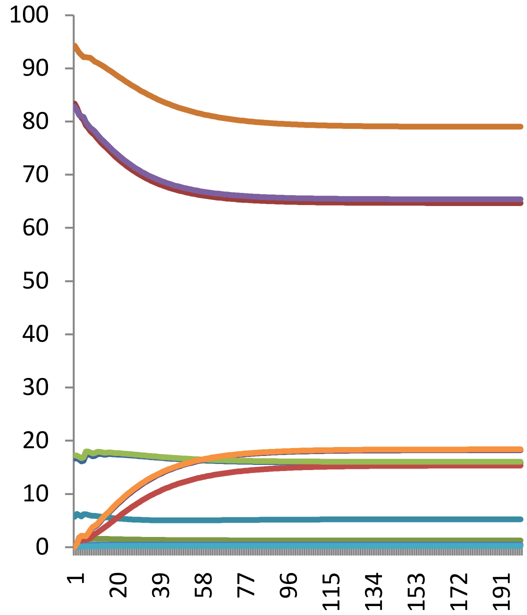
Panel 8.24: Variance Decompositions, EU/US (US, UK, ASIA time zones)

Quoted Spread

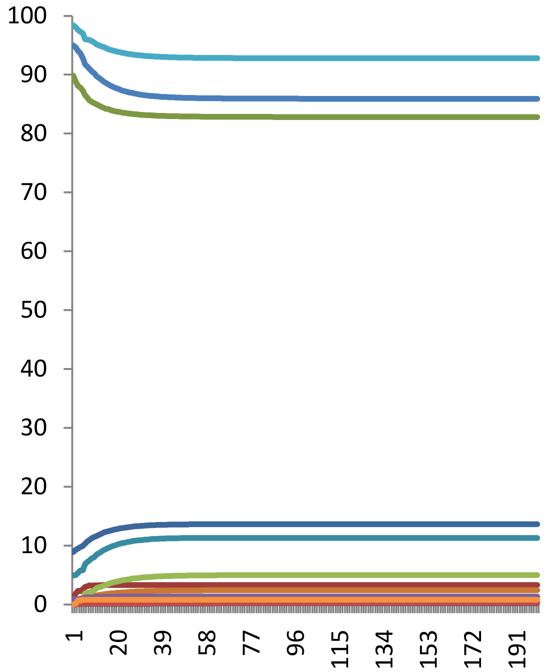
Plot 1
Number of Quote Revisions



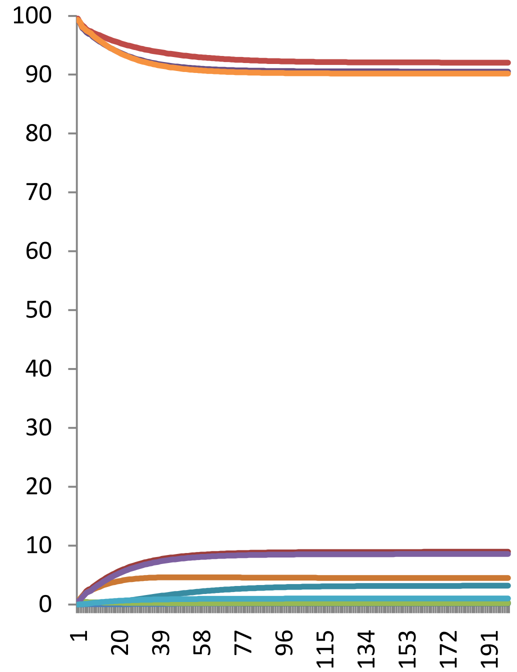
Plot 2
Quoted Spread



Plot 4
Volatility

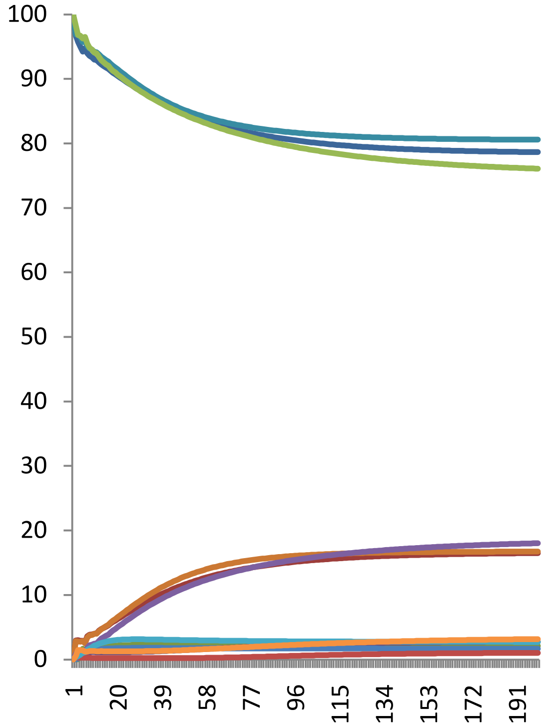


Plot 5
Interest Rate Differential

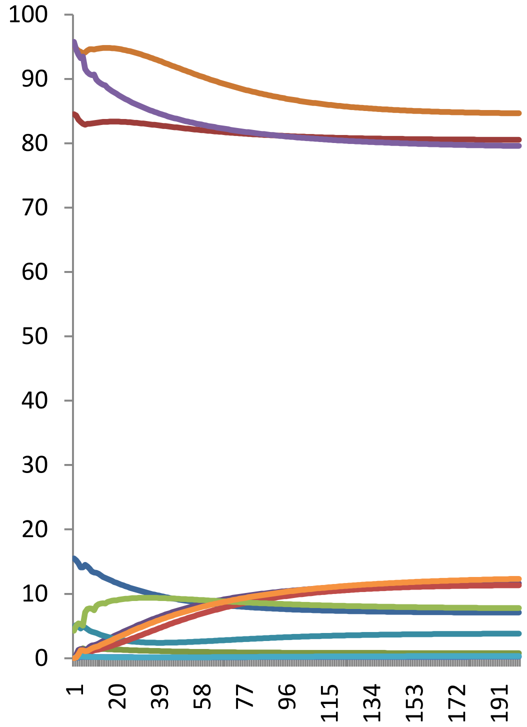


Relative Spread

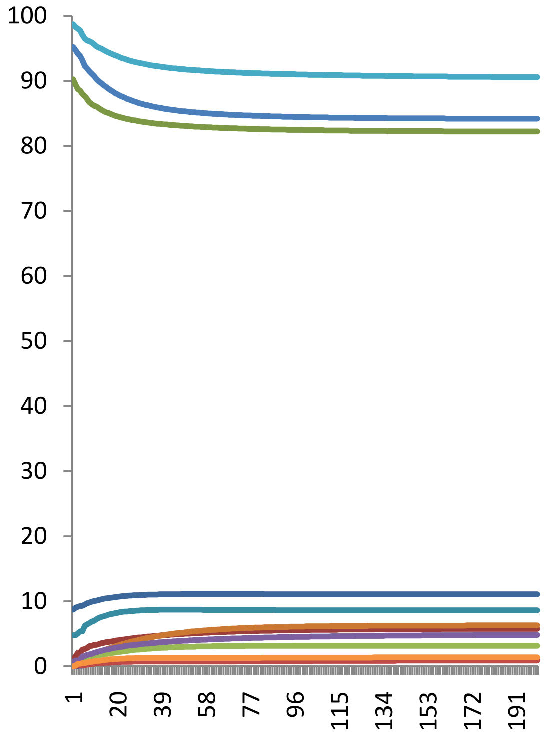
Plot 5
Number of Quote Revisions



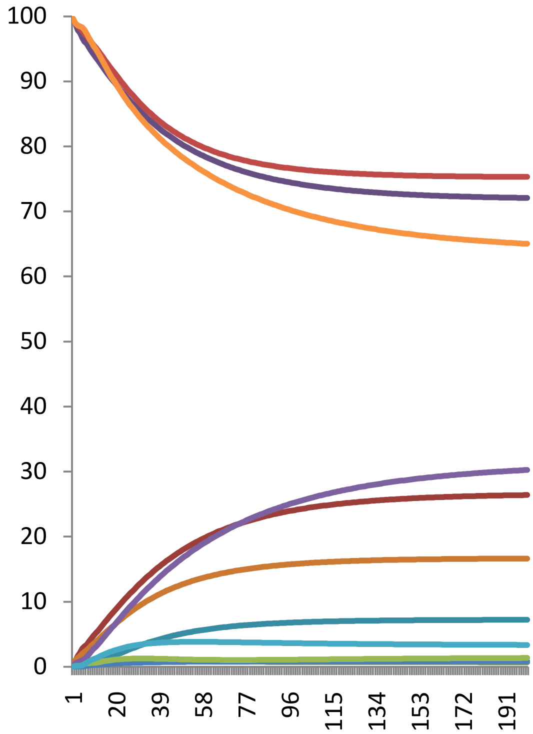
Plot 6
Relative Spread



Plot 7
Volatility



Plot 8
Interest Rate Differential



Panels 8.25 to 8.33: Standardised Impulse Response Functions, Intraday Sample

Note to Panels 8.25-8.33: The impulse response functions in this panel illustrate the reaction of the variables listed in the columns of the tables to a shock in the variable identified at the head of each table. These have been estimated using the VAR described in Section 8.6 The VAR is applied on our full intraday sample. Variables used in the VAR; The number of quote revisions recorded in 5-minute intervals, between 8:00am and 5:00pm local time; The quoted spread based on the last recorded bid and ask quotes at 5-minute intervals, between 8:00am and 5pm local time. The relative spreads based on the difference of the logarithm of the ask price and the logarithm of the bid price recorded at 5-minute intervals, between 8:00am and 5:00pm local time. *Volatility*: the squared result of the log of the exchange rate at time t+1 minus log of the exchange rate at time t, in 5-minute intervals; Interest rate differential (IRD) between Eurodollar overnight deposit rates (short) and Eurodollar one month deposit rate (long). The column headed *p* refers to the number of periods (one period: 5 minute interval) following the shock.

Panel 8.25

Standardized Impulse Response Functions

US Time Zone:JP/US

Table 1: Number of Quote Revisions

	NQR	Q. Spread	Volatility	IRD
1	1.0000	0.0000	0.0000	0.0000
2	0.4808	-0.0254	0.0359	-0.0029
3	0.3760	-0.0211	0.0391	-0.0013
4	0.3372	-0.0226	0.0375	0.0002
5	0.3171	-0.0237	0.0376	-0.0008
6	0.2916	-0.0245	0.0329	0.0009
7	0.2795	-0.0246	0.0320	0.0009
8	0.2597	-0.0279	0.0307	-0.0004
9	0.2499	-0.0316	0.0281	-0.0025
10	0.2368	-0.0341	0.0255	-0.0005
40	0.0915	-0.0334	0.0085	-0.0020

Table 2: Quoted Spread

	NQR	Q. Spread	Volatility	IRD
1	-0.0349	0.9994	0.0000	0.0000
2	-0.0297	0.1446	0.0047	-0.0007
3	-0.0276	0.1313	0.0050	0.0022
4	-0.0290	0.1208	0.0082	-0.0013
5	-0.0269	0.1200	0.0074	0.0006
6	-0.0251	0.1119	0.0066	-0.0013
7	-0.0289	0.1192	0.0089	-0.0027
8	-0.0291	0.1142	0.0062	-0.0020
9	-0.0340	0.1192	0.0061	-0.0023
10	-0.0350	0.1211	0.0065	-0.0032
40	-0.0369	0.0241	-0.0025	-0.0013

Table 3: Volatility

	NQR	Q. Spread	Volatility	IRD
1	0.1027	0.1027	0.9947	0.0000
2	-0.0075	-0.0075	0.0272	-0.0006
3	0.0027	0.0027	0.0039	-0.0002
4	-0.0026	-0.0026	0.0038	-0.0002
5	-0.0049	-0.0049	0.0073	-0.0003
6	-0.0063	-0.0063	0.0032	0.0000
7	-0.0056	-0.0056	0.0037	-0.0005
8	-0.0063	-0.0063	0.0024	0.0000
9	-0.0052	-0.0052	0.0017	0.0000
10	-0.0062	-0.0062	0.0021	0.0000
40	-0.0026	-0.0026	-0.0003	-0.0002

Table 4: Interest Rate Differential

	NQR	Q. Spread	Volatility	IRD
1	-0.0018	0.0016	0.0154	0.9999
2	0.0016	0.0010	0.0105	0.7068
3	-0.0006	0.0005	0.0088	0.5769
4	-0.0009	0.0011	0.0077	0.4994
5	0.0000	0.0015	0.0067	0.4465
6	-0.0015	0.0019	0.0063	0.4074
7	-0.0008	0.0010	0.0057	0.3771
8	-0.0005	0.0003	0.0053	0.3526
9	-0.0002	0.0004	0.0049	0.3323
10	-0.0004	0.0002	0.0047	0.3151
40	-0.0016	-0.0006	0.0021	0.1536

Table 5: Numbner of Quote Revisions

	NQR	R. Spread	Volatility	IRD
1	1.0000	0.0000	0.0000	0.0000
2	0.4807	-0.0248	0.0358	-0.0028
3	0.3758	-0.0204	0.0391	-0.0012
4	0.3370	-0.0218	0.0374	0.0003
5	0.3169	-0.0228	0.0375	-0.0006
6	0.2913	-0.0237	0.0328	0.0010
7	0.2793	-0.0239	0.0319	0.0011
8	0.2594	-0.0273	0.0306	-0.0002
9	0.2495	-0.0311	0.0280	-0.0023
10	0.2364	-0.0332	0.0254	-0.0003
40	0.0903	-0.0365	0.0083	-0.0016

Table 6: Relative Spread

	NQR	R. Spread	Volatility	IRD
1	-0.0353	0.9994	0.0000	0.0000
2	-0.0293	0.1513	0.0047	-0.0003
3	-0.0270	0.1370	0.0049	0.0026
4	-0.0283	0.1273	0.0078	-0.0011
5	-0.0263	0.1283	0.0073	0.0012
6	-0.0246	0.1197	0.0060	-0.0010
7	-0.0281	0.1284	0.0082	-0.0023
8	-0.0281	0.1246	0.0060	-0.0016
9	-0.0328	0.1314	0.0055	-0.0018
10	-0.0337	0.1341	0.0061	-0.0030
40	-0.0374	0.0328	-0.0021	0.0005

Table 7:Volatility

	NQR	R. Spread	Volatility	IRD
1	0.1027	0.0070	0.9947	0.0000
2	-0.0076	-0.0034	0.0272	-0.0005
3	0.0026	-0.0026	0.0039	-0.0001
4	-0.0026	-0.0013	0.0038	-0.0002
5	-0.0050	-0.0011	0.0073	-0.0003
6	-0.0064	-0.0035	0.0032	0.0000
7	-0.0057	0.0001	0.0036	-0.0005
8	-0.0064	-0.0003	0.0024	0.0000
9	-0.0053	-0.0005	0.0017	0.0000
10	-0.0064	-0.0002	0.0021	0.0000
40	-0.0026	0.0007	-0.0003	-0.0002

Table 8: Interest Rate Differential

	NQR	R. Spread	Volatility	IRD
1	-0.0017	0.0023	0.0154	0.9999
2	0.0017	0.0016	0.0105	0.7068
3	-0.0005	0.0013	0.0088	0.5769
4	-0.0007	0.0022	0.0077	0.4994
5	0.0002	0.0028	0.0067	0.4465
6	-0.0013	0.0032	0.0063	0.4074
7	-0.0006	0.0023	0.0057	0.3771
8	-0.0003	0.0016	0.0053	0.3526
9	0.0001	0.0018	0.0049	0.3323
10	-0.0001	0.0017	0.0047	0.3151
40	-0.0013	0.0011	0.0021	0.1536

Panel 8.26

Standardized Impulse Response Functions

US Time Zone:GB/US

Table 1: Number of Quote Revisions

p	NQR	Q. Spread	Volatility	IRD
1	1.0000	0.0000	0.0000	0.0000
2	0.4941	-0.0266	0.0473	-0.0069
3	0.3957	-0.0248	0.0449	-0.0031
4	0.3534	-0.0218	0.0423	-0.0033
5	0.3311	-0.0242	0.0403	-0.0033
6	0.3034	-0.0248	0.0377	-0.0031
7	0.2909	-0.0258	0.0379	-0.0021
8	0.2679	-0.0298	0.0338	-0.0033
9	0.2577	-0.0304	0.0315	-0.0035
10	0.2400	-0.0351	0.0298	-0.0019
40	0.0907	-0.0338	0.0118	-0.0024

Table 2: Quoted Spread

p	NQR	Q. Spread	Volatility	IRD
1	-0.0192	0.9998	0.0000	0.0000
2	-0.0267	0.1623	-0.0016	0.0042
3	-0.0254	0.1380	-0.0050	0.0032
4	-0.0251	0.1282	-0.0055	0.0000
5	-0.0264	0.1227	-0.0067	0.0048
6	-0.0247	0.1147	0.0000	0.0025
7	-0.0253	0.1199	-0.0038	0.0020
8	-0.0310	0.1168	-0.0027	0.0011
9	-0.0305	0.1226	-0.0052	0.0033
10	-0.0319	0.1281	-0.0013	0.0010
40	-0.0418	0.0276	-0.0052	0.0023

Table 3: Volatility

p	NQR	Q. Spread	Volatility	IRD
1	0.1470	-0.0039	0.9891	0.0000
2	-0.0054	-0.0028	0.0317	-0.0008
3	-0.0045	0.0006	0.0232	-0.0001
4	-0.0049	0.0023	0.0227	0.0000
5	-0.0028	0.0013	0.0213	0.0000
6	-0.0053	-0.0015	0.0214	-0.0007
7	-0.0041	0.0008	0.0247	-0.0012
8	-0.0046	-0.0041	0.0213	-0.0009
9	-0.0060	0.0018	0.0214	-0.0007
10	-0.0060	-0.0025	0.0209	-0.0005
40	-0.0028	0.0008	-0.0004	-0.0006

Table 4: Interest Rate Differential

p	NQR	Q. Spread	Volatility	IRD
1	-0.0043	0.0014	0.0151	0.9999
2	0.0000	0.0017	0.0099	0.7068
3	0.0005	0.0007	0.0077	0.5769
4	0.0011	0.0011	0.0064	0.4994
5	0.0017	0.0006	0.0055	0.4465
6	0.0015	-0.0007	0.0050	0.4074
7	0.0005	-0.0003	0.0045	0.3771
8	0.0002	0.0003	0.0043	0.3526
9	0.0000	0.0000	0.0040	0.3323
10	0.0005	0.0001	0.0037	0.3151
40	-0.0002	0.0002	0.0018	0.1557

Table 5: Numbner of Quote Revisions

p	NQR	R. Spread	Volatility	IRD
1	1.0000	0.0000	0.0000	0.0000
2	0.4940	-0.0268	0.0472	-0.0070
3	0.3956	-0.0249	0.0448	-0.0033
4	0.3533	-0.0219	0.0421	-0.0035
5	0.3310	-0.0244	0.0401	-0.0035
6	0.3033	-0.0252	0.0374	-0.0033
7	0.2907	-0.0261	0.0376	-0.0023
8	0.2678	-0.0300	0.0335	-0.0035
9	0.2575	-0.0307	0.0311	-0.0038
10	0.2398	-0.0354	0.0294	-0.0022
40	0.0903	-0.0349	0.0118	-0.0029

Table 6: Relative Spread

p	NQR	R. Spread	Volatility	IRD
1	-0.0205	0.9998	0.0000	0.0000
2	-0.0274	0.1604	-0.0019	0.0036
3	-0.0259	0.1375	-0.0057	0.0026
4	-0.0255	0.1281	-0.0061	-0.0004
5	-0.0269	0.1238	-0.0075	0.0043
6	-0.0250	0.1157	-0.0013	0.0019
7	-0.0256	0.1210	-0.0046	0.0013
8	-0.0312	0.1191	-0.0035	0.0006
9	-0.0306	0.1254	-0.0061	0.0026
10	-0.0320	0.1315	-0.0023	0.0003
40	-0.0419	0.0298	-0.0054	0.0001

Table 7:Volatility

p	NQR	R. Spread	Volatility	IRD
1	0.1468	-0.0042	0.9892	0.0000
2	-0.0055	-0.0031	0.0316	-0.0008
3	-0.0047	0.0002	0.0232	-0.0001
4	-0.0050	0.0017	0.0226	0.0000
5	-0.0030	0.0008	0.0213	-0.0001
6	-0.0054	-0.0022	0.0214	-0.0007
7	-0.0043	0.0002	0.0247	-0.0012
8	-0.0048	-0.0049	0.0213	-0.0009
9	-0.0062	0.0007	0.0214	-0.0007
10	-0.0062	-0.0035	0.0209	-0.0005
40	-0.0028	0.0006	-0.0004	-0.0006

Table 8: Interest Rate Differential

p	NQR	R. Spread	Volatility	IRD
1	-0.0044	0.0009	0.0151	0.9999
2	-0.0002	0.0010	0.0099	0.7068
3	0.0003	-0.0001	0.0077	0.5769
4	0.0009	0.0002	0.0064	0.4994
5	0.0014	-0.0004	0.0055	0.4465
6	0.0012	-0.0020	0.0050	0.4075
7	0.0002	-0.0016	0.0045	0.3771
8	-0.0001	-0.0011	0.0043	0.3526
9	-0.0003	-0.0015	0.0040	0.3323
10	0.0001	-0.0016	0.0037	0.3151
40	-0.0007	-0.0019	0.0017	0.1536

Panel 8.27

Standardized Impulse Response Functions

US Time Zone:EU/US

	Table 1: Number of Quote Revisions				Table 2: Quoted Spread				Table 3: Volatility				Table 4: Interest Rate Differential			
p	NQR	Q. Spread	Volatility	IRD	NQR	Q. Spread	Volatility	IRD	NQR	Q. Spread	Volatility	IRD	NQR	Q. Spread	Volatility	IRD
1	1.0000	0.0000	0.0000	0.0000	-0.0725	0.9974	0.0000	0.0000	0.2129	-0.0060	0.9771	0.0000	-0.0020	-0.0022	0.0041	1.0000
2	0.4996	-0.0252	0.0706	0.0013	-0.0507	0.0779	-0.0108	-0.0033	0.0088	0.0116	0.0028	-0.0001	0.0015	-0.0057	0.0022	0.7070
3	0.4041	-0.0160	0.0708	0.0027	-0.0495	0.0732	-0.0071	-0.0022	0.0063	0.0032	-0.0019	0.0010	0.0006	-0.0052	0.0021	0.5772
4	0.3603	-0.0171	0.0679	0.0021	-0.0477	0.0701	-0.0163	-0.0014	0.0108	0.0003	-0.0038	-0.0003	0.0014	-0.0075	0.0017	0.4998
5	0.3378	-0.0164	0.0623	0.0029	-0.0474	0.0701	-0.0076	-0.0007	0.0017	0.0066	-0.0008	0.0002	0.0008	-0.0093	0.0016	0.4469
6	0.3063	-0.0157	0.0603	0.0032	-0.0431	0.0725	-0.0085	0.0026	-0.0031	-0.0021	-0.0015	0.0002	0.0013	-0.0071	0.0014	0.4079
7	0.2950	-0.0166	0.0631	0.0025	-0.0463	0.0695	-0.0109	-0.0001	0.0067	0.0061	0.0040	-0.0047	0.0011	-0.0058	0.0014	0.3776
8	0.2703	-0.0125	0.0566	0.0016	-0.0443	0.0673	-0.0087	-0.0052	-0.0029	0.0054	0.0002	-0.0006	-0.0002	-0.0058	0.0015	0.3532
9	0.2535	-0.0104	0.0515	0.0022	-0.0409	0.0681	-0.0115	0.0012	-0.0111	0.0044	0.0023	-0.0005	-0.0008	-0.0063	0.0015	0.3329
10	0.2342	-0.0110	0.0499	0.0019	-0.0458	0.0738	-0.0138	-0.0030	-0.0091	0.0056	0.0006	0.0002	0.0016	-0.0067	0.0009	0.3158
40	0.0623	-0.0028	0.0133	0.0061	-0.0165	0.0020	-0.0036	-0.0048	-0.0032	0.0002	-0.0007	-0.0005	0.0045	-0.0042	0.0013	0.1565

	Table 5: Numbner of Quote Revisions				Table 6: Relative Spread				Table 7:Volatility				Table 8: Interest Rate Differential			
p	NQR	R. Spread	Volatility	IRD	NQR	R. Spread	Volatility	IRD	NQR	R. Spread	Volatility	IRD	NQR	R. Spread	Volatility	IRD
1	1.0000	0.0000	0.0000	0.0000	-0.0769	0.9970	0.0000	0.0000	0.2129	-0.0075	0.9770	0.0000	-0.0022	-0.0023	0.0041	1.0000
2	0.4991	-0.0296	0.0708	0.0011	-0.0558	0.0877	-0.0118	-0.0039	0.0088	0.0088	0.0030	-0.0002	0.0012	-0.0063	0.0023	0.7070
3	0.4035	-0.0210	0.0710	0.0025	-0.0537	0.0862	-0.0081	-0.0029	0.0062	0.0008	-0.0017	0.0010	0.0003	-0.0062	0.0021	0.5772
4	0.3595	-0.0235	0.0682	0.0018	-0.0521	0.0846	-0.0177	-0.0019	0.0107	-0.0025	-0.0036	-0.0003	0.0010	-0.0086	0.0017	0.4997
5	0.3369	-0.0240	0.0627	0.0025	-0.0521	0.0850	-0.0089	-0.0010	0.0016	0.0037	-0.0006	0.0002	0.0004	-0.0108	0.0017	0.4469
6	0.3053	-0.0245	0.0608	0.0028	-0.0491	0.0899	-0.0107	0.0026	-0.0032	-0.0051	-0.0014	0.0002	0.0009	-0.0088	0.0015	0.4079
7	0.2939	-0.0270	0.0637	0.0021	-0.0517	0.0873	-0.0125	-0.0005	0.0066	0.0032	0.0042	-0.0048	0.0006	-0.0079	0.0015	0.3775
8	0.2691	-0.0239	0.0572	0.0012	-0.0498	0.0874	-0.0107	-0.0054	-0.0030	0.0031	0.0003	-0.0006	-0.0007	-0.0080	0.0016	0.3531
9	0.2521	-0.0236	0.0522	0.0017	-0.0464	0.0911	-0.0124	0.0005	-0.0112	0.0006	0.0024	-0.0005	-0.0013	-0.0089	0.0016	0.3328
10	0.2327	-0.0258	0.0506	0.0014	-0.0532	0.0992	-0.0148	-0.0040	-0.0091	0.0023	0.0007	0.0002	0.0010	-0.0095	0.0010	0.3157
40	0.0618	-0.0127	0.0136	0.0056	-0.0234	0.0089	-0.0052	-0.0082	-0.0032	0.0007	-0.0007	-0.0004	0.0040	-0.0078	0.0013	0.1564

Panel 8.28

Standardized Impulse Response Functions

UK Time Zone:JP/US

	Table 1: Number of Quote Revisions				Table 2: Quoted Spread				Table 3: Volatility				Table 4: Interest Rate Differential			
	NQR	Q. Spread	Volatility	IRD	NQR	Q. Spread	Volatility	IRD	NQR	Q. Spread	Volatility	IRD	NQR	Q. Spread	Volatility	IRD
1	1.0000	0.0000	0.0000	0.0000	-0.0062	1.0000	0.0000	0.0000	0.0594	0.0073	0.9982	0.0000	-0.0031	-0.0003	-0.0084	1.0000
2	0.4153	-0.0209	0.0193	-0.0015	-0.0146	0.0842	0.0089	0.0032	-0.0098	0.0032	0.0213	0.0002	-0.0046	0.0001	-0.0059	0.7068
3	0.2808	-0.0168	0.0197	-0.0019	-0.0170	0.0901	0.0048	0.0019	-0.0098	0.0071	0.0212	-0.0008	-0.0056	-0.0006	-0.0046	0.5769
4	0.2411	-0.0204	0.0171	-0.0028	-0.0207	0.0894	0.0024	0.0036	-0.0075	-0.0017	0.0136	-0.0001	-0.0034	-0.0016	-0.0041	0.4994
5	0.2234	-0.0198	0.0154	-0.0049	-0.0189	0.0919	0.0057	-0.0009	-0.0008	0.0078	0.0211	0.0005	-0.0017	-0.0001	-0.0038	0.4465
6	0.2075	-0.0256	0.0143	-0.0031	-0.0219	0.0891	0.0123	0.0000	-0.0077	0.0048	0.0092	-0.0002	-0.0018	0.0008	-0.0035	0.4075
7	0.2065	-0.0260	0.0144	-0.0009	-0.0235	0.1042	0.0105	-0.0013	-0.0044	0.0101	0.0130	0.0000	-0.0013	0.0002	-0.0032	0.3771
8	0.1973	-0.0296	0.0101	-0.0034	-0.0250	0.0940	0.0099	-0.0010	-0.0046	0.0071	0.0077	0.0001	-0.0006	0.0006	-0.0031	0.3526
9	0.1996	-0.0350	0.0084	-0.0037	-0.0264	0.1053	0.0092	0.0005	0.0028	0.0033	0.0102	0.0002	-0.0002	-0.0003	-0.0029	0.3323
10	0.2018	-0.0388	0.0071	-0.0009	-0.0334	0.1095	0.0097	-0.0024	0.0016	0.0065	0.0054	-0.0001	-0.0003	-0.0005	-0.0028	0.3152
40	0.1117	-0.0371	0.0024	-0.0020	-0.0418	0.0217	0.0000	0.0002	-0.0014	0.0010	0.0000	-0.0002	-0.0013	0.0000	-0.0014	0.1536

	Table 5: Numbner of Quote Revisions				Table 6: Relative Spread				Table 7:Volatility				Table 8: Interest Rate Differential			
	NQR	R. Spread	Volatility	IRD	NQR	R. Spread	Volatility	IRD	NQR	R. Spread	Volatility	IRD	NQR	R. Spread	Volatility	IRD
1	1.0000	0.0000	0.0000	0.0000	-0.0073	1.0000	0.0000	0.0000	0.0593	0.0068	0.9982	0.0000	-0.0031	-0.0003	-0.0085	1.0000
2	0.4151	-0.0210	0.0192	-0.0014	-0.0150	0.0874	0.0084	0.0038	-0.0099	0.0031	0.0214	0.0002	-0.0045	0.0003	-0.0059	0.7068
3	0.2804	-0.0169	0.0196	-0.0018	-0.0178	0.0927	0.0046	0.0025	-0.0099	0.0068	0.0213	-0.0008	-0.0054	-0.0004	-0.0047	0.5769
4	0.2406	-0.0206	0.0170	-0.0027	-0.0215	0.0926	0.0017	0.0041	-0.0076	-0.0017	0.0137	-0.0001	-0.0032	-0.0012	-0.0042	0.4994
5	0.2229	-0.0199	0.0153	-0.0048	-0.0195	0.0977	0.0049	-0.0004	-0.0009	0.0070	0.0212	0.0004	-0.0015	0.0004	-0.0038	0.4465
6	0.2069	-0.0257	0.0142	-0.0030	-0.0229	0.0939	0.0116	0.0001	-0.0078	0.0042	0.0092	-0.0002	-0.0016	0.0014	-0.0035	0.4075
7	0.2059	-0.0259	0.0144	-0.0007	-0.0240	0.1096	0.0097	-0.0010	-0.0045	0.0090	0.0130	0.0000	-0.0010	0.0009	-0.0032	0.3771
8	0.1966	-0.0300	0.0101	-0.0032	-0.0256	0.1011	0.0088	-0.0007	-0.0047	0.0058	0.0078	0.0001	-0.0003	0.0014	-0.0032	0.3526
9	0.1988	-0.0357	0.0083	-0.0035	-0.0272	0.1127	0.0082	0.0009	0.0027	0.0023	0.0103	0.0002	0.0001	0.0006	-0.0030	0.3323
10	0.2008	-0.0393	0.0071	-0.0008	-0.0342	0.1165	0.0093	-0.0023	0.0015	0.0055	0.0055	-0.0001	0.0001	0.0006	-0.0029	0.3152
40	0.1104	-0.0400	0.0024	-0.0016	-0.0444	0.0266	0.0001	0.0018	-0.0013	0.0011	0.0000	-0.0002	-0.0009	0.0012	-0.0014	0.1536

Panel 8.29

Standardized Impulse Response Functions

UK Time Zone:GB/US

	Table 1: Number of Quote Revisions				Table 2: Quoted Spread				Table 3: Volatility				Table 4: Interest Rate Differential			
p	NQR	Q. Spread	Volatility	IRD	NQR	Q. Spread	Volatility	IRD	NQR	Q. Spread	Volatility	IRD	NQR	Q. Spread	Volatility	IRD
1	1.0000	0.0000	0.0000	0.0000	0.0076	1.0000	0.0000	0.0000	0.0826	0.0081	0.9965	0.0000	0.0041	-0.0008	-0.0067	1.0000
2	0.4097	-0.0165	0.0267	0.0018	-0.0071	0.1006	0.0025	0.0007	-0.0058	0.0096	0.0288	0.0000	0.0054	-0.0009	-0.0053	0.7068
3	0.2769	-0.0211	0.0174	0.0009	-0.0082	0.1018	0.0032	0.0022	-0.0079	0.0020	0.0172	0.0000	0.0041	-0.0005	-0.0043	0.5769
4	0.2347	-0.0188	0.0162	0.0020	-0.0080	0.1015	0.0038	0.0002	-0.0034	0.0111	0.0141	0.0009	0.0052	-0.0019	-0.0040	0.4994
5	0.2255	-0.0225	0.0124	0.0031	-0.0093	0.1031	0.0075	0.0029	-0.0005	0.0018	0.0099	0.0007	0.0073	-0.0018	-0.0041	0.4465
6	0.2083	-0.0228	0.0122	0.0038	-0.0108	0.1017	0.0025	0.0002	-0.0034	0.0039	0.0101	-0.0003	0.0059	-0.0012	-0.0040	0.4074
7	0.2080	-0.0201	0.0101	0.0025	-0.0136	0.1139	0.0038	-0.0021	-0.0068	0.0032	0.0098	-0.0003	0.0066	-0.0009	-0.0039	0.3771
8	0.1986	-0.0268	0.0071	-0.0004	-0.0140	0.1116	0.0040	0.0001	-0.0020	0.0037	0.0074	0.0006	0.0063	-0.0013	-0.0037	0.3526
9	0.2050	-0.0289	0.0039	0.0017	-0.0206	0.1236	0.0041	0.0021	0.0015	0.0025	0.0070	0.0001	0.0073	-0.0004	-0.0037	0.3323
10	0.2044	-0.0333	0.0028	0.0003	-0.0212	0.1301	0.0034	0.0037	0.0015	0.0050	0.0059	-0.0006	0.0053	-0.0007	-0.0033	0.3151
40	0.1112	-0.0373	0.0021	0.0001	-0.0386	0.0302	-0.0001	0.0022	0.0005	0.0007	0.0000	-0.0006	0.0012	0.0003	-0.0017	0.1536

	Table 5: Numbner of Quote Revisions				Table 6: Relative Spread				Table 7:Volatility				Table 8: Interest Rate Differential			
p	NQR	R. Spread	Volatility	IRD	NQR	R. Spread	Volatility	IRD	NQR	R. Spread	Volatility	IRD	NQR	R. Spread	Volatility	IRD
1	1.0000	0.0000	0.0000	0.0000	0.0059	1.0000	0.0000	0.0000	0.0825	0.0075	0.9966	0.0000	0.0040	-0.0012	-0.0067	1.0000
2	0.4094	-0.0176	0.0266	0.0016	-0.0086	0.0977	0.0022	0.0003	-0.0060	0.0090	0.0289	0.0001	0.0052	-0.0015	-0.0052	0.7068
3	0.2764	-0.0226	0.0172	0.0007	-0.0098	0.0983	0.0028	0.0017	-0.0081	0.0014	0.0173	0.0001	0.0039	-0.0012	-0.0043	0.5769
4	0.2341	-0.0205	0.0161	0.0018	-0.0097	0.0980	0.0030	-0.0001	-0.0036	0.0101	0.0142	0.0009	0.0049	-0.0027	-0.0039	0.4994
5	0.2248	-0.0245	0.0122	0.0029	-0.0112	0.0994	0.0069	0.0023	-0.0007	0.0009	0.0101	0.0007	0.0070	-0.0027	-0.0040	0.4465
6	0.2076	-0.0251	0.0120	0.0036	-0.0127	0.0974	0.0018	-0.0002	-0.0036	0.0032	0.0102	-0.0002	0.0055	-0.0023	-0.0039	0.4074
7	0.2072	-0.0228	0.0099	0.0023	-0.0157	0.1094	0.0030	-0.0027	-0.0070	0.0024	0.0100	-0.0002	0.0062	-0.0021	-0.0038	0.3771
8	0.1977	-0.0297	0.0069	-0.0006	-0.0164	0.1072	0.0034	-0.0005	-0.0023	0.0029	0.0075	0.0006	0.0059	-0.0027	-0.0036	0.3525
9	0.2040	-0.0321	0.0037	0.0015	-0.0233	0.1182	0.0034	0.0014	0.0012	0.0014	0.0072	0.0001	0.0068	-0.0019	-0.0035	0.3323
10	0.2033	-0.0369	0.0026	0.0001	-0.0244	0.1238	0.0026	0.0029	0.0012	0.0040	0.0060	-0.0005	0.0047	-0.0024	-0.0032	0.3151
40	0.1107	-0.0392	0.0021	-0.0004	-0.0410	0.0275	-0.0003	0.0002	0.0004	0.0004	0.0000	-0.0006	0.0006	-0.0018	-0.0017	0.1536

Panel 8.30

Standardized Impulse Response Functions

UK Time Zone:EU/US

	Table 1: Number of Quote Revisions				Table 2: Quoted Spread				Table 3: Volatility				Table 4: Interest Rate Differential			
p	NQR	Q. Spread	Volatility	IRD	NQR	Q. Spread	Volatility	IRD	NQR	Q. Spread	Volatility	IRD	NQR	Q. Spread	Volatility	IRD
1	1.0000	0.0000	0.0000	0.0000	-0.0258	0.9997	0.0000	0.0000	0.0787	-0.0006	0.9969	0.0000	0.0043	-0.0016	-0.0046	0.9999
2	0.4617	-0.0087	0.0184	0.0046	-0.0071	0.0536	-0.0002	-0.0035	0.0091	0.0134	0.0130	-0.0006	0.0048	-0.0026	-0.0037	0.7070
3	0.3330	-0.0006	0.0118	0.0014	-0.0046	0.0553	0.0002	-0.0004	0.0105	0.0074	0.0044	-0.0006	0.0010	-0.0003	-0.0030	0.5772
4	0.2844	-0.0003	0.0119	0.0008	-0.0095	0.0535	0.0005	-0.0052	0.0040	-0.0025	0.0042	-0.0002	-0.0002	-0.0003	-0.0027	0.4998
5	0.2596	-0.0054	0.0079	0.0027	-0.0052	0.0523	0.0025	0.0015	0.0037	0.0043	0.0022	-0.0001	-0.0024	0.0000	-0.0022	0.4470
6	0.2347	-0.0059	0.0067	0.0025	-0.0077	0.0451	0.0026	-0.0038	-0.0005	0.0030	0.0037	-0.0005	-0.0033	-0.0012	-0.0019	0.4080
7	0.2290	-0.0067	0.0043	0.0040	-0.0058	0.0579	0.0003	0.0011	0.0056	-0.0014	0.0051	0.0036	-0.0035	-0.0014	-0.0018	0.3777
8	0.2185	-0.0084	0.0009	0.0017	-0.0117	0.0598	0.0054	-0.0047	0.0015	0.0055	0.0021	-0.0001	-0.0028	-0.0031	-0.0016	0.3532
9	0.2160	-0.0101	-0.0024	0.0002	-0.0132	0.0531	0.0028	-0.0031	0.0033	-0.0018	0.0013	-0.0010	-0.0021	-0.0049	-0.0018	0.3330
10	0.2180	-0.0084	-0.0019	0.0007	-0.0106	0.0603	0.0023	-0.0092	-0.0009	0.0024	0.0015	-0.0001	-0.0019	-0.0046	-0.0015	0.3158
40	0.1075	-0.0065	-0.0009	0.0015	-0.0109	0.0013	0.0001	-0.0045	0.0025	-0.0001	0.0000	-0.0006	-0.0004	-0.0042	-0.0009	0.1567

	Table 5: Numbner of Quote Revisions				Table 6: Relative Spread				Table 7:Volatility				Table 8: Interest Rate Differential			
p	NQR	R. Spread	Volatility	IRD	NQR	R. Spread	Volatility	IRD	NQR	R. Spread	Volatility	IRD	NQR	R. Spread	Volatility	IRD
1	1.0000	0.0000	0.0000	0.0000	-0.0324	0.9995	0.0000	0.0000	0.0789	-0.0010	0.9969	0.0000	0.0042	-0.0025	-0.0046	1.0000
2	0.4615	-0.0132	0.0185	0.0045	-0.0115	0.0694	-0.0010	-0.0041	0.0092	0.0119	0.0130	-0.0005	0.0046	-0.0039	-0.0036	0.7069
3	0.3326	-0.0042	0.0119	0.0012	-0.0079	0.0714	-0.0005	-0.0012	0.0106	0.0078	0.0044	-0.0006	0.0007	-0.0016	-0.0029	0.5771
4	0.2839	-0.0037	0.0121	0.0005	-0.0135	0.0720	0.0003	-0.0059	0.0041	-0.0030	0.0042	-0.0002	-0.0005	-0.0016	-0.0027	0.4997
5	0.2590	-0.0100	0.0081	0.0024	-0.0097	0.0714	0.0017	0.0011	0.0038	0.0042	0.0022	-0.0001	-0.0028	-0.0014	-0.0021	0.4469
6	0.2340	-0.0114	0.0069	0.0022	-0.0122	0.0669	0.0024	-0.0046	-0.0005	0.0025	0.0037	-0.0005	-0.0037	-0.0029	-0.0018	0.4079
7	0.2283	-0.0124	0.0045	0.0038	-0.0107	0.0814	-0.0003	0.0002	0.0056	-0.0016	0.0051	0.0036	-0.0039	-0.0031	-0.0016	0.3776
8	0.2177	-0.0145	0.0012	0.0014	-0.0168	0.0848	0.0050	-0.0054	0.0015	0.0053	0.0021	-0.0001	-0.0034	-0.0052	-0.0015	0.3532
9	0.2151	-0.0173	-0.0021	-0.0001	-0.0186	0.0808	0.0028	-0.0040	0.0034	-0.0015	0.0013	-0.0010	-0.0027	-0.0073	-0.0016	0.3329
10	0.2170	-0.0165	-0.0015	0.0004	-0.0164	0.0900	0.0025	-0.0107	-0.0008	0.0022	0.0015	-0.0001	-0.0025	-0.0072	-0.0014	0.3158
40	0.1068	-0.0146	-0.0009	0.0010	-0.0196	0.0065	0.0003	-0.0081	0.0024	-0.0002	0.0000	-0.0006	-0.0010	-0.0077	-0.0009	0.1565

Panel 8.31

Standardized Impulse Response Functions

ASIA Time Zone:JP/US

Table 1: Number of Quote Revisions

	NQR	Q. Spread	Volatility	IRD
1	1.0000	0.0000	0.0000	0.0000
2	0.4690	-0.0241	-0.0305	-0.0016
3	0.3668	-0.0215	-0.0334	-0.0001
4	0.3260	-0.0201	-0.0330	-0.0027
5	0.2981	-0.0239	-0.0292	-0.0008
6	0.2739	-0.0311	-0.0267	0.0005
7	0.2588	-0.0337	-0.0229	-0.0012
8	0.2368	-0.0402	-0.0168	-0.0030
9	0.2250	-0.0428	-0.0162	-0.0001
10	0.2126	-0.0467	-0.0131	-0.0005
40	0.0790	-0.0345	-0.0055	-0.0028

Table 2: Quoted Spread

	NQR	Q. Spread	Volatility	IRD
1	-0.0189	0.9998	0.0000	0.0000
2	-0.0182	0.1233	0.0069	0.0031
3	-0.0188	0.1048	0.0042	0.0013
4	-0.0209	0.1046	0.0036	0.0010
5	-0.0264	0.1012	0.0018	0.0030
6	-0.0307	0.0945	0.0058	-0.0005
7	-0.0325	0.1021	0.0068	-0.0012
8	-0.0392	0.0950	0.0050	0.0015
9	-0.0389	0.0968	0.0080	-0.0012
10	-0.0440	0.1092	0.0089	-0.0014
40	-0.0406	0.0220	0.0032	-0.0034

Table 3: Volatility

	NQR	Q. Spread	Volatility	IRD
1	-0.0747	0.0038	0.9972	0.0000
2	0.0042	0.0068	0.0412	-0.0023
3	0.0035	0.0106	0.0278	-0.0015
4	0.0034	0.0061	0.0132	0.0007
5	0.0067	0.0095	0.0074	-0.0004
6	0.0067	0.0095	0.0069	-0.0003
7	0.0079	0.0059	0.0031	0.0002
8	0.0068	0.0116	0.0025	0.0002
9	0.0071	0.0099	0.0029	0.0002
10	0.0044	0.0137	0.0021	0.0001
40	0.0003	0.0004	0.0000	0.0000

Table 4: Interest Rate Differential

	NQR	Q. Spread	Volatility	IRD
1	-0.0005	0.0004	0.0123	0.9999
2	0.0009	-0.0016	0.0086	0.7068
3	-0.0002	-0.0022	0.0069	0.5769
4	-0.0006	-0.0020	0.0060	0.4994
5	-0.0012	-0.0022	0.0053	0.4465
6	-0.0012	-0.0021	0.0049	0.4074
7	-0.0017	-0.0026	0.0046	0.3771
8	-0.0020	-0.0028	0.0043	0.3526
9	-0.0020	-0.0036	0.0041	0.3323
10	-0.0016	-0.0039	0.0038	0.3151
40	-0.0020	-0.0041	0.0018	0.1536

Table 5: Numbner of Quote Revisions

	NQR	R. Spread	Volatility	IRD
1	1.0000	0.0000	0.0000	0.0000
2	0.4687	-0.0234	-0.0305	-0.0014
3	0.3664	-0.0207	-0.0334	0.0001
4	0.3254	-0.0194	-0.0329	-0.0025
5	0.2974	-0.0232	-0.0291	-0.0006
6	0.2731	-0.0305	-0.0266	0.0007
7	0.2580	-0.0331	-0.0228	-0.0010
8	0.2358	-0.0399	-0.0166	-0.0028
9	0.2238	-0.0424	-0.0160	0.0002
10	0.2113	-0.0464	-0.0129	-0.0002
40	0.0772	-0.0396	-0.0055	-0.0024

Table 6: Relative Spread

	NQR	R. Spread	Volatility	IRD
1	-0.0187	0.9998	0.0000	0.0000
2	-0.0172	0.1324	0.0067	0.0038
3	-0.0179	0.1135	0.0042	0.0019
4	-0.0200	0.1133	0.0032	0.0017
5	-0.0254	0.1111	0.0017	0.0036
6	-0.0304	0.1048	0.0054	0.0001
7	-0.0320	0.1127	0.0064	-0.0004
8	-0.0387	0.1081	0.0050	0.0023
9	-0.0381	0.1115	0.0077	-0.0001
10	-0.0428	0.1243	0.0081	-0.0006
40	-0.0429	0.0295	0.0035	-0.0012

Table 7:Volatility

	NQR	R. Spread	Volatility	IRD
1	-0.0747	0.0036	0.9972	0.0000
2	0.0043	0.0061	0.0413	-0.0023
3	0.0036	0.0101	0.0279	-0.0016
4	0.0035	0.0055	0.0132	0.0006
5	0.0068	0.0088	0.0075	-0.0004
6	0.0068	0.0085	0.0069	-0.0003
7	0.0080	0.0053	0.0031	0.0001
8	0.0069	0.0107	0.0025	0.0001
9	0.0072	0.0086	0.0029	0.0002
10	0.0045	0.0126	0.0020	0.0001
40	0.0004	0.0006	0.0000	0.0000

Table 8: Interest Rate Differential

	NQR	R. Spread	Volatility	IRD
1	-0.0004	-0.0004	0.0122	0.9999
2	0.0016	0.0011	0.0085	0.7068
3	0.0001	0.0000	0.0068	0.5769
4	-0.0007	-0.0003	0.0058	0.4994
5	-0.0020	-0.0009	0.0052	0.4465
6	-0.0022	-0.0009	0.0047	0.4075
7	-0.0037	-0.0014	0.0044	0.3771
8	-0.0045	-0.0016	0.0042	0.3526
9	-0.0048	-0.0016	0.0039	0.3323
10	-0.0037	-0.0012	0.0036	0.3151
40	-0.0113	-0.0017	0.0017	0.1536

Panel 8.32

Standardized Impulse Response Functions

ASIA Time Zone:GB/US

Table 1: Number of Quote Revisions

p	NQR	Q. Spread	Volatility	IRD
1	1.0000	0.0000	0.0000	0.0000
2	0.4624	-0.0265	-0.0494	-0.0028
3	0.3652	-0.0177	-0.0509	0.0014
4	0.3216	-0.0173	-0.0479	0.0011
5	0.2956	-0.0211	-0.0475	0.0015
6	0.2714	-0.0231	-0.0444	0.0037
7	0.2550	-0.0245	-0.0405	0.0025
8	0.2348	-0.0289	-0.0340	0.0019
9	0.2240	-0.0325	-0.0329	0.0003
10	0.2135	-0.0343	-0.0305	0.0018
40	0.0660	-0.0229	-0.0101	-0.0013

Table 2: Quoted Spread

p	NQR	Q. Spread	Volatility	IRD
1	-0.0496	0.9988	0.0000	0.0000
2	-0.0356	0.1650	0.0083	0.0002
3	-0.0401	0.1200	0.0080	-0.0003
4	-0.0373	0.1023	0.0090	0.0001
5	-0.0413	0.0953	0.0083	-0.0026
6	-0.0446	0.0920	0.0101	-0.0017
7	-0.0449	0.0991	0.0112	-0.0014
8	-0.0510	0.0951	0.0169	-0.0013
9	-0.0445	0.0978	0.0133	-0.0001
10	-0.0449	0.1020	0.0160	-0.0028
40	-0.0273	0.0136	0.0046	-0.0020

Table 3: Volatility

p	NQR	Q. Spread	Volatility	IRD
1	-0.1220	0.0106	0.9925	0.0000
2	-0.0022	0.0062	0.1544	-0.0121
3	-0.0025	0.0048	0.1000	-0.0126
4	0.0049	0.0019	0.0426	-0.0122
5	0.0068	0.0047	0.0300	-0.0116
6	0.0093	0.0074	0.0184	-0.0120
7	0.0105	0.0084	0.0093	-0.0121
8	0.0120	0.0063	0.0007	0.0007
9	0.0111	0.0093	0.0008	0.0010
10	0.0133	0.0078	-0.0002	0.0008
40	0.0042	-0.0009	-0.0006	0.0002

Table 4: Interest Rate Differential

p	NQR	Q. Spread	Volatility	IRD
1	-0.0051	0.0015	-0.0070	1.0000
2	-0.0053	0.0025	-0.0052	0.7068
3	-0.0049	0.0016	-0.0042	0.5769
4	-0.0042	0.0009	-0.0035	0.4994
5	-0.0031	-0.0006	-0.0029	0.4465
6	-0.0030	0.0002	-0.0026	0.4074
7	-0.0023	-0.0001	-0.0023	0.3771
8	-0.0022	0.0000	-0.0022	0.3526
9	-0.0014	-0.0006	-0.0019	0.3323
10	-0.0026	-0.0016	-0.0019	0.3151
40	-0.0031	-0.0026	-0.0008	0.1536

Table 5: Numbner of Quote Revisions

p	NQR	R. Spread	Volatility	IRD
1	1.0000	0.0000	0.0000	0.0000
2	0.4621	-0.0274	-0.0494	-0.0029
3	0.3649	-0.0191	-0.0509	0.0013
4	0.3211	-0.0189	-0.0479	0.0009
5	0.2951	-0.0230	-0.0476	0.0013
6	0.2708	-0.0249	-0.0444	0.0035
7	0.2544	-0.0266	-0.0405	0.0022
8	0.2341	-0.0312	-0.0340	0.0016
9	0.2232	-0.0349	-0.0330	0.0000
10	0.2126	-0.0371	-0.0306	0.0015
40	0.0656	-0.0257	-0.0100	-0.0017

Table 6: Relative Spread

p	NQR	R. Spread	Volatility	IRD
1	-0.0513	0.9987	0.0000	0.0000
2	-0.0370	0.1658	0.0079	-0.0002
3	-0.0416	0.1222	0.0074	-0.0008
4	-0.0388	0.1052	0.0085	-0.0005
5	-0.0428	0.0990	0.0078	-0.0033
6	-0.0461	0.0958	0.0095	-0.0023
7	-0.0461	0.1032	0.0107	-0.0022
8	-0.0525	0.0992	0.0163	-0.0020
9	-0.0460	0.1029	0.0126	-0.0010
10	-0.0464	0.1071	0.0151	-0.0037
40	-0.0294	0.0166	0.0049	-0.0043

Table 7:Volatility

p	NQR	R. Spread	Volatility	IRD
1	-0.1220	0.0100	0.9925	0.0000
2	-0.0022	0.0059	0.1544	-0.0120
3	-0.0024	0.0045	0.1000	-0.0126
4	0.0050	0.0017	0.0426	-0.0122
5	0.0069	0.0043	0.0301	-0.0115
6	0.0094	0.0070	0.0184	-0.0119
7	0.0106	0.0081	0.0094	-0.0120
8	0.0121	0.0059	0.0008	0.0008
9	0.0112	0.0087	0.0008	0.0010
10	0.0133	0.0074	-0.0002	0.0008
40	0.0043	-0.0010	-0.0006	0.0002

Table 8: Interest Rate Differential

p	NQR	R. Spread	Volatility	IRD
1	-0.0053	0.0009	-0.0069	1.0000
2	-0.0055	0.0017	-0.0051	0.7068
3	-0.0052	0.0007	-0.0042	0.5768
4	-0.0045	-0.0002	-0.0035	0.4994
5	-0.0034	-0.0018	-0.0029	0.4465
6	-0.0033	-0.0012	-0.0025	0.4074
7	-0.0027	-0.0016	-0.0022	0.3771
8	-0.0026	-0.0017	-0.0021	0.3526
9	-0.0018	-0.0025	-0.0018	0.3323
10	-0.0031	-0.0036	-0.0019	0.3151
40	-0.0035	-0.0048	-0.0008	0.1535

Panel 8.33

Standardized Impulse Response Functions

ASIA Time Zone:EU/US

Table 1: Number of Quote Revisions

p	NQR	Q. Spread	Volatility	IRD
1	1.0000	0.0000	0.0000	0.0000
2	0.4707	-0.0360	-0.0511	0.0087
3	0.3610	-0.0210	-0.0578	0.0019
4	0.3193	-0.0132	-0.0566	0.0018
5	0.2942	-0.0144	-0.0526	0.0048
6	0.2651	-0.0081	-0.0464	0.0034
7	0.2477	-0.0076	-0.0406	0.0064
8	0.2255	-0.0037	-0.0343	0.0087
9	0.2158	0.0009	-0.0340	0.0077
10	0.1978	0.0033	-0.0274	0.0120
40	0.0352	0.0035	-0.0041	0.0100

Table 2: Quoted Spread

p	NQR	Q. Spread	Volatility	IRD
1	-0.0855	0.9963	0.0000	0.0000
2	-0.0596	0.0844	0.0192	-0.0010
3	-0.0563	0.0718	0.0157	-0.0039
4	-0.0546	0.0630	0.0195	0.0012
5	-0.0478	0.0623	0.0154	-0.0039
6	-0.0461	0.0713	0.0159	-0.0030
7	-0.0491	0.0603	0.0155	-0.0027
8	-0.0483	0.0615	0.0097	-0.0017
9	-0.0423	0.0562	0.0099	-0.0082
10	-0.0410	0.0647	0.0178	-0.0090
40	-0.0088	0.0000	0.0011	-0.0061

Table 3: Volatility

p	NQR	Q. Spread	Volatility	IRD
1	-0.1459	0.0092	0.9893	0.0000
2	0.0113	-0.0054	0.0108	-0.0013
3	0.0111	-0.0033	0.0018	-0.0011
4	0.0139	-0.0063	-0.0054	-0.0005
5	0.0124	-0.0053	-0.0055	-0.0005
6	0.0140	-0.0117	-0.0058	-0.0006
7	0.0153	-0.0017	-0.0053	-0.0005
8	0.0163	-0.0053	-0.0041	-0.0004
9	0.0153	-0.0074	-0.0044	-0.0005
10	0.0197	-0.0070	-0.0036	-0.0003
40	0.0044	0.0004	-0.0005	-0.0003

Table 4: Interest Rate Differential

p	NQR	Q. Spread	Volatility	IRD
1	-0.0032	-0.0053	0.0215	0.9997
2	-0.0022	-0.0034	0.0136	0.7069
3	-0.0022	-0.0050	0.0106	0.5771
4	-0.0010	-0.0055	0.0088	0.4997
5	-0.0003	-0.0053	0.0077	0.4469
6	0.0003	-0.0049	0.0067	0.4079
7	0.0006	-0.0069	0.0061	0.3776
8	0.0013	-0.0068	0.0059	0.3531
9	0.0014	-0.0077	0.0051	0.3329
10	0.0012	-0.0076	0.0044	0.3157
40	0.0029	-0.0054	0.0017	0.1566

Table 5: Numbner of Quote Revisions

p	NQR	R. Spread	Volatility	IRD
1	1.0000	0.0000	0.0000	0.0000
2	0.4704	-0.0408	-0.0513	0.0084
3	0.3607	-0.0298	-0.0582	0.0015
4	0.3188	-0.0240	-0.0571	0.0014
5	0.2937	-0.0272	-0.0531	0.0043
6	0.2644	-0.0229	-0.0470	0.0030
7	0.2469	-0.0247	-0.0412	0.0059
8	0.2246	-0.0223	-0.0351	0.0082
9	0.2147	-0.0196	-0.0347	0.0072
10	0.1965	-0.0195	-0.0282	0.0115
40	0.0353	-0.0053	-0.0048	0.0098

Table 6: Relative Spread

p	NQR	R. Spread	Volatility	IRD
1	-0.0890	0.9960	0.0000	0.0000
2	-0.0646	0.0994	0.0198	-0.0011
3	-0.0608	0.0892	0.0169	-0.0041
4	-0.0599	0.0816	0.0206	0.0009
5	-0.0542	0.0831	0.0168	-0.0041
6	-0.0517	0.0934	0.0177	-0.0037
7	-0.0558	0.0834	0.0163	-0.0030
8	-0.0553	0.0890	0.0116	-0.0020
9	-0.0507	0.0865	0.0117	-0.0093
10	-0.0502	0.0966	0.0186	-0.0101
40	-0.0157	0.0066	0.0024	-0.0098

Table 7:Volatility

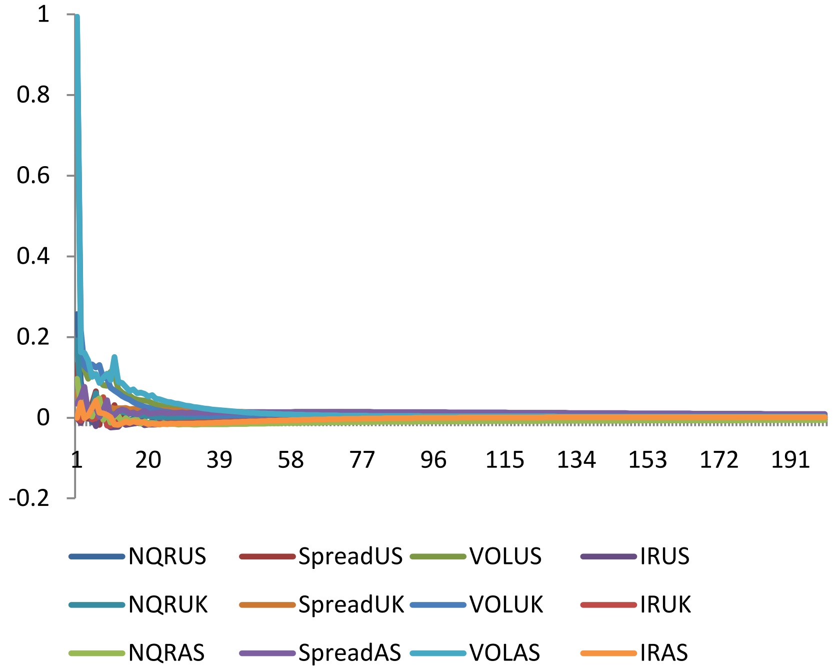
p	NQR	R. Spread	Volatility	IRD
1	-0.1461	0.0110	0.9892	0.0000
2	0.0111	-0.0013	0.0110	-0.0011
3	0.0110	-0.0001	0.0020	-0.0011
4	0.0138	-0.0020	-0.0052	-0.0004
5	0.0125	-0.0017	-0.0053	-0.0005
6	0.0140	-0.0071	-0.0057	-0.0005
7	0.0154	0.0015	-0.0051	-0.0004
8	0.0164	-0.0009	-0.0039	-0.0004
9	0.0154	-0.0036	-0.0043	-0.0004
10	0.0199	-0.0024	-0.0036	-0.0003
40	0.0044	-0.0006	-0.0006	-0.0004

Table 8: Interest Rate Differential

p	NQR	R. Spread	Volatility	IRD
1	-0.0034	-0.0060	0.0216	0.9997
2	-0.0026	-0.0039	0.0136	0.7068
3	-0.0027	-0.0056	0.0107	0.5770
4	-0.0015	-0.0065	0.0089	0.4996
5	-0.0008	-0.0066	0.0078	0.4468
6	-0.0003	-0.0064	0.0069	0.4078
7	0.0000	-0.0086	0.0063	0.3775
8	0.0006	-0.0087	0.0060	0.3530
9	0.0007	-0.0097	0.0052	0.3328
10	0.0004	-0.0096	0.0045	0.3157
40	0.0025	-0.0089	0.0016	0.1564

Panel 8.34 to 8.36: Impulse Response Plots, Intraday Sample

Colour Guide to Impulse Response Plots
(the plot below is a sample)

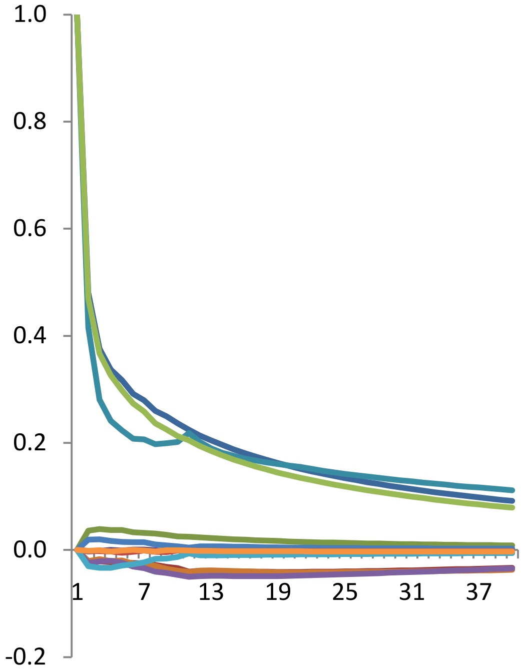


Note for Panels 8.34-8.36: Plot 1 shows the impact that a shock in the number of quote revisions (NQR) has on the number of quote revisions (own shock), quoted spread, exchange rate volatility, and interest rate differential, up to 40 periods ahead. (one period is equal to five minutes). Plot 2-4: Defined as Plot 1 but for quoted spread, exchange rate volatility and interest rate differential respectively. Plot 5 shows the impact that a shock in the number of quote revisions (NQR) has on the number of quote revisions (own shock), relative spread, exchange rate volatility, and interest rate differential, up to 40 periods ahead. (one period is equal to five minutes). Plot 6-8: Defined as Plot 1 but for Relative spread, exchange rate volatility and interest rate differential respectively. The impulse response results are obtained from the VAR models described in section 8.6 applied on our full intraday sample. Variables used in the VAR; The number of quote revisions recorded in 5-minute intervals, between 8:00am and 5:00pm local time; The quoted spread based on the last recorded bid and ask quotes at 5-minute intervals, between 8:00am and 5pm local time. The relative spreads based on the difference of the logarithm of the ask price and the logarithm of the bid price recorded at 5-minute intervals, between 8:00am and 5:00pm local time. *Volatility*: the squared result of the log of the exchange rate at time t+1 minus log of the exchange rate at time t, in 5-minute intervals; Interest rate differential (IRD) between Eurodollar overnight deposit rates (short) and Eurodollar one month deposit rate (long). The x-axis values give the number of periods (forecast horizon in days) since the shock was first felt.

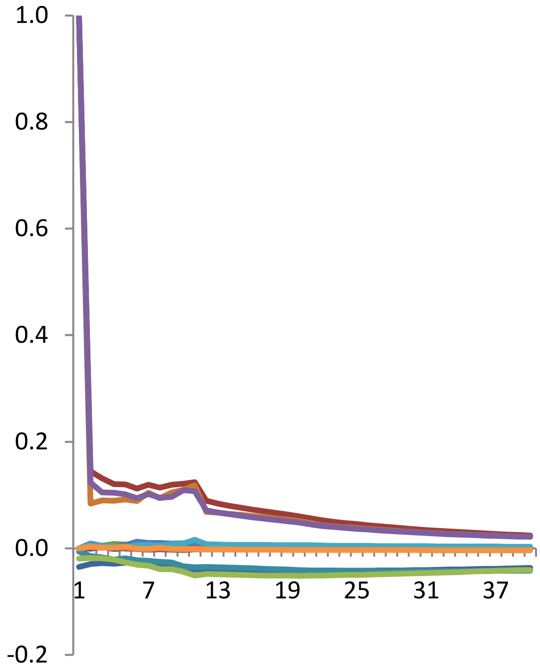
Panel 8.34: Impulse Response, JP/US (US, UK, ASIA time zones)

Quoted Spread

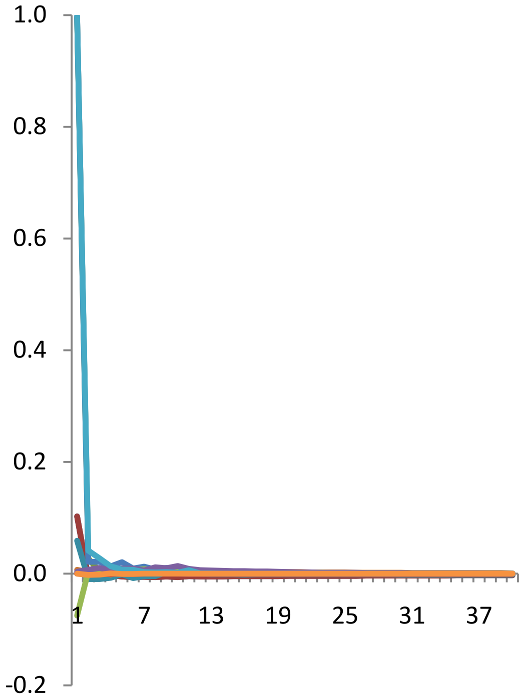
Plot 1
Number of Quote Revisions



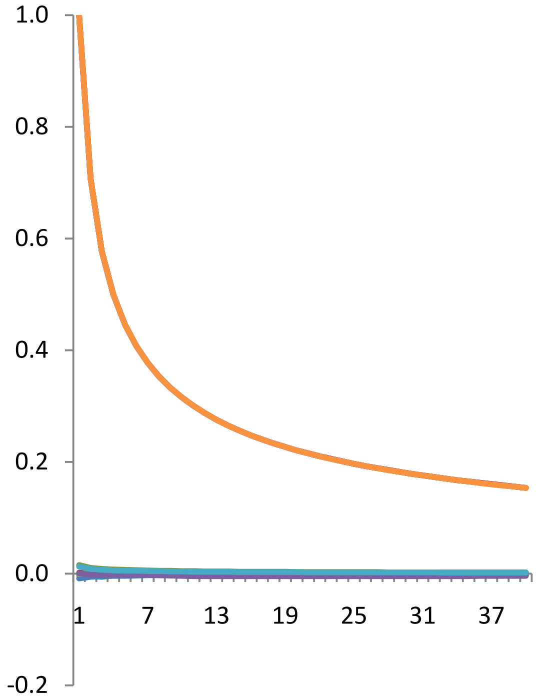
Plot 2
Quoted Spread



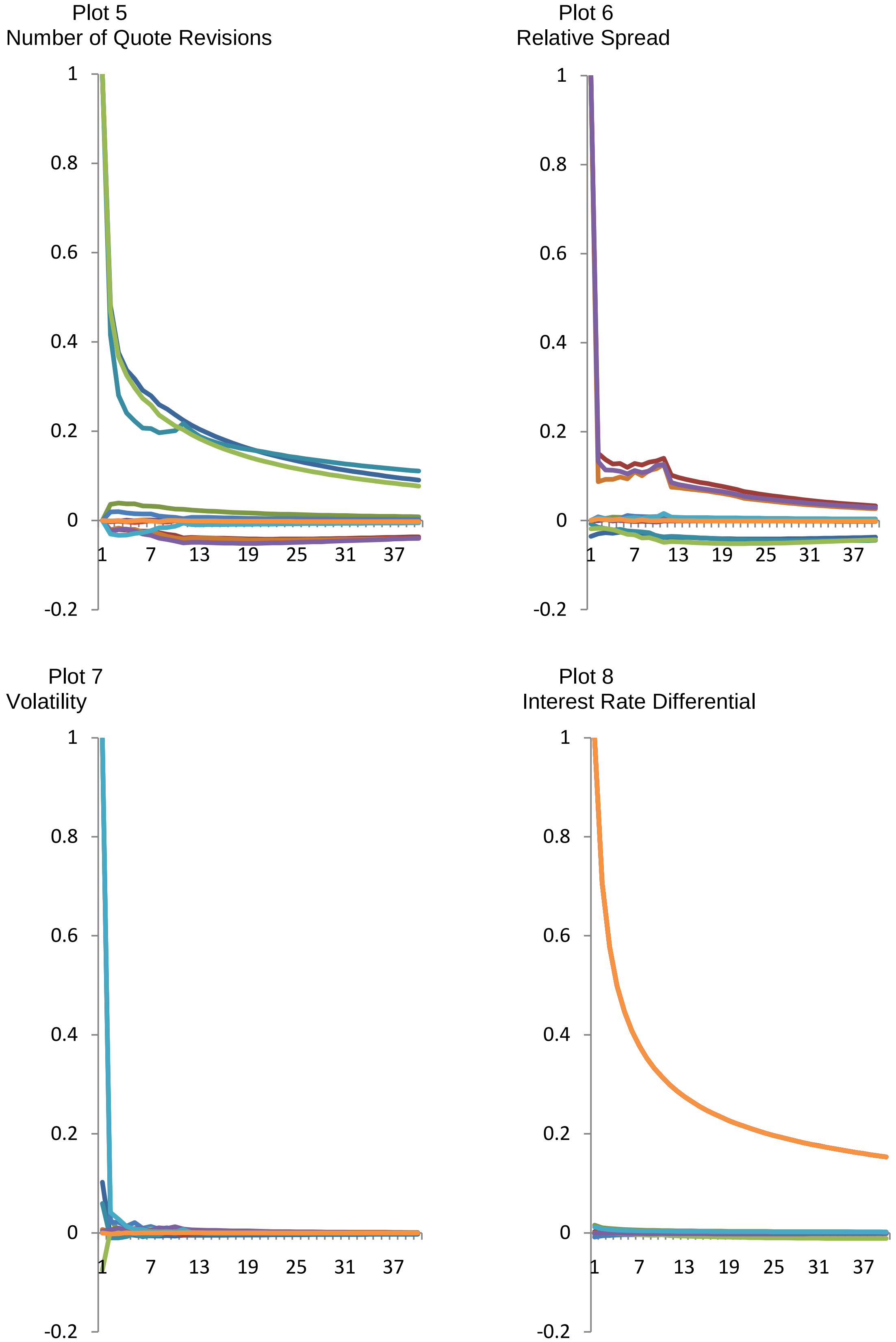
Plot 3
Volatility



Plot 4
Interest Rate Differential



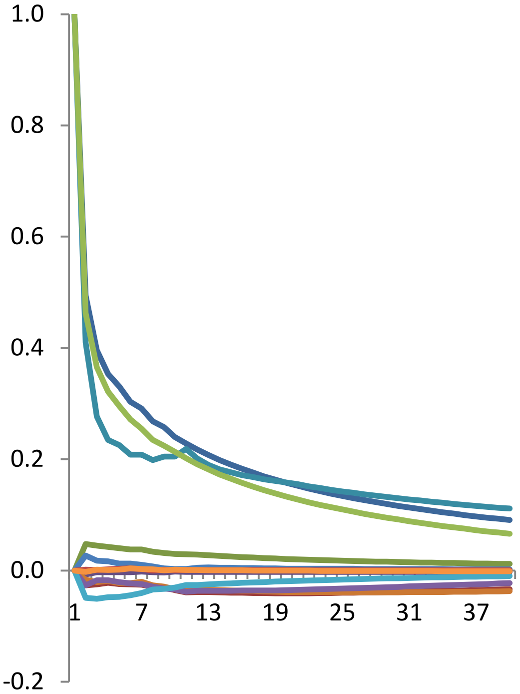
Relative Spread



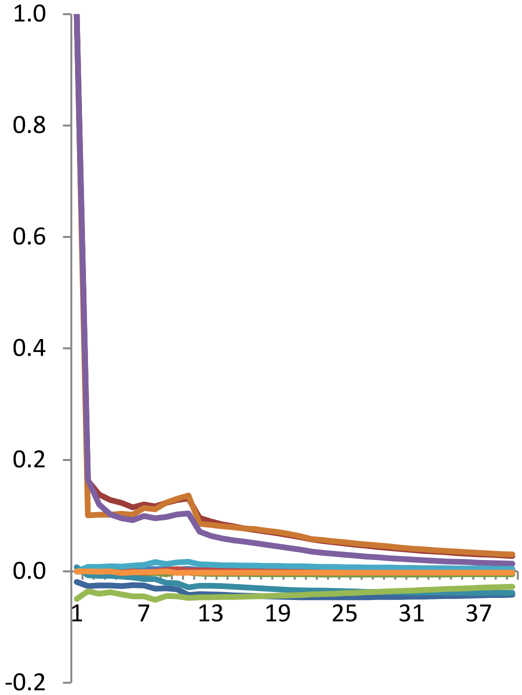
Panel 8.35: Impulse Response, GB/US (US, UK, ASIA time zones)

Quoted Spread

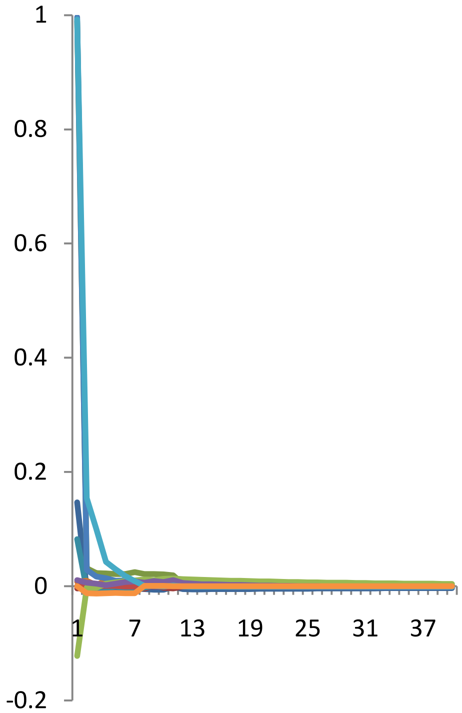
Plot 1
Number of Quote Revisions



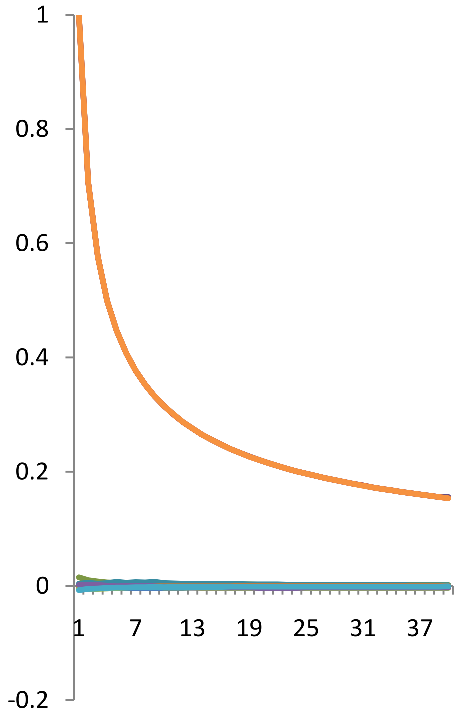
Plot 2
Quoted Spread



Plot 4
Volatility

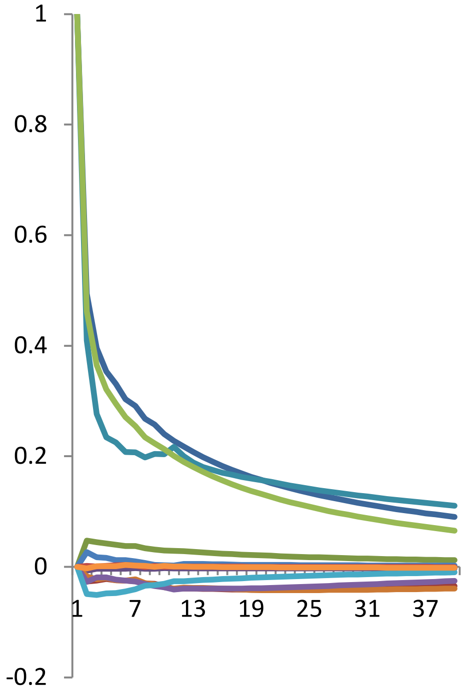


Plot 5
Interest Rate Differential

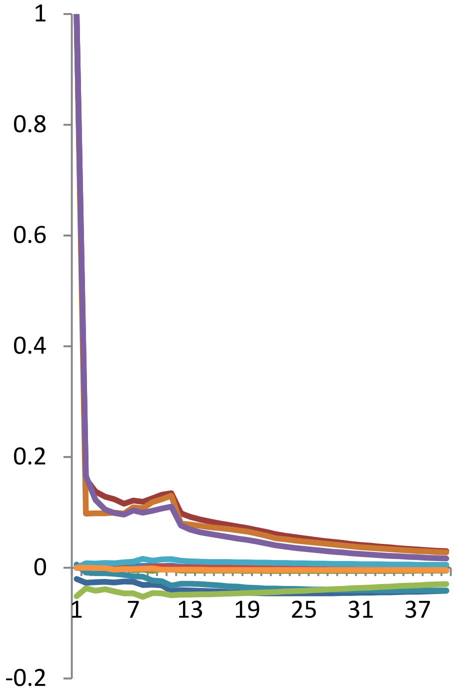


Relative Spread

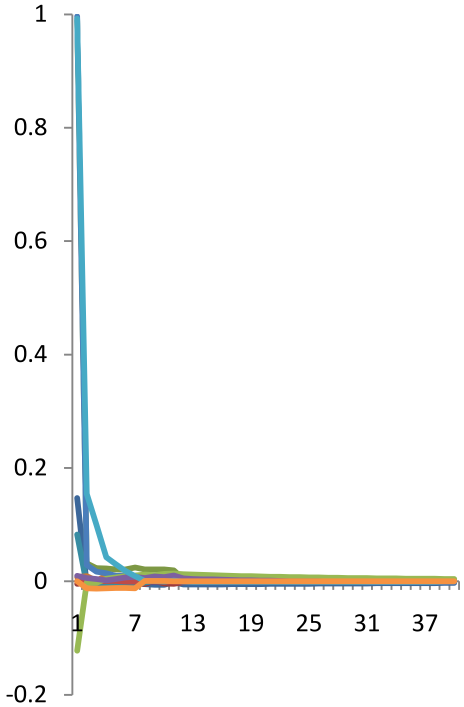
Plot 5
Number of Quote Revisions



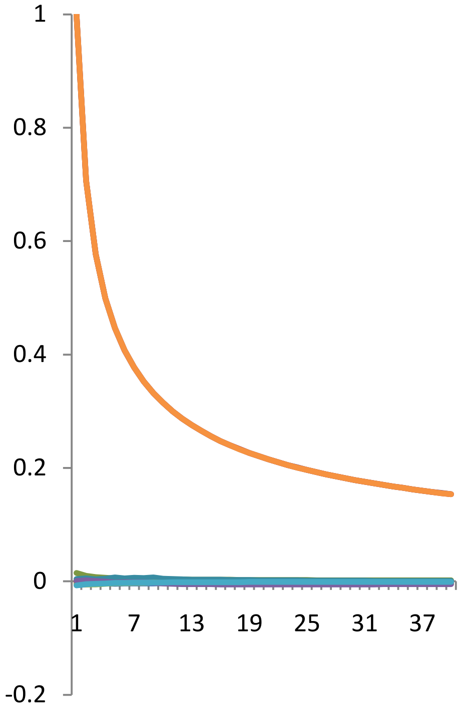
Plot 6
Relative Spread



Plot 7
Volatility



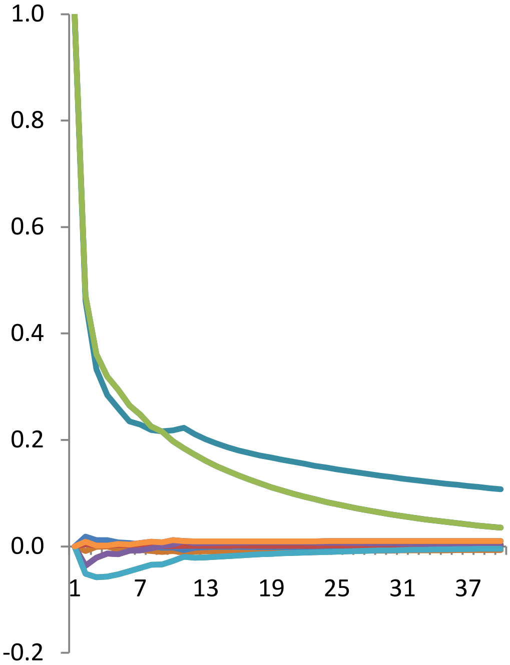
Plot 8
Interest Rate Differential



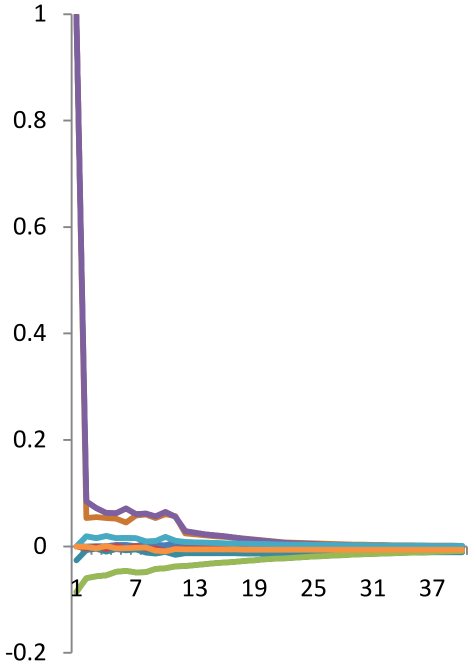
Panel 8.36: Impulse Response, EU/US (US, UK, ASIA time zones)

Quoted Spread

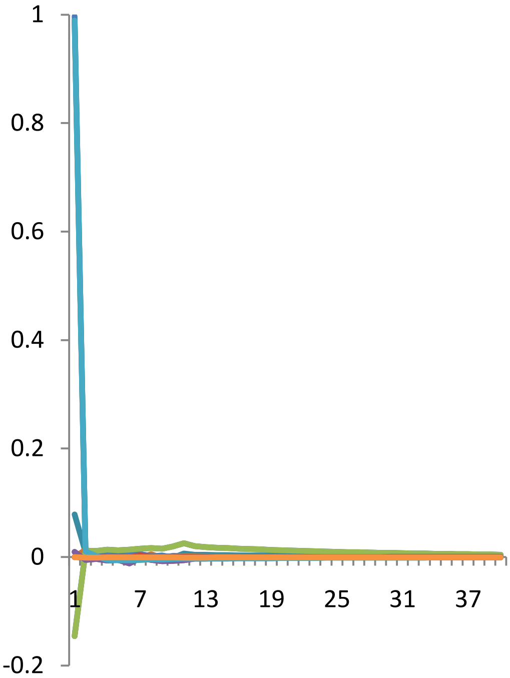
Plot 1
Number of Quote Revisions



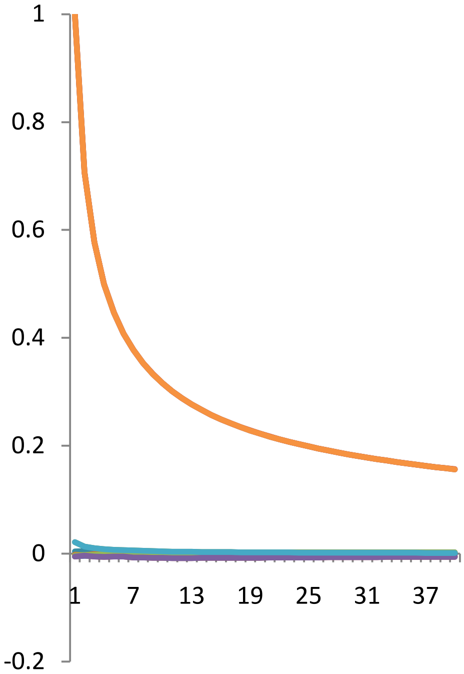
Plot 2
Quoted Spread



Plot 4
Volatility

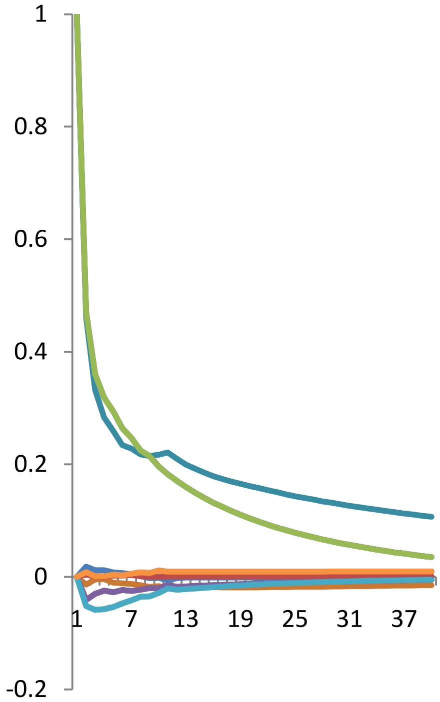


Plot 5
Interest Rate Differential

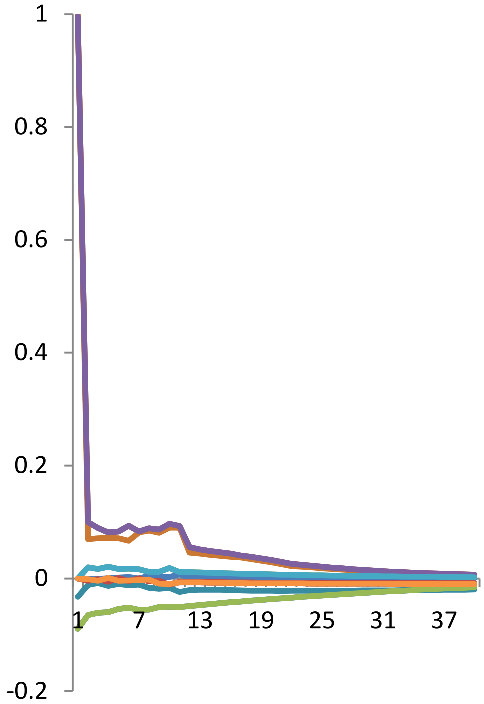


Relative Spread

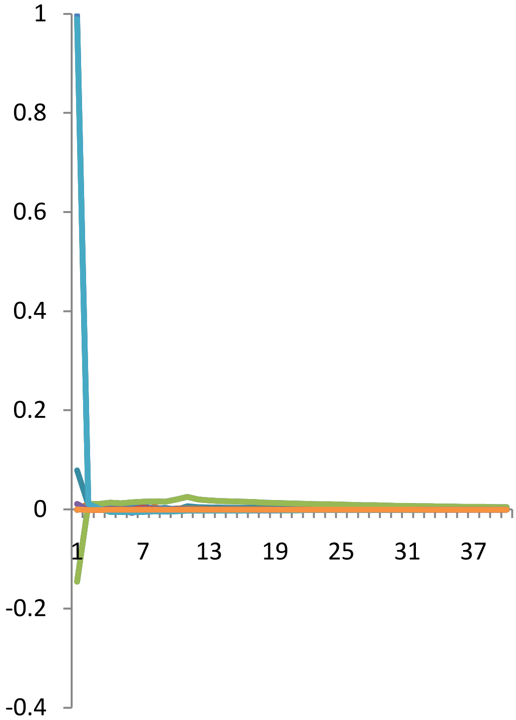
Plot 5
Number of Quote Revisions



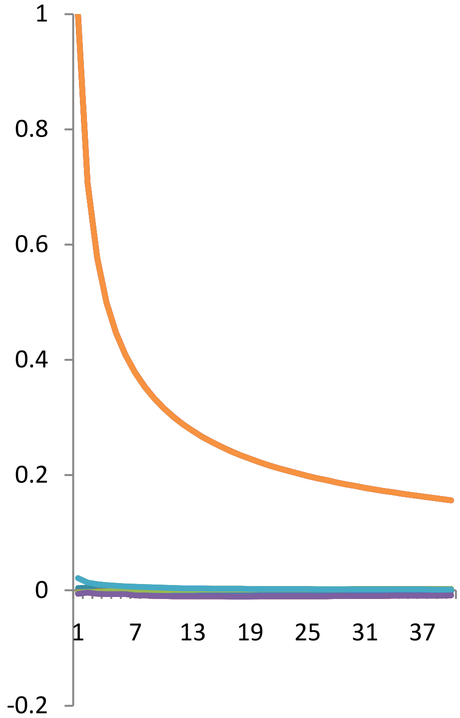
Plot 6
Relative Spread



Plot 7
Volatility



Plot 8
Interest Rate Differential



Panels 8.37 to 8.45: Variance Decompositions, Intraday Sample

Note for Panels 8.35- 8.45: Table 1 shows the percentage of the forecast error variance shift of the number of quote revisions (NQR) that is explained by innovations in the number of quote revisions (own shock), quoted spread, exchange rate volatility, and interest rate differential, up to 40 periods ahead. (one period is equal to five minutes). Table 2-4: Defined as Table 1 but for quoted spread, exchange rate volatility and interest rate differential respectively. Table 5 shows the percentage of the forecast error variance shift of the number of quote revisions (NQR) that is explained by innovations in the number of quote revisions (own shock), relative spread, exchange rate volatility, and interest rate differential, up to 40 periods ahead. (one period is equal to five minutes). Table 6-8: Defined as Table 1 but for Relative spread, exchange rate volatility and interest rate differential respectively. The variance decompositions results are obtained from the VAR models described in section 8.6 applied on our full intraday sample. Variables used in the VAR; The number of quote revisions recorded in 5-minute intervals, between 8:00am and 5:00pm local time; The quoted spread based on the last recorded bid and ask quotes at 5-minute intervals, between 8:00am and 5pm local time. The relative spread based on the difference of the logarithm of the ask price and the logarithm of the bid price recorded at 5-minute intervals, between 8:00am and 5:00pm local time. *Volatility*: the squared result of the log of the exchange rate at time t+1 minus log of the exchange rate at time t, in 5-minute intervals; Interest rate differential (IRD) between Eurodollar overnight deposit rates (short) and Eurodollar one month deposit rate (long). The column headed *p* refers to the number of periods (one period: 5 minute interval) following the shock.

Panel 8.37

Variance Decompositions

US Time Zone: JP/US

Innovation in

Table 1: Number of Quote Revisions

p	NQR	Q. Spread	Volatility	IRD
1	100.0000	0.0000	0.0000	0.0000
2	99.8058	0.0646	0.1288	0.0008
3	99.6355	0.1001	0.2636	0.0009
4	99.4864	0.1394	0.3734	0.0008
5	99.3415	0.1812	0.4765	0.0008
6	99.2302	0.2253	0.5437	0.0008
7	99.1285	0.2680	0.6027	0.0008
8	99.0166	0.3272	0.6554	0.0008
9	98.9006	0.4060	0.6921	0.0013
10	98.7824	0.4991	0.7172	0.0013
40	95.3972	3.7599	0.8354	0.0074

Table 2: Quoted Spread

p	NQR	Q. Spread	Volatility	IRD
1	0.1218	99.8782	0.0000	0.0000
2	0.2072	99.7906	0.0022	0.0001
3	0.2796	99.7152	0.0047	0.0005
4	0.3592	99.6288	0.0113	0.0007
5	0.4259	99.5567	0.0167	0.0007
6	0.4832	99.4951	0.0208	0.0009
7	0.5595	99.4107	0.0283	0.0016
8	0.6362	99.3301	0.0317	0.0020
9	0.7423	99.2202	0.0350	0.0025
10	0.8532	99.1047	0.0387	0.0035
40	5.4149	94.5295	0.0460	0.0096

Table 3: Volatility

p	NQR	Q. Spread	Volatility	IRD
1	1.0551	0.0050	98.9399	0.0000
2	1.0599	0.0063	98.9338	0.0000
3	1.0606	0.0073	98.9322	0.0000
4	1.0612	0.0074	98.9314	0.0000
5	1.0635	0.0075	98.9290	0.0000
6	1.0674	0.0085	98.9240	0.0000
7	1.0705	0.0085	98.9209	0.0001
8	1.0744	0.0085	98.9170	0.0001
9	1.0771	0.0085	98.9144	0.0001
10	1.0809	0.0085	98.9105	0.0001
40	1.1226	0.0108	98.8664	0.0003

Table 4: Interest Rate Differential

p	NQR	Q. Spread	Volatility	IRD
1	0.0003	0.0003	0.0238	99.9756
2	0.0004	0.0002	0.0230	99.9763
3	0.0003	0.0002	0.0231	99.9764
4	0.0003	0.0003	0.0232	99.9762
5	0.0003	0.0004	0.0231	99.9762
6	0.0004	0.0007	0.0232	99.9757
7	0.0004	0.0007	0.0232	99.9757
8	0.0004	0.0006	0.0231	99.9759
9	0.0004	0.0006	0.0230	99.9761
10	0.0003	0.0005	0.0229	99.9762
40	0.0042	0.0008	0.0203	99.9747

Table 5: Numbner of Quote Revisions

p	NQR	R. Spread	Volatility	IRD
1	100.0000	0.0000	0.0000	0.0000
2	99.8095	0.0614	0.1284	0.0008
3	99.6426	0.0940	0.2626	0.0008
4	99.4967	0.1308	0.3719	0.0007
5	99.3554	0.1694	0.4745	0.0007
6	99.2470	0.2111	0.5412	0.0007
7	99.1481	0.2513	0.5999	0.0008
8	99.0387	0.3085	0.6522	0.0007
9	98.9248	0.3855	0.6886	0.0012
10	98.8117	0.4737	0.7134	0.0012
40	95.1118	4.0533	0.8307	0.0042

Table 6: Relative Spread

p	NQR	R. Spread	Volatility	IRD
1	0.1250	99.8750	0.0000	0.0000
2	0.2076	99.7901	0.0022	0.0000
3	0.2766	99.7182	0.0045	0.0007
4	0.3520	99.6366	0.0106	0.0008
5	0.4151	99.5682	0.0158	0.0009
6	0.4695	99.5104	0.0192	0.0010
7	0.5403	99.4327	0.0255	0.0015
8	0.6104	99.3591	0.0288	0.0017
9	0.7067	99.2600	0.0313	0.0020
10	0.8067	99.1560	0.0344	0.0029
40	5.1134	94.8454	0.0384	0.0029

Table 7:Volatility

p	NQR	R. Spread	Volatility	IRD
1	1.0538	0.0049	98.9413	0.0000
2	1.0587	0.0061	98.9352	0.0000
3	1.0593	0.0067	98.9339	0.0000
4	1.0600	0.0069	98.9331	0.0000
5	1.0624	0.0070	98.9306	0.0000
6	1.0665	0.0082	98.9253	0.0000
7	1.0696	0.0082	98.9221	0.0001
8	1.0737	0.0082	98.9180	0.0001
9	1.0765	0.0082	98.9152	0.0001
10	1.0805	0.0082	98.9112	0.0001
40	1.1233	0.0105	98.8659	0.0002

Table 8: Interest Rate Differential

p	NQR	R. Spread	Volatility	IRD
1	0.0003	0.0005	0.0238	99.9754
2	0.0004	0.0005	0.0230	99.9760
3	0.0003	0.0005	0.0231	99.9761
4	0.0003	0.0009	0.0232	99.9756
5	0.0002	0.0015	0.0231	99.9752
6	0.0004	0.0022	0.0232	99.9742
7	0.0003	0.0025	0.0231	99.9740
8	0.0003	0.0024	0.0231	99.9742
9	0.0003	0.0025	0.0230	99.9743
10	0.0002	0.0025	0.0229	99.9744
40	0.0024	0.0033	0.0210	99.9733

Panel 8.38

Variance Decompositions

US Time Zone: GB/US

Innovation in

Table 1: Number of Quote Revisions

p	NQR	Q. Spread	Volatility	IRD
1	100.0000	0.0000	0.0000	0.0000
2	99.7005	0.0708	0.2239	0.0048
3	99.4837	0.1211	0.3902	0.0050
4	99.3219	0.1534	0.5192	0.0055
5	99.1754	0.1951	0.6236	0.0060
6	99.0485	0.2383	0.7069	0.0064
7	98.9208	0.2841	0.7888	0.0063
8	98.7968	0.3518	0.8445	0.0069
9	98.6862	0.4204	0.8858	0.0076
10	98.5523	0.5188	0.9214	0.0075
40	94.9266	3.8026	1.2537	0.0171

Table 2: Quoted Spread

p	NQR	Q. Spread	Volatility	IRD
1	0.0369	99.9631	0.0000	0.0000
2	0.1071	99.8909	0.0003	0.0017
3	0.1695	99.8250	0.0028	0.0027
4	0.2296	99.7620	0.0057	0.0027
5	0.2957	99.6892	0.0101	0.0050
6	0.3527	99.6318	0.0100	0.0055
7	0.4115	99.5715	0.0112	0.0058
8	0.5014	99.4809	0.0118	0.0058
9	0.5866	99.3922	0.0143	0.0069
10	0.6781	99.3008	0.0142	0.0068
40	6.2011	93.6905	0.0889	0.0195

Table 3: Volatility

p	NQR	Q. Spread	Volatility	IRD
1	2.1604	0.0015	97.8381	0.0000
2	2.1611	0.0023	97.8366	0.0001
3	2.1619	0.0023	97.8357	0.0001
4	2.1631	0.0028	97.8340	0.0001
5	2.1629	0.0030	97.8340	0.0001
6	2.1646	0.0032	97.8320	0.0001
7	2.1650	0.0033	97.8315	0.0003
8	2.1660	0.0050	97.8287	0.0003
9	2.1686	0.0053	97.8257	0.0004
10	2.1712	0.0059	97.8225	0.0004
40	2.2166	0.0078	97.7740	0.0016

Table 4: Interest Rate Differential

p	NQR	Q. Spread	Volatility	IRD
1	0.0018	0.0002	0.0229	99.9751
2	0.0009	0.0004	0.0213	99.9774
3	0.0006	0.0003	0.0202	99.9789
4	0.0006	0.0003	0.0192	99.9798
5	0.0008	0.0003	0.0184	99.9805
6	0.0009	0.0003	0.0178	99.9810
7	0.0008	0.0003	0.0173	99.9816
8	0.0007	0.0003	0.0171	99.9820
9	0.0006	0.0002	0.0167	99.9824
10	0.0006	0.0002	0.0164	99.9828
40	0.0002	0.0001	0.0141	99.9857

Table 5: Numbner of Quote Revisions

p	NQR	R. Spread	Volatility	IRD
1	100.0000	0.0000	0.0000	0.0000
2	99.7005	0.0718	0.2227	0.0050
3	99.4846	0.1223	0.3878	0.0052
4	99.3238	0.1548	0.5155	0.0058
5	99.1781	0.1969	0.6186	0.0064
6	99.0509	0.2418	0.7005	0.0069
7	98.9231	0.2891	0.7810	0.0068
8	98.7992	0.3579	0.8354	0.0076
9	98.6883	0.4279	0.8754	0.0085
10	98.5544	0.5274	0.9098	0.0084
40	94.7809	3.9557	1.2397	0.0237

Table 6: Relative Spread

p	NQR	R. Spread	Volatility	IRD
1	0.0420	99.9580	0.0000	0.0000
2	0.1158	99.8825	0.0004	0.0013
3	0.1806	99.8139	0.0036	0.0020
4	0.2424	99.7485	0.0072	0.0020
5	0.3108	99.6728	0.0127	0.0038
6	0.3692	99.6141	0.0127	0.0041
7	0.4288	99.5525	0.0146	0.0042
8	0.5194	99.4609	0.0156	0.0041
9	0.6043	99.3720	0.0190	0.0048
10	0.6953	99.2808	0.0192	0.0047
40	6.1512	93.7400	0.1042	0.0046

Table 7:Volatility

p	NQR	R. Spread	Volatility	IRD
1	2.1565	0.0018	97.8418	0.0000
2	2.1573	0.0027	97.8399	0.0001
3	2.1583	0.0027	97.8389	0.0001
4	2.1597	0.0030	97.8373	0.0001
5	2.1595	0.0031	97.8373	0.0001
6	2.1614	0.0036	97.8349	0.0001
7	2.1618	0.0036	97.8343	0.0003
8	2.1631	0.0059	97.8307	0.0003
9	2.1659	0.0060	97.8278	0.0004
10	2.1687	0.0072	97.8237	0.0004
40	2.2164	0.0100	97.7720	0.0016

Table 8: Interest Rate Differential

p	NQR	R. Spread	Volatility	IRD
1	0.0020	0.0001	0.0229	99.9751
2	0.0010	0.0001	0.0213	99.9776
3	0.0007	0.0001	0.0201	99.9791
4	0.0006	0.0001	0.0192	99.9802
5	0.0007	0.0001	0.0184	99.9809
6	0.0007	0.0004	0.0178	99.9811
7	0.0006	0.0006	0.0173	99.9814
8	0.0005	0.0007	0.0170	99.9818
9	0.0005	0.0008	0.0167	99.9820
10	0.0004	0.0010	0.0164	99.9821
40	0.0010	0.0078	0.0139	99.9773

Panel 8.39

Variance Decompositions

US Time Zone: EU/US

Innovation in

	Table 1: Number of Quote Revisions				Table 2: Quoted Spread				Table 3: Volatility				Table 4: Interest Rate Differential			
p	NQR	Q. Spread	Volatility	IRD	NQR	Q. Spread	Volatility	IRD	NQR	Q. Spread	Volatility	IRD	NQR	Q. Spread	Volatility	IRD
1	100.0000	0.0000	0.0000	0.0000	0.5256	99.4744	0.0000	0.0000	4.5307	0.0036	95.4657	0.0000	0.0004	0.0005	0.0016	99.9975
2	99.4376	0.0633	0.4989	0.0002	0.7780	99.2093	0.0116	0.0011	4.5374	0.0172	95.4454	0.0000	0.0004	0.0035	0.0013	99.9948
3	99.0051	0.0783	0.9158	0.0009	1.0170	98.9649	0.0166	0.0015	4.5412	0.0182	95.4405	0.0001	0.0003	0.0051	0.0013	99.9933
4	98.6484	0.0969	1.2535	0.0012	1.2367	98.7185	0.0432	0.0017	4.5522	0.0182	95.4295	0.0001	0.0004	0.0094	0.0013	99.9889
5	98.3919	0.1124	1.4938	0.0019	1.4528	98.4967	0.0487	0.0017	4.5522	0.0226	95.4251	0.0001	0.0004	0.0162	0.0013	99.9821
6	98.1597	0.1262	1.7115	0.0027	1.6283	98.3137	0.0556	0.0024	4.5531	0.0231	95.4237	0.0001	0.0005	0.0185	0.0013	99.9797
7	97.9013	0.1420	1.9536	0.0031	1.8309	98.0997	0.0670	0.0024	4.5570	0.0267	95.4139	0.0023	0.0006	0.0192	0.0013	99.9789
8	97.7258	0.1467	2.1245	0.0031	2.0152	97.9055	0.0742	0.0051	4.5577	0.0297	95.4103	0.0024	0.0005	0.0202	0.0014	99.9779
9	97.6016	0.1478	2.2473	0.0034	2.1699	97.7379	0.0869	0.0052	4.5694	0.0316	95.3966	0.0024	0.0005	0.0220	0.0014	99.9761
10	97.4779	0.1513	2.3673	0.0035	2.3631	97.5256	0.1052	0.0061	4.5771	0.0348	95.3857	0.0024	0.0007	0.0242	0.0014	99.9737
40	96.5753	0.1692	3.1913	0.0642	4.7332	94.9802	0.2312	0.0554	4.6690	0.0475	95.2807	0.0028	0.0287	0.0543	0.0032	99.9138

	Table 5: Numbner of Quote Revisions				Table 6: Relative Spread				Table 7:Volatility				Table 8: Interest Rate Differential			
p	NQR	R. Spread	Volatility	IRD	NQR	R. Spread	Volatility	IRD	NQR	R. Spread	Volatility	IRD	NQR	R. Spread	Volatility	IRD
1	100.0000	0.0000	0.0000	0.0000	0.5916	99.4084	0.0000	0.0000	4.5334	0.0057	95.4609	0.0000	0.0005	0.0005	0.0017	99.9973
2	99.4113	0.0877	0.5009	0.0001	0.8968	99.0876	0.0140	0.0016	4.5404	0.0134	95.4462	0.0000	0.0004	0.0043	0.0013	99.9940
3	98.9610	0.1170	0.9213	0.0007	1.1756	98.8016	0.0204	0.0024	4.5441	0.0134	95.4423	0.0001	0.0003	0.0068	0.0013	99.9916
4	98.5793	0.1566	1.2631	0.0009	1.4348	98.5110	0.0514	0.0027	4.5550	0.0141	95.4308	0.0001	0.0003	0.0125	0.0013	99.9859
5	98.2950	0.1959	1.5077	0.0015	1.6916	98.2467	0.0589	0.0028	4.5552	0.0155	95.4292	0.0001	0.0003	0.0217	0.0013	99.9767
6	98.0309	0.2370	1.7301	0.0021	1.9144	98.0124	0.0697	0.0035	4.5560	0.0181	95.4258	0.0001	0.0003	0.0259	0.0013	99.9725
7	97.7318	0.2884	1.9775	0.0024	2.1613	97.7505	0.0847	0.0035	4.5600	0.0191	95.4186	0.0024	0.0003	0.0284	0.0014	99.9699
8	97.5203	0.3237	2.1537	0.0023	2.3866	97.5116	0.0954	0.0064	4.5608	0.0201	95.4167	0.0024	0.0003	0.0312	0.0015	99.9670
9	97.3584	0.3575	2.2817	0.0024	2.5766	97.3074	0.1096	0.0064	4.5727	0.0201	95.4047	0.0024	0.0004	0.0356	0.0016	99.9624
10	97.1871	0.4034	2.4070	0.0025	2.8261	97.0358	0.1302	0.0079	4.5806	0.0206	95.3963	0.0024	0.0005	0.0411	0.0015	99.9569
40	95.4900	1.1975	3.2639	0.0487	6.6404	92.8869	0.3304	0.1424	4.6710	0.0269	95.2993	0.0028	0.0208	0.1522	0.0035	99.8230

Panel 8.40

Variance Decompositions

UK Time Zone: JP/US

Innovation in

	Table 1: Number of Quote Revisions				Table 2: Quoted Spread				Table 3: Volatility				Table 4: Interest Rate Differential			
p	NQR	Q. Spread	Volatility	IRD	NQR	Q. Spread	Volatility	IRD	NQR	Q. Spread	Volatility	IRD	NQR	Q. Spread	Volatility	IRD
1	100.0000	0.0000	0.0000	0.0000	0.0039	99.9961	0.0000	0.0000	0.3526	0.0053	99.6421	0.0000	0.0010	0.0000	0.0071	99.9919
2	99.9187	0.0438	0.0373	0.0002	0.0251	99.9659	0.0079	0.0010	0.3620	0.0063	99.6317	0.0000	0.0026	0.0000	0.0070	99.9903
3	99.8577	0.0686	0.0731	0.0006	0.0537	99.9347	0.0102	0.0014	0.3713	0.0114	99.6173	0.0001	0.0049	0.0000	0.0068	99.9882
4	99.7944	0.1062	0.0981	0.0013	0.0961	99.8905	0.0107	0.0027	0.3769	0.0117	99.6114	0.0001	0.0048	0.0003	0.0068	99.9881
5	99.7395	0.1400	0.1169	0.0037	0.1309	99.8525	0.0139	0.0028	0.3768	0.0177	99.6054	0.0001	0.0041	0.0002	0.0069	99.9888
6	99.6641	0.1992	0.1322	0.0045	0.1779	99.7905	0.0289	0.0027	0.3826	0.0200	99.5974	0.0001	0.0038	0.0002	0.0069	99.9890
7	99.5904	0.2580	0.1473	0.0044	0.2309	99.7267	0.0395	0.0029	0.3844	0.0302	99.5854	0.0001	0.0034	0.0002	0.0069	99.9894
8	99.5076	0.3354	0.1517	0.0054	0.2915	99.6566	0.0490	0.0030	0.3865	0.0352	99.5782	0.0001	0.0030	0.0002	0.0070	99.9897
9	99.3971	0.4440	0.1524	0.0065	0.3578	99.5823	0.0569	0.0029	0.3872	0.0363	99.5764	0.0001	0.0027	0.0002	0.0071	99.9900
10	99.2673	0.5754	0.1510	0.0063	0.4648	99.4661	0.0656	0.0035	0.3875	0.0405	99.5720	0.0001	0.0024	0.0002	0.0072	99.9902
40	95.9193	3.9570	0.1108	0.0129	5.1737	94.7349	0.0883	0.0032	0.3935	0.0648	99.5415	0.0002	0.0035	0.0001	0.0077	99.9887

	Table 5: Numbner of Quote Revisions				Table 6: Relative Spread				Table 7:Volatility				Table 8: Interest Rate Differential			
p	NQR	R. Spread	Volatility	IRD	NQR	R. Spread	Volatility	IRD	NQR	R. Spread	Volatility	IRD	NQR	R. Spread	Volatility	IRD
1	100.0000	0.0000	0.0000	0.0000	0.0054	99.9946	0.0000	0.0000	0.3516	0.0047	99.6437	0.0000	0.0009	0.0000	0.0072	99.9919
2	99.9186	0.0442	0.0370	0.0002	0.0279	99.9635	0.0071	0.0015	0.3611	0.0057	99.6332	0.0000	0.0025	0.0000	0.0071	99.9904
3	99.8578	0.0692	0.0726	0.0005	0.0593	99.9294	0.0092	0.0021	0.3706	0.0103	99.6190	0.0001	0.0046	0.0000	0.0069	99.9885
4	99.7939	0.1076	0.0973	0.0012	0.1052	99.8817	0.0094	0.0037	0.3764	0.0106	99.6130	0.0001	0.0044	0.0002	0.0070	99.9884
5	99.7390	0.1417	0.1159	0.0034	0.1423	99.8424	0.0117	0.0037	0.3763	0.0155	99.6082	0.0001	0.0038	0.0001	0.0070	99.9890
6	99.6632	0.2016	0.1310	0.0042	0.1932	99.7781	0.0250	0.0036	0.3823	0.0173	99.6004	0.0001	0.0034	0.0003	0.0071	99.9892
7	99.5898	0.2601	0.1460	0.0040	0.2483	99.7139	0.0342	0.0037	0.3842	0.0254	99.5903	0.0001	0.0030	0.0003	0.0072	99.9895
8	99.5049	0.3399	0.1503	0.0049	0.3113	99.6434	0.0415	0.0037	0.3864	0.0288	99.5847	0.0001	0.0027	0.0005	0.0073	99.9896
9	99.3897	0.4532	0.1511	0.0060	0.3809	99.5677	0.0477	0.0037	0.3871	0.0293	99.5835	0.0001	0.0024	0.0005	0.0074	99.9898
10	99.2557	0.5888	0.1497	0.0058	0.4920	99.4482	0.0557	0.0042	0.3873	0.0324	99.5803	0.0001	0.0021	0.0005	0.0075	99.9899
40	95.4821	4.3984	0.1106	0.0089	5.6054	94.3108	0.0745	0.0093	0.3929	0.0526	99.5543	0.0002	0.0018	0.0030	0.0079	99.9874

Panel 8.41

Variance Decompositions

UK Time Zone: GB/US

Innovation in

Table 1: Number of Quote Revisions

p	NQR	Q. Spread	Volatility	IRD
1	100.0000	0.0000	0.0000	0.0000
2	99.9010	0.0273	0.0714	0.0003
3	99.8338	0.0698	0.0960	0.0004
4	99.7810	0.1012	0.1171	0.0007
5	99.7256	0.1464	0.1264	0.0017
6	99.6693	0.1920	0.1356	0.0031
7	99.6324	0.2241	0.1399	0.0036
8	99.5704	0.2869	0.1392	0.0035
9	99.5036	0.3580	0.1348	0.0036
10	99.4129	0.4538	0.1298	0.0035
40	96.3243	3.5866	0.0867	0.0025

Table 2: Quoted Spread

p	NQR	Q. Spread	Volatility	IRD
1	0.0057	99.9943	0.0000	0.0000
2	0.0106	99.9887	0.0006	0.0001
3	0.0172	99.9806	0.0017	0.0006
4	0.0235	99.9729	0.0031	0.0006
5	0.0319	99.9580	0.0087	0.0014
6	0.0431	99.9463	0.0092	0.0014
7	0.0611	99.9265	0.0105	0.0018
8	0.0799	99.9063	0.0120	0.0018
9	0.1211	99.8632	0.0135	0.0022
10	0.1639	99.8181	0.0144	0.0036
40	3.5893	96.3776	0.0191	0.0141

Table 3: Volatility

p	NQR	Q. Spread	Volatility	IRD
1	0.6824	0.0066	99.3110	0.0000
2	0.6851	0.0158	99.2991	0.0000
3	0.6911	0.0161	99.2927	0.0000
4	0.6921	0.0285	99.2794	0.0001
5	0.6920	0.0288	99.2790	0.0001
6	0.6931	0.0304	99.2764	0.0001
7	0.6976	0.0314	99.2709	0.0001
8	0.6980	0.0328	99.2691	0.0002
9	0.6981	0.0334	99.2683	0.0002
10	0.6983	0.0359	99.2656	0.0002
40	0.7113	0.0512	99.2363	0.0012

Table 4: Interest Rate Differential

p	NQR	Q. Spread	Volatility	IRD
1	0.0017	0.0001	0.0045	99.9937
2	0.0038	0.0001	0.0051	99.9910
3	0.0043	0.0001	0.0053	99.9904
4	0.0059	0.0005	0.0055	99.9882
5	0.0100	0.0007	0.0061	99.9832
6	0.0118	0.0007	0.0067	99.9807
7	0.0145	0.0007	0.0073	99.9775
8	0.0167	0.0008	0.0078	99.9747
9	0.0202	0.0007	0.0083	99.9708
10	0.0210	0.0007	0.0086	99.9698
40	0.0159	0.0003	0.0111	99.9728

Table 5: Numbner of Quote Revisions

p	NQR	R. Spread	Volatility	IRD
1	100.0000	0.0000	0.0000	0.0000
2	99.8980	0.0308	0.0709	0.0003
3	99.8252	0.0795	0.0951	0.0003
4	99.7666	0.1171	0.1157	0.0006
5	99.7029	0.1711	0.1246	0.0014
6	99.6371	0.2267	0.1335	0.0027
7	99.5906	0.2687	0.1375	0.0031
8	99.5142	0.3460	0.1367	0.0030
9	99.4306	0.4340	0.1323	0.0031
10	99.3183	0.5514	0.1273	0.0030
40	95.7924	4.1219	0.0840	0.0017

Table 6: Relative Spread

p	NQR	R. Spread	Volatility	IRD
1	0.0034	99.9966	0.0000	0.0000
2	0.0108	99.9887	0.0005	0.0000
3	0.0203	99.9781	0.0013	0.0003
4	0.0295	99.9680	0.0021	0.0003
5	0.0419	99.9504	0.0069	0.0008
6	0.0576	99.9344	0.0071	0.0008
7	0.0816	99.9089	0.0080	0.0016
8	0.1076	99.8818	0.0090	0.0016
9	0.1605	99.8277	0.0100	0.0017
10	0.2174	99.7695	0.0106	0.0026
40	4.2696	95.7152	0.0128	0.0024

Table 7:Volatility

p	NQR	R. Spread	Volatility	IRD
1	0.6800	0.0057	99.3143	0.0000
2	0.6830	0.0137	99.3033	0.0000
3	0.6893	0.0139	99.2968	0.0000
4	0.6903	0.0241	99.2855	0.0001
5	0.6903	0.0242	99.2854	0.0001
6	0.6915	0.0252	99.2832	0.0001
7	0.6964	0.0258	99.2777	0.0002
8	0.6968	0.0266	99.2764	0.0002
9	0.6969	0.0268	99.2761	0.0002
10	0.6971	0.0284	99.2744	0.0002
40	0.7085	0.0370	99.2534	0.0011

Table 8: Interest Rate Differential

p	NQR	R. Spread	Volatility	IRD
1	0.0016	0.0001	0.0045	99.9938
2	0.0036	0.0003	0.0050	99.9912
3	0.0039	0.0003	0.0051	99.9906
4	0.0053	0.0010	0.0054	99.9884
5	0.0091	0.0015	0.0059	99.9834
6	0.0107	0.0018	0.0065	99.9811
7	0.0130	0.0020	0.0070	99.9780
8	0.0148	0.0025	0.0074	99.9752
9	0.0178	0.0026	0.0079	99.9717
10	0.0183	0.0029	0.0081	99.9707
40	0.0104	0.0092	0.0104	99.9701

Panel 8.42

Variance Decompositions

UK Time Zone: EU/US

Innovation in

Table 1: Number of Quote Revisions

p	NQR	Q. Spread	Volatility	IRD
1	100.0000	0.0000	0.0000	0.0000
2	99.9565	0.0076	0.0338	0.0022
3	99.9472	0.0068	0.0439	0.0021
4	99.9373	0.0062	0.0545	0.0020
5	99.9317	0.0087	0.0570	0.0026
6	99.9268	0.0117	0.0584	0.0030
7	99.9228	0.0156	0.0571	0.0045
8	99.9191	0.0218	0.0545	0.0046
9	99.9121	0.0310	0.0525	0.0044
10	99.9088	0.0366	0.0504	0.0042
40	99.7864	0.1772	0.0300	0.0065

Table 2: Quoted Spread

p	NQR	Q. Spread	Volatility	IRD
1	0.0664	99.9336	0.0000	0.0000
2	0.0712	99.9275	0.0000	0.0012
3	0.0731	99.9256	0.0000	0.0012
4	0.0820	99.9140	0.0000	0.0040
5	0.0845	99.9106	0.0007	0.0042
6	0.0902	99.9028	0.0014	0.0056
7	0.0933	99.8997	0.0014	0.0057
8	0.1065	99.8813	0.0043	0.0079
9	0.1235	99.8626	0.0051	0.0088
10	0.1342	99.8431	0.0056	0.0172
40	0.5952	99.3196	0.0113	0.0739

Table 3: Volatility

p	NQR	Q. Spread	Volatility	IRD
1	0.6200	0.0000	99.3800	0.0000
2	0.6279	0.0180	99.3540	0.0000
3	0.6388	0.0236	99.3375	0.0001
4	0.6404	0.0242	99.3353	0.0001
5	0.6418	0.0261	99.3321	0.0001
6	0.6418	0.0269	99.3311	0.0001
7	0.6449	0.0271	99.3266	0.0014
8	0.6451	0.0302	99.3233	0.0014
9	0.6461	0.0305	99.3218	0.0015
10	0.6462	0.0311	99.3212	0.0015
40	0.6771	0.0317	99.2886	0.0027

Table 4: Interest Rate Differential

p	NQR	Q. Spread	Volatility	IRD
1	0.0019	0.0002	0.0021	99.9958
2	0.0032	0.0008	0.0024	99.9935
3	0.0023	0.0006	0.0025	99.9947
4	0.0017	0.0004	0.0026	99.9952
5	0.0020	0.0003	0.0026	99.9951
6	0.0027	0.0004	0.0026	99.9943
7	0.0036	0.0006	0.0025	99.9934
8	0.0039	0.0015	0.0024	99.9922
9	0.0039	0.0037	0.0025	99.9899
10	0.0039	0.0055	0.0025	99.9881
40	0.0024	0.0454	0.0030	99.9492

Table 5: Numbner of Quote Revisions

p	NQR	R. Spread	Volatility	IRD
1	100.0000	0.0000	0.0000	0.0000
2	99.9463	0.0175	0.0342	0.0020
3	99.9361	0.0173	0.0446	0.0019
4	99.9253	0.0173	0.0556	0.0018
5	99.9131	0.0261	0.0584	0.0023
6	99.8995	0.0378	0.0601	0.0026
7	99.8858	0.0513	0.0590	0.0039
8	99.8698	0.0700	0.0563	0.0039
9	99.8455	0.0967	0.0541	0.0037
10	99.8252	0.1195	0.0518	0.0036
40	99.2194	0.7468	0.0301	0.0036

Table 6: Relative Spread

p	NQR	R. Spread	Volatility	IRD
1	0.1052	99.8949	0.0000	0.0000
2	0.1179	99.8804	0.0001	0.0017
3	0.1235	99.8746	0.0001	0.0018
4	0.1409	99.8537	0.0001	0.0053
5	0.1497	99.8445	0.0004	0.0054
6	0.1638	99.8277	0.0010	0.0075
7	0.1742	99.8173	0.0010	0.0075
8	0.2013	99.7849	0.0035	0.0104
9	0.2344	99.7495	0.0043	0.0119
10	0.2594	99.7124	0.0048	0.0233
40	1.5288	98.2791	0.0119	0.1802

Table 7:Volatility

p	NQR	R. Spread	Volatility	IRD
1	0.6221	0.0001	99.3778	0.0000
2	0.6302	0.0142	99.3555	0.0000
3	0.6413	0.0203	99.3383	0.0001
4	0.6430	0.0212	99.3358	0.0001
5	0.6444	0.0230	99.3326	0.0001
6	0.6444	0.0236	99.3319	0.0001
7	0.6475	0.0239	99.3272	0.0014
8	0.6478	0.0266	99.3242	0.0014
9	0.6489	0.0269	99.3227	0.0015
10	0.6490	0.0274	99.3222	0.0015
40	0.6801	0.0281	99.2892	0.0026

Table 8: Interest Rate Differential

p	NQR	R. Spread	Volatility	IRD
1	0.0017	0.0006	0.0021	99.9956
2	0.0030	0.0019	0.0023	99.9929
3	0.0020	0.0015	0.0024	99.9941
4	0.0015	0.0014	0.0025	99.9946
5	0.0020	0.0013	0.0025	99.9942
6	0.0031	0.0019	0.0024	99.9926
7	0.0042	0.0026	0.0023	99.9908
8	0.0048	0.0050	0.0023	99.9879
9	0.0050	0.0097	0.0023	99.9830
10	0.0051	0.0139	0.0022	99.9787
40	0.0057	0.1382	0.0027	99.8534

Panel 8.43

Variance Decompositions

ASIA Time Zone: JP/US

Innovation in

p	Table 1: Number of Quote Revisions				Table 2: Quoted Spread				Table 3: Volatility				Table 4: Interest Rate Differential			
	NQR	Q. Spread	Volatility	IRD	NQR	Q. Spread	Volatility	IRD	NQR	Q. Spread	Volatility	IRD	NQR	Q. Spread	Volatility	IRD
1	100.0000	0.0000	0.0000	0.0000	0.0358	99.9642	0.0000	0.0000	0.5583	0.0015	99.4402	0.0000	0.0000	0.0000	0.0152	99.9848
2	99.8488	0.0581	0.0929	0.0002	0.0684	99.9259	0.0047	0.0010	0.5591	0.0061	99.4343	0.0005	0.0001	0.0003	0.0149	99.9847
3	99.7113	0.0966	0.1918	0.0002	0.1031	99.8893	0.0064	0.0011	0.5599	0.0174	99.4220	0.0007	0.0001	0.0007	0.0148	99.9845
4	99.5924	0.1267	0.2799	0.0009	0.1454	99.8457	0.0077	0.0012	0.5609	0.0211	99.4173	0.0008	0.0001	0.0009	0.0147	99.9844
5	99.4872	0.1724	0.3396	0.0009	0.2134	99.7765	0.0079	0.0021	0.5653	0.0300	99.4039	0.0008	0.0002	0.0012	0.0146	99.9840
6	99.3585	0.2558	0.3848	0.0008	0.3053	99.6814	0.0112	0.0021	0.5696	0.0390	99.3906	0.0008	0.0003	0.0014	0.0146	99.9837
7	99.2367	0.3516	0.4107	0.0009	0.4072	99.5749	0.0157	0.0022	0.5759	0.0426	99.3808	0.0008	0.0006	0.0019	0.0146	99.9830
8	99.0903	0.4928	0.4151	0.0018	0.5562	99.4233	0.0181	0.0024	0.5804	0.0561	99.3628	0.0008	0.0009	0.0024	0.0146	99.9821
9	98.9286	0.6502	0.4195	0.0017	0.7011	99.2720	0.0243	0.0025	0.5853	0.0658	99.3481	0.0008	0.0012	0.0034	0.0147	99.9807
10	98.7445	0.8373	0.4166	0.0017	0.8850	99.0804	0.0319	0.0027	0.5871	0.0847	99.3274	0.0008	0.0013	0.0046	0.0147	99.9795
40	94.4125	5.1934	0.3775	0.0166	7.2490	92.6019	0.1219	0.0273	0.6029	0.1158	99.2804	0.0009	0.0103	0.0409	0.0141	99.9346

p	Table 5: Numbner of Quote Revisions				Table 6: Relative Spread				Table 7:Volatility				Table 8: Interest Rate Differential			
	NQR	R. Spread	Volatility	IRD	NQR	R. Spread	Volatility	IRD	NQR	R. Spread	Volatility	IRD	NQR	R. Spread	Volatility	IRD
1	100.0000	0.0000	0.0000	0.0000	0.0350	99.9650	0.0000	0.0000	0.5577	0.0013	99.4410	0.0000	0.0000	0.0001	0.0150	99.9849
2	99.8523	0.0547	0.0928	0.0002	0.0641	99.9301	0.0045	0.0014	0.5586	0.0050	99.4359	0.0005	0.0001	0.0001	0.0146	99.9851
3	99.7182	0.0900	0.1916	0.0002	0.0953	99.8968	0.0062	0.0018	0.5594	0.0151	99.4247	0.0008	0.0001	0.0002	0.0144	99.9853
4	99.6019	0.1178	0.2794	0.0008	0.1341	99.8568	0.0071	0.0020	0.5605	0.0182	99.4205	0.0008	0.0001	0.0002	0.0142	99.9855
5	99.4992	0.1611	0.3389	0.0007	0.1969	99.7925	0.0073	0.0033	0.5650	0.0259	99.4083	0.0009	0.0001	0.0002	0.0140	99.9856
6	99.3739	0.2416	0.3838	0.0007	0.2872	99.6994	0.0102	0.0033	0.5695	0.0332	99.3964	0.0009	0.0002	0.0002	0.0140	99.9857
7	99.2553	0.3345	0.4094	0.0008	0.3860	99.5966	0.0142	0.0032	0.5759	0.0361	99.3872	0.0009	0.0004	0.0002	0.0139	99.9856
8	99.1105	0.4745	0.4136	0.0015	0.5309	99.4489	0.0165	0.0037	0.5805	0.0475	99.3711	0.0009	0.0006	0.0003	0.0139	99.9853
9	98.9510	0.6299	0.4177	0.0014	0.6687	99.3055	0.0222	0.0037	0.5857	0.0549	99.3585	0.0009	0.0008	0.0004	0.0139	99.9849
10	98.7686	0.8154	0.4146	0.0014	0.8406	99.1273	0.0285	0.0036	0.5876	0.0708	99.3407	0.0009	0.0008	0.0007	0.0138	99.9847
40	93.6198	5.9978	0.3708	0.0116	7.4019	92.4694	0.1231	0.0056	0.6059	0.1037	99.2896	0.0009	0.0070	0.0115	0.0132	99.9682

Panel 8.44

Variance Decompositions

ASIA Time Zone: GB/US

Innovation in

p	Table 1: Number of Quote Revisions				Table 2: Quoted Spread				Table 3: Volatility				Table 4: Interest Rate Differential			
	NQR	Q. Spread	Volatility	IRD	NQR	Q. Spread	Volatility	IRD	NQR	Q. Spread	Volatility	IRD	NQR	Q. Spread	Volatility	IRD
1	100.0000	0.0000	0.0000	0.0000	0.2460	99.7540	0.0000	0.0000	1.4895	0.0113	98.4992	0.0000	0.0026	0.0002	0.0049	99.9923
2	99.6851	0.0701	0.2441	0.0008	0.3656	99.6275	0.0069	0.0000	1.4542	0.0149	98.5162	0.0147	0.0041	0.0007	0.0051	99.9901
3	99.4374	0.0919	0.4698	0.0009	0.5209	99.4660	0.0131	0.0000	1.4400	0.0170	98.5125	0.0305	0.0051	0.0007	0.0052	99.9889
4	99.2374	0.1122	0.6495	0.0009	0.6539	99.3250	0.0211	0.0000	1.4395	0.0174	98.4977	0.0454	0.0056	0.0006	0.0052	99.9886
5	99.0354	0.1465	0.8170	0.0011	0.8174	99.1541	0.0278	0.0007	1.4426	0.0196	98.4792	0.0587	0.0054	0.0005	0.0050	99.9890
6	98.8573	0.1886	0.9517	0.0024	1.0073	98.9540	0.0377	0.0010	1.4504	0.0250	98.4516	0.0730	0.0054	0.0005	0.0049	99.9893
7	98.7096	0.2359	1.0517	0.0028	1.1965	98.7526	0.0498	0.0011	1.4609	0.0320	98.4195	0.0876	0.0052	0.0004	0.0047	99.9897
8	98.5842	0.3059	1.1069	0.0030	1.4423	98.4786	0.0778	0.0013	1.4750	0.0360	98.4013	0.0877	0.0050	0.0003	0.0046	99.9901
9	98.4442	0.3954	1.1576	0.0029	1.6234	98.2807	0.0946	0.0013	1.4871	0.0446	98.3806	0.0877	0.0046	0.0003	0.0044	99.9906
10	98.3071	0.4945	1.1954	0.0031	1.8041	98.0747	0.1192	0.0021	1.5044	0.0506	98.3573	0.0878	0.0048	0.0006	0.0044	99.9902
40	95.6969	2.8321	1.4672	0.0038	5.9960	93.6712	0.3168	0.0160	1.6977	0.0740	98.1405	0.0878	0.0213	0.0158	0.0033	99.9596

p	Table 5: Numbner of Quote Revisions				Table 6: Relative Spread				Table 7:Volatility				Table 8: Interest Rate Differential			
	NQR	R. Spread	Volatility	IRD	NQR	R. Spread	Volatility	IRD	NQR	R. Spread	Volatility	IRD	NQR	R. Spread	Volatility	IRD
1	100.0000	0.0000	0.0000	0.0000	0.2627	99.7373	0.0000	0.0000	1.4886	0.0101	98.5014	0.0000	0.0028	0.0001	0.0048	99.9923
2	99.6797	0.0753	0.2441	0.0009	0.3920	99.6017	0.0063	0.0000	1.4533	0.0133	98.5190	0.0145	0.0044	0.0003	0.0050	99.9903
3	99.4275	0.1017	0.4699	0.0009	0.5588	99.4295	0.0116	0.0001	1.4390	0.0151	98.5157	0.0302	0.0056	0.0003	0.0051	99.9891
4	99.2226	0.1267	0.6498	0.0009	0.7025	99.2787	0.0187	0.0001	1.4386	0.0154	98.5011	0.0449	0.0062	0.0002	0.0050	99.9886
5	99.0131	0.1684	0.8176	0.0010	0.8772	99.0971	0.0246	0.0012	1.4418	0.0172	98.4828	0.0581	0.0061	0.0005	0.0048	99.9885
6	98.8275	0.2178	0.9526	0.0021	1.0795	98.8854	0.0334	0.0017	1.4498	0.0221	98.4559	0.0722	0.0062	0.0006	0.0047	99.9885
7	98.6707	0.2740	1.0529	0.0025	1.2785	98.6749	0.0444	0.0021	1.4605	0.0286	98.4242	0.0867	0.0060	0.0007	0.0045	99.9887
8	98.5332	0.3557	1.1085	0.0026	1.5376	98.3894	0.0706	0.0025	1.4748	0.0321	98.4063	0.0868	0.0060	0.0009	0.0044	99.9887
9	98.3787	0.4593	1.1595	0.0024	1.7295	98.1823	0.0856	0.0026	1.4871	0.0398	98.3863	0.0868	0.0056	0.0015	0.0042	99.9887
10	98.2246	0.5750	1.1979	0.0025	1.9212	97.9676	0.1072	0.0039	1.5046	0.0452	98.3633	0.0869	0.0060	0.0026	0.0041	99.9872
40	95.1225	3.4078	1.4642	0.0055	6.5381	93.1046	0.3037	0.0537	1.6980	0.0663	98.1487	0.0870	0.0283	0.0525	0.0031	99.9162

Panel 8.45

Variance Decompositions

ASIA Time Zone: EU/US

Innovation in

	Table 1: Number of Quote Revisions				Table 2: Quoted Spread				Table 3: Volatility				Table 4: Interest Rate Differential			
p	NQR	Q. Spread	Volatility	IRD	NQR	Q. Spread	Volatility	IRD	NQR	Q. Spread	Volatility	IRD	NQR	Q. Spread	Volatility	IRD
1	100.0000	0.0000	0.0000	0.0000	0.7308	99.2692	0.0000	0.0000	2.1287	0.0085	97.8628	0.0000	0.0010	0.0028	0.0464	99.9498
2	99.6016	0.1296	0.2613	0.0075	1.0783	98.8846	0.0370	0.0001	2.1408	0.0114	97.8476	0.0002	0.0010	0.0025	0.0416	99.9549
3	99.2761	0.1563	0.5608	0.0069	1.3855	98.5515	0.0614	0.0016	2.1528	0.0125	97.8344	0.0003	0.0012	0.0041	0.0389	99.9558
4	99.0137	0.1573	0.8225	0.0064	1.6732	98.2259	0.0992	0.0018	2.1715	0.0165	97.8117	0.0003	0.0010	0.0061	0.0369	99.9560
5	98.8024	0.1640	1.0255	0.0081	1.8908	97.9837	0.1223	0.0032	2.1865	0.0193	97.7939	0.0003	0.0008	0.0077	0.0354	99.9560
6	98.6663	0.1586	1.1663	0.0087	2.0891	97.7603	0.1465	0.0041	2.2052	0.0330	97.7615	0.0004	0.0007	0.0089	0.0341	99.9564
7	98.5760	0.1544	1.2574	0.0122	2.3166	97.5090	0.1696	0.0048	2.2281	0.0332	97.7383	0.0004	0.0006	0.0123	0.0330	99.9541
8	98.5234	0.1478	1.3097	0.0191	2.5356	97.2814	0.1780	0.0051	2.2541	0.0360	97.7095	0.0004	0.0007	0.0155	0.0323	99.9515
9	98.4725	0.1408	1.3626	0.0241	2.7018	97.0996	0.1869	0.0118	2.2767	0.0414	97.6814	0.0004	0.0008	0.0198	0.0314	99.9481
10	98.4431	0.1362	1.3832	0.0376	2.8532	96.9095	0.2174	0.0199	2.3147	0.0463	97.6386	0.0004	0.0009	0.0235	0.0302	99.9455
40	98.0924	0.2102	1.4008	0.2967	4.2480	95.3563	0.2697	0.1260	2.7248	0.0525	97.2215	0.0012	0.0145	0.0855	0.0176	99.8824

	Table 5: Numbner of Quote Revisions				Table 6: Relative Spread				Table 7:Volatility				Table 8: Interest Rate Differential			
p	NQR	R. Spread	Volatility	IRD	NQR	R. Spread	Volatility	IRD	NQR	R. Spread	Volatility	IRD	NQR	R. Spread	Volatility	IRD
1	100.0000	0.0000	0.0000	0.0000	0.7918	99.2082	0.0000	0.0000	2.1335	0.0120	97.8545	0.0000	0.0012	0.0036	0.0467	99.9486
2	99.5628	0.1666	0.2636	0.0071	1.1977	98.7632	0.0390	0.0001	2.1453	0.0122	97.8423	0.0001	0.0012	0.0033	0.0420	99.9535
3	99.1940	0.2329	0.5668	0.0064	1.5526	98.3786	0.0670	0.0018	2.1571	0.0122	97.8304	0.0002	0.0015	0.0053	0.0394	99.9537
4	98.8951	0.2660	0.8330	0.0059	1.8951	97.9945	0.1086	0.0018	2.1758	0.0126	97.8114	0.0003	0.0014	0.0083	0.0375	99.9529
5	98.6365	0.3158	1.0404	0.0072	2.1692	97.6917	0.1357	0.0035	2.1909	0.0129	97.7960	0.0003	0.0012	0.0109	0.0361	99.9519
6	98.4611	0.3455	1.1859	0.0076	2.4110	97.4189	0.1653	0.0048	2.2098	0.0179	97.7720	0.0003	0.0010	0.0132	0.0347	99.9511
7	98.3241	0.3844	1.2809	0.0106	2.6969	97.1072	0.1902	0.0056	2.2329	0.0181	97.7487	0.0003	0.0008	0.0188	0.0337	99.9467
8	98.2323	0.4141	1.3368	0.0167	2.9729	96.8196	0.2015	0.0060	2.2592	0.0182	97.7223	0.0003	0.0008	0.0241	0.0331	99.9421
9	98.1524	0.4328	1.3937	0.0211	3.1994	96.5729	0.2131	0.0146	2.2823	0.0195	97.6978	0.0004	0.0007	0.0309	0.0321	99.9363
10	98.0955	0.4535	1.4177	0.0334	3.4117	96.3186	0.2451	0.0246	2.3209	0.0201	97.6586	0.0004	0.0007	0.0371	0.0310	99.9313
40	97.5824	0.6542	1.4893	0.2742	6.2789	93.1108	0.3521	0.2582	2.7272	0.0257	97.2459	0.0012	0.0085	0.1951	0.0175	99.7789

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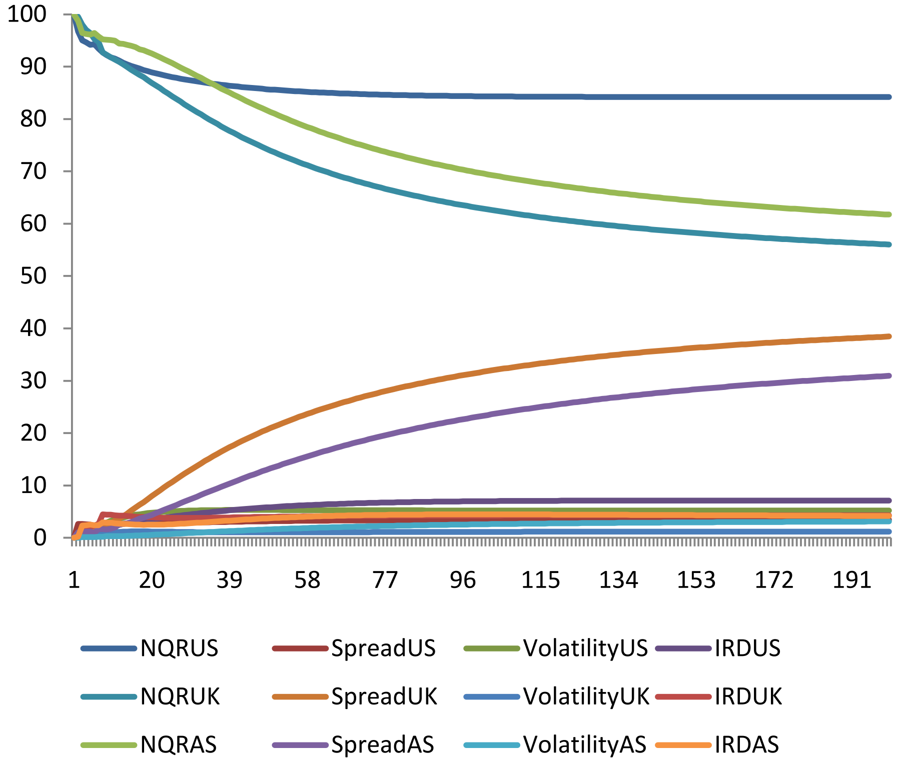
Panel 8.46 to 8.48: Variance Decompositions Plots, Daily Sample

Colour Guide to Variance Decompositions Plots
(the plot below is a sample)

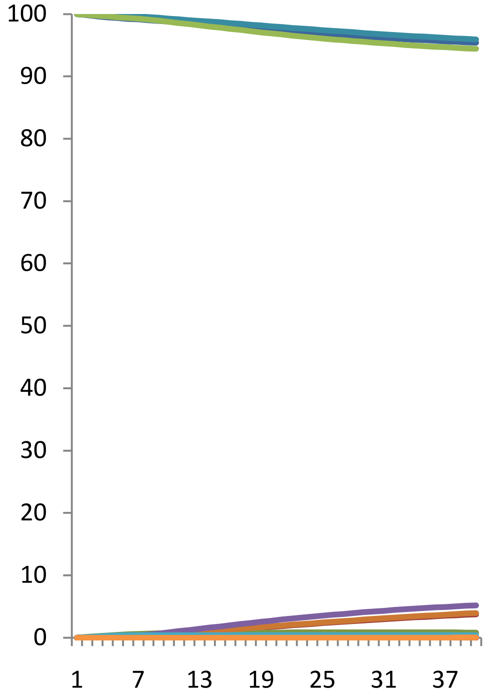


Note for Panels 8.46-8.48: Plot 1 shows the percentage of the forecast error variance shift of the number of quote revisions (NQR) that is explained by innovations in the number of quote revisions (own shock), quoted spread, exchange rate volatility, and interest rate differential, up to 40 periods ahead. (one period is equal to five minutes). Plot 2-4: Defined as Plot 1 but for quoted spread, exchange rate volatility and interest rate differential respectively. Plot 5 shows the percentage of the forecast error variance shift of the number of quote revisions (NQR) that is explained by innovations in the number of quote revisions (own shock), relative spread, exchange rate volatility, and interest rate differential, up to 40 periods ahead. (one period is equal to five minutes). Plot 6-8: Defined as Plot 1 but for Relative spread, exchange rate volatility and interest rate differential respectively. The variance decompositions results are obtained from the VAR models described in section 8.6 applied on our full intraday sample. Variables used in the VAR; The number of quote revisions recorded in 5-minute intervals, between 8:00am and 5:00pm local time; The quoted spread based on the last recorded bid and ask quotes at 5-minute intervals, between 8:00am and 5pm local time. The relative spreads based on the difference of the logarithm of the ask price and the logarithm of the bid price recorded at 5-minute intervals, between 8:00am and 5:00pm local time. *Volatility*: the squared result of the log of the exchange rate at time t+1 minus log of the exchange rate at time t, in 5-minute intervals; Interest rate differential (IRD) between Eurodollar overnight deposit rates (short) and Eurodollar one month deposit rate (long). The x-axis values give the number of periods (forecast horizon in days) since the shock was first felt.

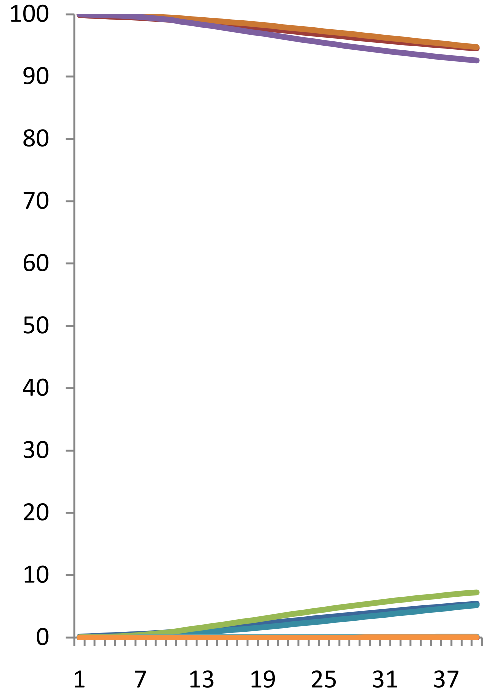
Panel 8.46: Variance Decompositions Plots, JP/US (US,UK, ASIA time zones)

Quoted Spread

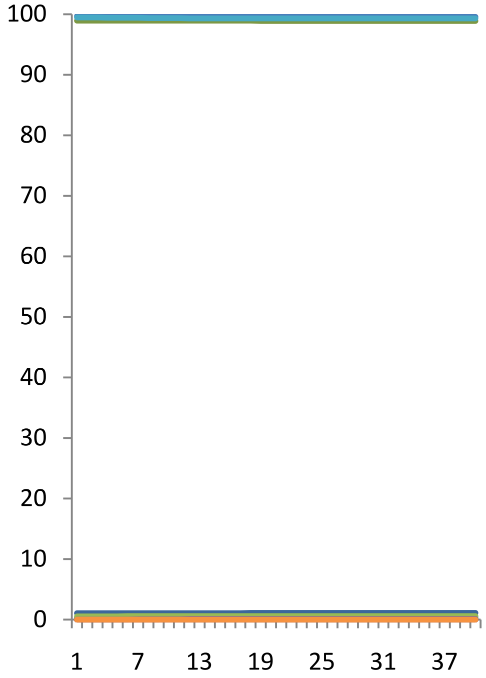
Plot 1
Number of Quote Revisions



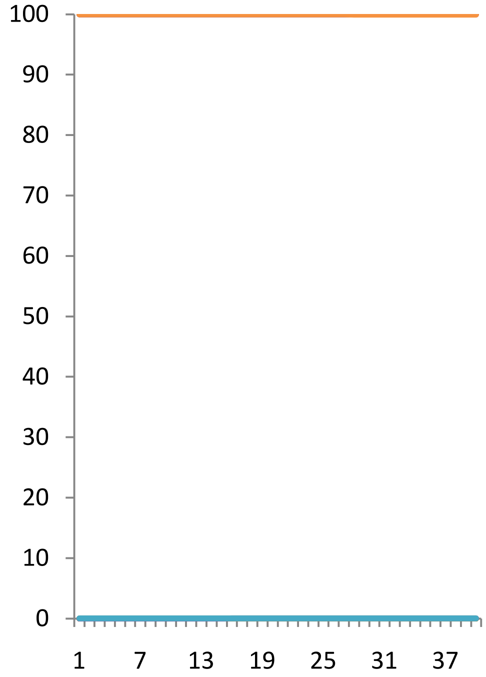
Plot 2
Quoted Spread



Plot 3
Volatility

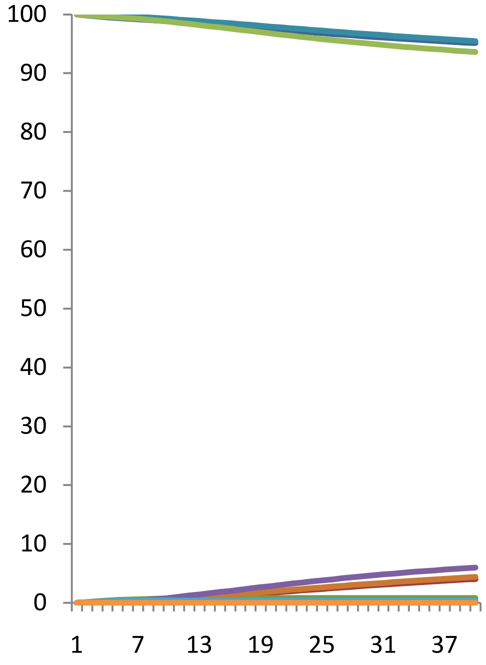


Plot 4
Interest Rate Differential

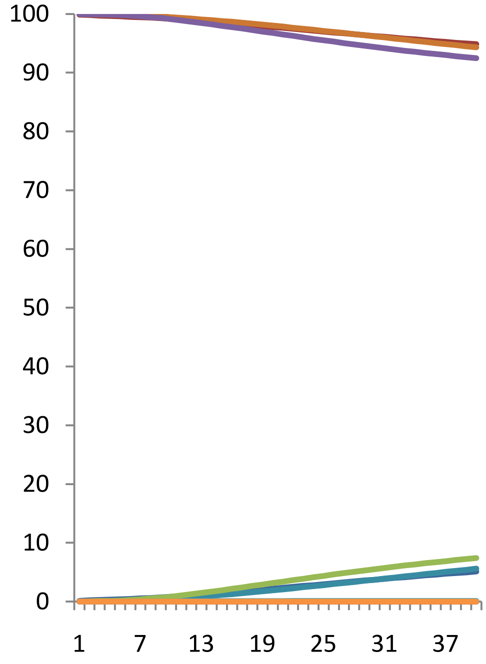


Relative Spread

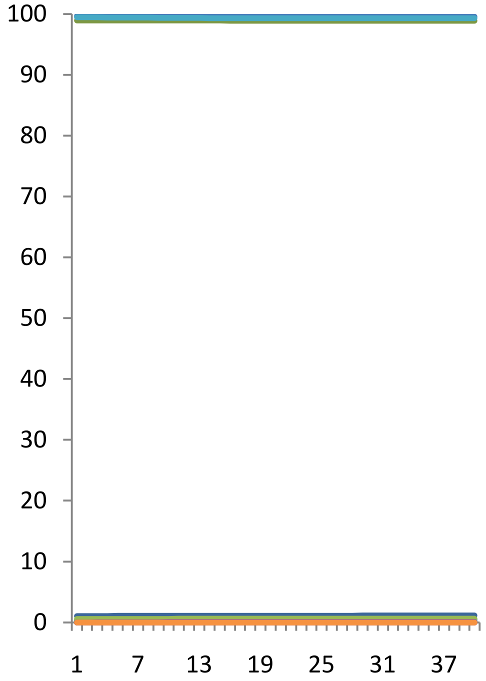
Plot 5
Number of Quote Revisions



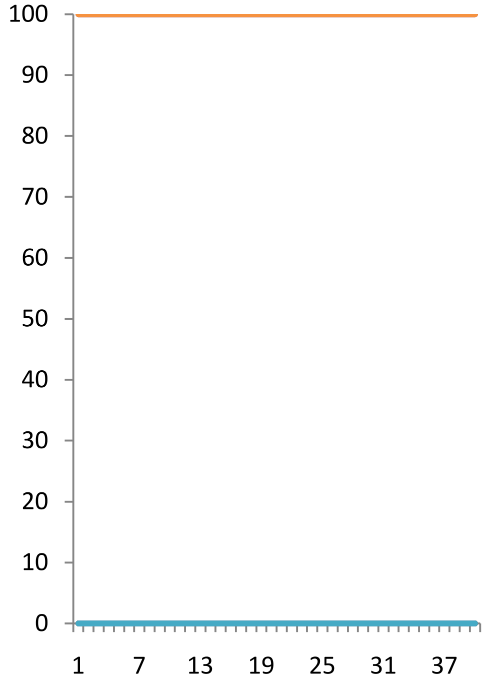
Plot 6
Relative Spread



Plot 7
Volatility



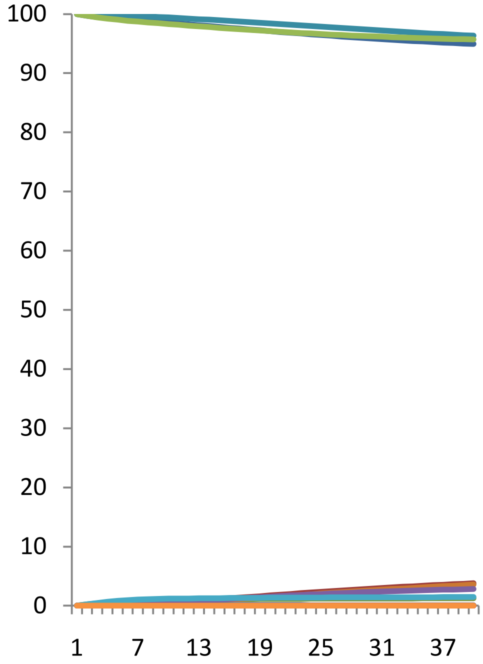
Plot 8
Interest Rate Differential



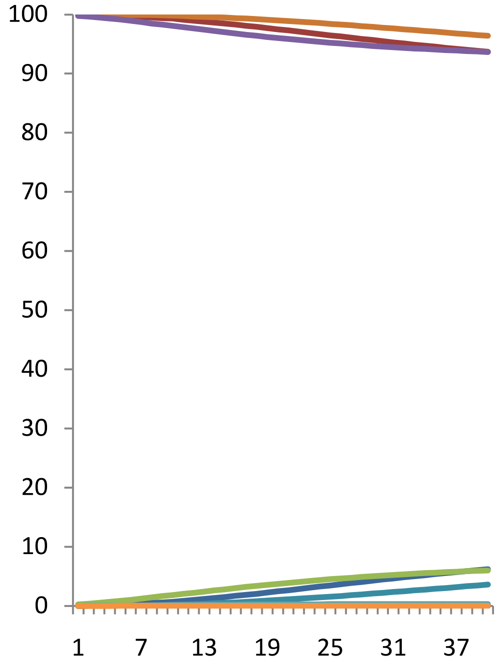
Panel 8.47: Variance Decompositions Plots, GB/US (US,UK,ASIA time zones)

Quoted Spread

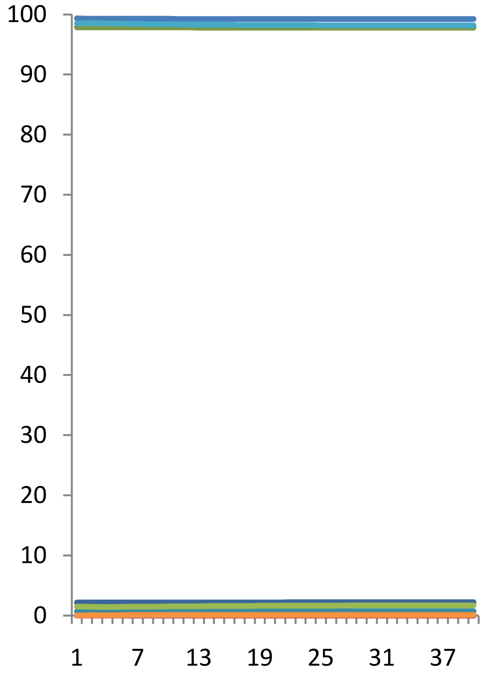
Plot 1
Number of Quote Revisions



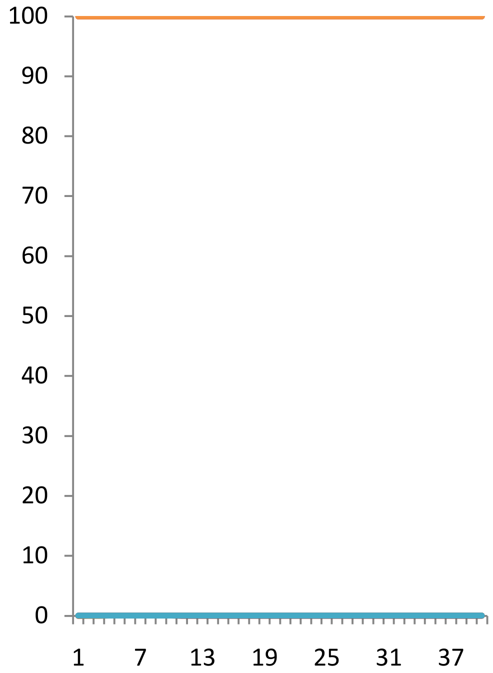
Plot 2
Quoted Spread



Plot 3
Volatility

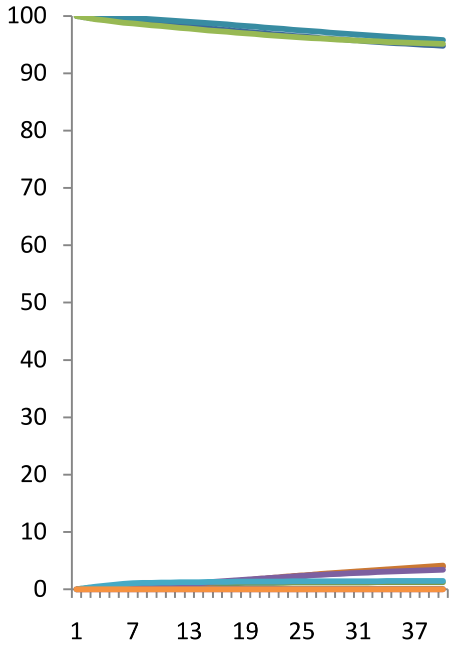


Plot 4
Interest Rate Differential

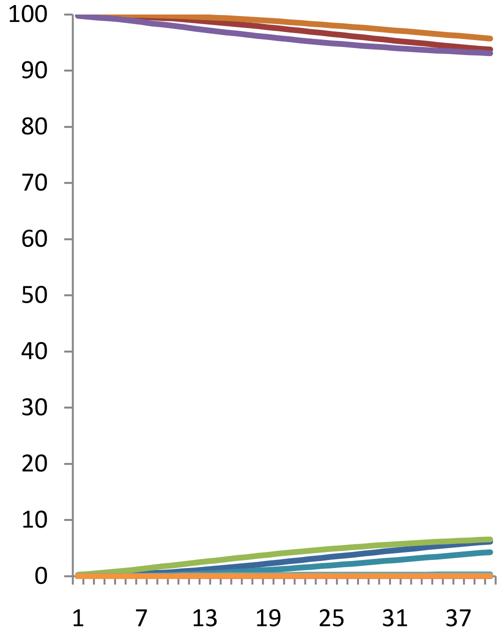


Relative Spread

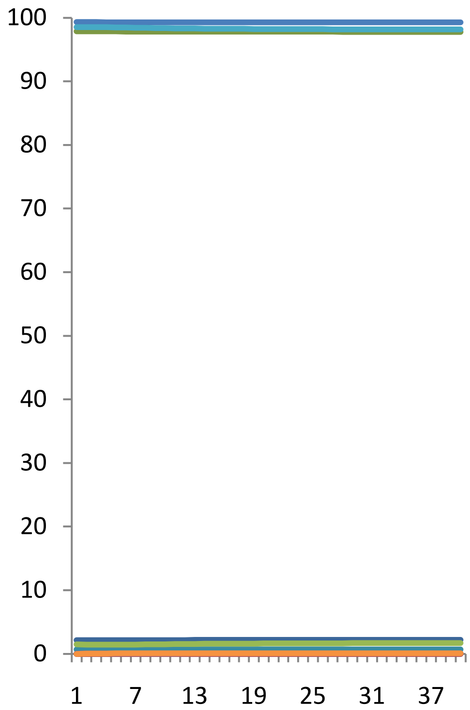
Plot 5
Number of Quote Revisions



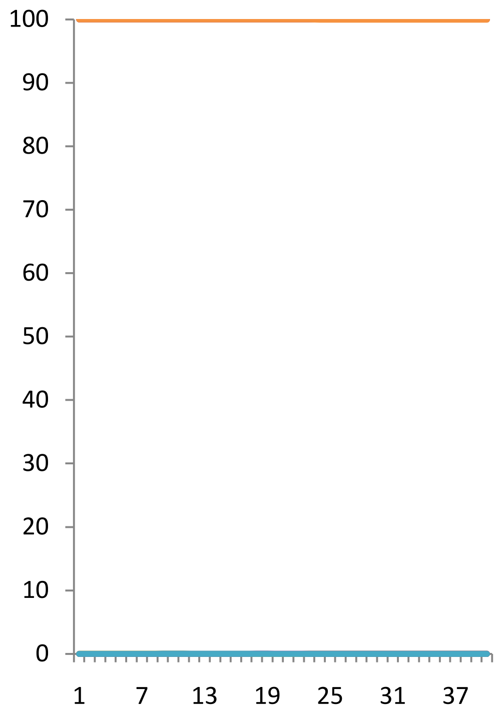
Plot 6
Relative Spread



Plot 7
Volatility



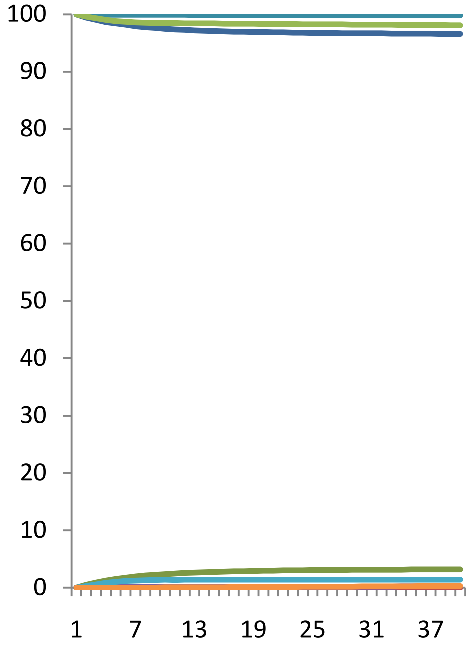
Plot 8
Interest Rate Differential



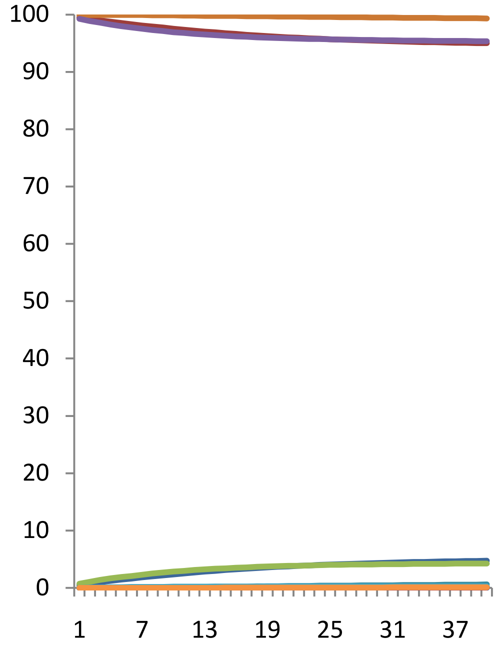
Panel 8.48: Variance Decompositions Plots, EU/US (US,UK,ASIA time zones)

Quoted Spread

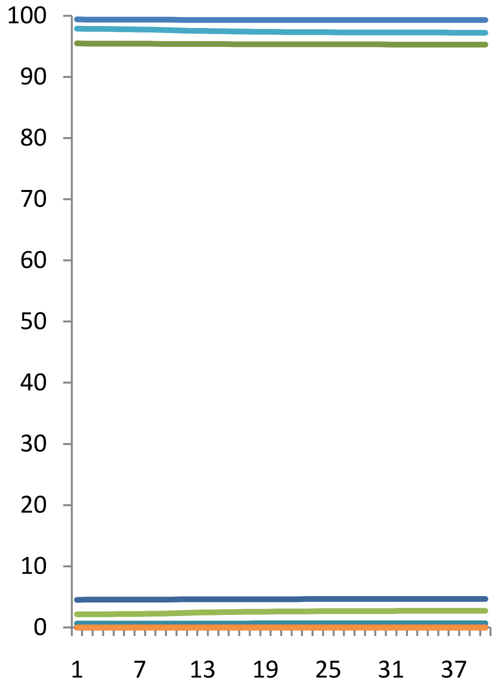
Plot 1
Number of Quote Revisions



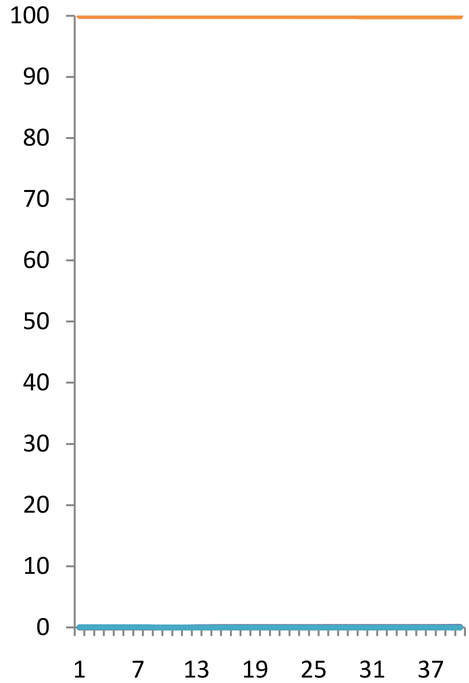
Plot 2
Quoted Spread



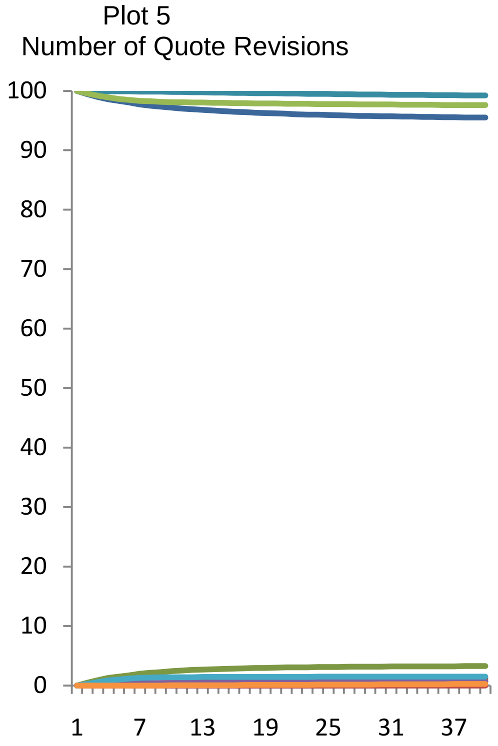
Plot 3
Volatility

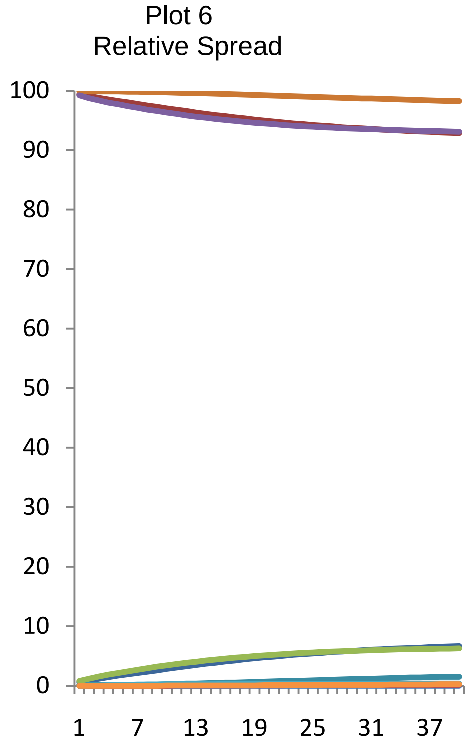


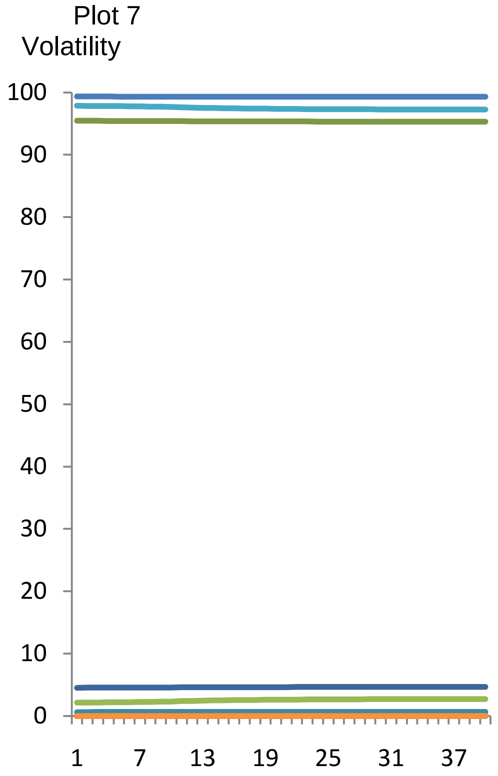
Plot 4
Interest Rate Differential

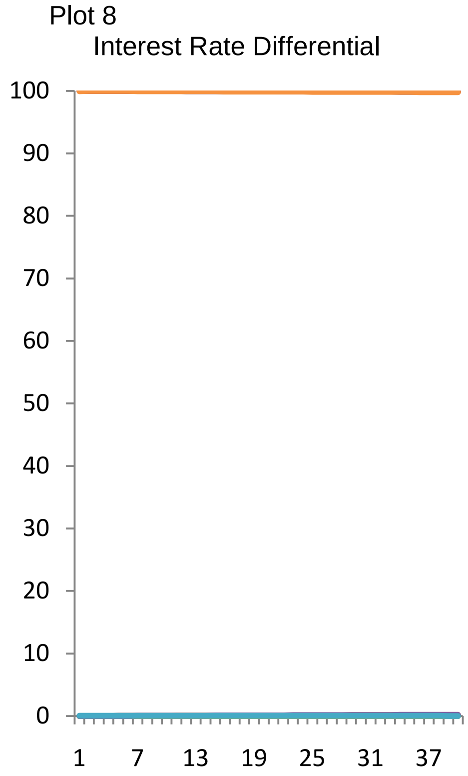


Relative Spread









Chapter 9: Summary and conclusions

Section 9.1: Summary of methodology and data

In this thesis I focus on the FX market microstructure by examining the determinants of bid-ask spread for three currencies pairs, the US dollar/Japanese yen (JP/US), the British pound/US dollar (GB/US) and the Euro/US dollar (EU/US) in different time zones. The main contribution of the empirical work is the examination of the commonality in liquidity with the elaboration of FX market microstructure variables in financial centres across the world (US, UK, JAPAN).

I use an aggregate sample using data from Olsen, that extends from 01.01.1995 to 31.01.2005 (full sample) and three other sub-samples in order to capture changes over the sample and during the Asian crisis. Since the FX market is in operation 24 hours and trading moves over the course of the 24hour day I segregate the data into three time zones; US time zone (New York), UK time zone (London) and Asia time zone (Tokyo). I use four currencies, US dollar, pound sterling, euro and yen, because they are the most traded ones in the FX market. According to the most recent research results by BIS (2007 survey), published in December of 2007, the most traded currency in all past BIS surveys was the US dollar, being on one side of at least 80% of transactions during the years. In 2007, the actual percentage was 86.3%. The euro remained the second most traded currency (37%) followed by the yen (16.5%) and the pound sterling (15%).

Section 9.2: Main findings and their implications

Using the ICSS algorithm to identify structural breaks in the variance of the exchange rate and spread series my work contributes in the empirical literature that examines the impact of Asian crisis on major currency spreads, the intraday spread patterns, and allows for a market wide comparison between exchange rate volatility and spread volatility. My results show that the number of volatility shifts was highest during the Asian crisis for the daily exchange rate series but not for the spread series. Moreover, I don't find enough evidence to support that spread volatility coincides with exchange rate volatility. In line with previous work [Baillie and Bollerslev (1990), Goodhart and Giugale (1993), Hsieh and Kleidon (1996)] I find seasonal patterns in the volatility of liquidity for the exchange rates under examination. As for the spreads they tend to be higher at the opening of the trading day but overall most of the change points are spread during the day. Identifying such patterns can be helpful as traders can choose the most advantageous time of the day (e.g times with high liquidity and lower costs) and financial market supervisors can become aware of consistent patterns in behaviour, which may have regulatory implications. Finally, I find that intraday spread series are much less volatile than the exchange rate series, that is, the determination of the cost of trading for market participants in general involves less risk even during periods of high exchange rate volatility.

My work also contributes in the FX microstructure literature on the determinants of the bid-ask spreads as most of the current work is fragmented. I use a wide range of variables, both inventory-based and information-based, across the three major financial markets, New York, London and Tokyo, to study the determinants of the bid-ask spread. Time-series regressions results [(GARCH 1,1) estimations] of daily and intraday bid-ask spreads on various potential determinants show that the explanatory variables work better when I use higher frequency data (intraday results). However, their explanatory power is significantly lower compared to the results based on the daily sample, as the R square statistics indicate. The key finding is that macroeconomic news announcements, such as base rate, GDP, CPI and trade balance announcements are significant in the determination of the intraday bid-ask spreads. This finding contributes to the existing microstructure literature on the effect of macroeconomic announcements on returns, trading volume and volatility. Moreover, regression results from both the daily and intraday samples show that quoted and relative spreads respond to changes in trading activity. The negative relationship of spread and trading activity is well-documented in the literature (Glassman 1987, Bessembinder, 1994, Ding 1999). My results are in line with other papers (Huang and Masulis 1999, Goodhart and Figliuoli 1991, Bollerslev and Domowitz 1993) that use the number of quote revisions as a proxy for trading activity and provide additional evidence using a much broader sample to support this relationship across locations[53].

The interest rate differential is statistically significant in almost all US (negative sign) and many UK estimated equations, but not in Asia estimated equations, when we the daily sample is considered. This may be explained by the fact that I use the dollar rate to consider the inventory holding cost. Of course, not all traders use the dollar to consider holding costs. Bessembinder (1994) finds that the coefficient on the Eurodollar based proxy for the opportunity cost of liquidity is positive for each currency (British pound, Swiss franc, Japanese, German mark). Becker and Sy (2005), researching bid-ask spreads for Asian emerging market currencies, find that the Eurodollar short-long differential has a coefficient with mixed sign and hardly turns up significant in any estimated equation. When I use the intraday sample, I find evidence that the interest rate differential has an impact on the spread in all three time zones. The coefficient of the volatility variable is positive and statistically significant for all quoted and relative spread in many cases in the US and UK time zones implying that an increase in volatility will increase the spread both for daily and intraday sample. The positive relationship between volatility and spreads is reported in many empirical papers, among others Bessembinder 1994, Glassman 1987, Boothe 1987, Bollerslev and Melvin 1994.

The last day of the month dummy is significant in some cases in the UK time zone but not in the US and ASIA, indicating that the last day of the month is not a significant variable to determine the shifts of the spreads under examination. The intraday results suggest that the EU/US quoted spread (US

[53] Previous papers cover periods ranging from few days to one or two years. However, I need to note that some papers use tick-by-tick data while I use five-minute intervals. I refer to a time-wise broader sample.

time zone) and JP/US spread (Asia time zone) increase due to last day of the month effect. This provides some additional support for the findings of Huang and Masulis (1999) that spreads are higher the last day of the month for the deutschmark/dollar rate.

I find evidence that spreads increase in the US and Asia (but not the UK) before holidays in major trading centers when common holidays across markets are considered. Bessembinder (1994) finds that holidays observed simultaneously in major financial centers are associated with higher spreads, while holidays in observed in only a single financial center do not decrease spreads significantly. Huang and Masulis (1999) find the deutschmark/dollar spread increases before Pacific, European and North American holidays but does not change significantly before Asian holidays. I also find that post holiday dummies have explanatory power on the spread. In particular, spread decreases after holidays are observed either in a single financial market or observed simultaneously in three financial markets. Using the intraday sample I find much stronger evidence that spreads increase before holidays in major trading centers when local holidays (US time zone) and when common holidays across markets are considered (all three time zones).

Theoretical and empirical research, for example Glassman (1987) and Bessembinder (1994), support the fact that spreads should be higher before weekends to reflect the increased risk and the reduced liquidity. However, I don't find any evidence that spreads are higher on Fridays using daily spread measures. This may be explained by the fact that spreads only increase late Friday, towards the end of the trading day. I find evidence that spreads increase before weekends when using five-minute interval data and Friday closing-time indicators. I also find that spreads decrease on Mondays reflecting the lower holding risk and increased liquidity.

My results suggest that there is a different quote revision pattern and different volatility impact before weekends and holiday, as for some spread equations the estimated parameters are significant. This implies that spreads in some cases are more sensitive to the number of quote revisions and volatility on

Fridays and before holidays. This means that market participants react differently to the increase in trading activity and volatility on different days. These results to some extent support the results of Bessembinder (1994), who finds that spreads are more sensitive to liquidity costs when combined with lack of liquidity over the weekends. Bessembinder also finds that these effects hold for days preceding holidays.

The VAR chapter contributes in the investigation of information asymmetry and volatility of liquidity across major financial centres. To my knowledge no other work is using a vector autoregression analysis to examine the effect of trading activity, exchange rate volatility and inventory holding costs on both quoted and relative spreads in the FX market. My results support the presence of asymmetric information in intraday trading. In addition, I find strong evidence of commonality in liquidity across major financial centres as this is documented by the similar general pattern of most variables examined in this chapter. The presence of commonality in liquidity has important implications to regulators and investors. Recent events during the financial crisis of 2007-2008 have highlighted the significance of liquidity and the importance of coordinated actions by central banks to restore liquidity. Investors, speculators and liquidity providers can understand better the risk of their trading, for example the effect of a sudden shock to market-wide liquidity, and how they should account for the premium for bearing liquidity risk in their FX return models.

Impulse responses for the daily sample show that in all time zones, spread is affected by prior trading activity (as captured by the number of quote revisions). A shock in the number of quote revisions has a long-term effect on the future spread. Moreover, for all currency pairs (both quoted and relative spread), the spread reacts strongly to own shocks, and these shocks have long-term effects especially for JP/US and GB/US. The effects of a shock in volatility on the spread are generally mixed, with the exception of JP/US spread that is affected positively by a change in volatility. Mixed signs are found for the impact of the interest rate differential variable on the spread - in line with Becker and Sy (2005), who find that the Eurodollar short-long differential has a coefficient with mixed sign[54] - with the exception of the EU/US spread.

The general pattern of the variance decompositions in the US time zone is very similar to the ASIA time zone, almost identical in many cases for the variance decompositions of spread. This provides strong evidence of the link between the trading in two different geographical areas, the markets of New York and Tokyo. Daily sample results suggest that the number of quote revisions variable is more important in determining the spread in the US and ASIA time zone than the UK time zone. Volatility and interest rate differential, explain only a small fraction of the variation in the spread. Overall, comparing the results from the three time zones, I find that trading activity has more impact on the spread in the US and ASIA time zones, while in the UK time zone, trading activity has less impact on spread. Finally, there is a two way causal relationship between the spread and trading activity in all three time zones.

Intraday VAR results show some differences in the behaviour of the variables at high frequencies compared to the results from the daily sample. A shock in the number of quote revisions has more effect on the spread when short term trading intervals are considered (intra-day) compared to its own shocks. When longer trading intervals are considered (daily) then the shocks in the spread have more effect on the future spread. In other words, the past trading activity is a more informative about the future spread when intra-day trading is considered while past spread is a more informative about the future spread when daily trading is considered. Moreover, I find more evidence of the positive impact of volatility on spread in the intra-day sample than in the daily sample. In all time zones, a very large percentage (over 92 percent) of the error variance in the spread is attributable to own shocks. The number of quote revisions variable has slightly higher explanatory power in the Asia time zone but still it doesn't exceed eight percent. As for the remaining variables, in

[54] Researching bid-ask spreads for Asian emerging market currencies.

all cases, volatility and interest rate differential, can't explain the spread variations (in all cases the value is close to zero).

Summarising, in this thesis I provide evidence of commonality in liquidity in major financial centres, New York, London and Tokyo based on the quotes of the three most active exchange rate currency pairs JP/US, GB/US, EU/US over a ten-year period. To my knowledge there is no other research that addresses commonality issues across different locations for a ten-year period comparing the results of three different currency pairs using both daily and intraday results.

Section 9.3: Future research

My thesis provides evidence of market-wide liquidity in the FX market. Future research should consider how this documented liquidity co-movement drives individual currency liquidity as this can prove useful for the investors and central banks. Moreover, another direction of research is the investigation of the effect of a sudden shock to market-wide liquidity, and how this should be accounted for in FX return models when determining the premium for bearing liquidity risk. Last but not list, since my results from the GARCH modelling suggests that other factors determine the behaviour of spreads at high frequencies (intraday) than at lower frequencies (daily) research in this area should investigate those plausible variables that can explain better the bid-ask spreads at high frequencies.

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Appendices

Appendix 1

The model presented below is developed by Lyons (2001) in order to show how a dealer determines his quotes and demands for the risky asset.

There are two periods in the model. In the first period the model shows how the dealer decides to place his outgoing interdealer orders (T_{it}, T_{i1} in particular, for the first period). His decision is conditional to three factors explained next. In the second period the model shows how the dealer decides to place outgoing interdealer order T_{i2} based also (now) on information from the first period.

Period 1

The dealer decides to place his outgoing interdealer orders (T_{it}) as follows:

a) Dealer *i* has his desired position (D_{it}) in the risky asset. The model assumes an initial position of zero.
b) Dealer *i*'s desired position will be altered by a customer placing an order. Let C_i denote the net customer order received by dealer *i*. Customers orders are distributed Normal (0, σ_c^2). Note also, that C_i is positive for net customer purchases and negative for net sales.
c) In addition to (b), dealer *i*'s desired position will be altered by the net incoming interdealer orders (T'_{it}) therefore, in period one he has to factor the expected value ($E[T'_{it1}]$) of that order based on his information set (Ω_{Ti1}).

Therefore, the interdealer trade in period 1 can be written as:

$$T_{i1} = D_{i1} + C_i + E[T'_{i1}|\Omega_{ti1}] \qquad \text{Eq. A1.1}$$

Period 2

If dealers *i* 's zero position is altered by a purchase (sale) order he must repurchase (resell) that amount in interdealer trading to reverse to his desired position (D_{i1}). Therefore, in period two the dealer decides to place his outgoing interdealer order as follows:

a) Dealer i's desired position (D_{i2}) in the risky asset.
b) Dealer i's position is reverted.
c) Dealer must again factor the net incoming dealer orders in period two based on his information set ($E[T_{i2}|\Omega_{ti2}$).
d) Dealer will adjust his outgoing interdealer orders according to his expectation of incoming interdealer order in period one- The actual incoming interdealer order less his expectation is the inventory shock ($T'_{i1} - E[T'_{i1}|\Omega_{ti1}]$)

Therefore, the interdealer trade in period 2 can be written as:

$$T_{i2} = D_{i2} + E[T'_{i2}|\Omega_{ti2}] - D_{i1} + T'_{i1} - E[T'_{i1}|\Omega_{ti1}] \qquad \text{Eq. A1.2}$$

At the close of period one, dealers observe period-one interdealer order flow (X). This can be analogous to the information provided by interdealer brokers. Customer-dealer trades have zero transparency and therefore, the aggregation of this type of trade information in prices, is both indirect and a "two-stage process". It is reflected in interdealer trades, which are later observable. However, one must note that the actual transparency of interdealer trades is not complete.

Dealer's wealth

Based on the above two-period procedure, Lyons develops the dealer's utility function in order to show how a dealer determines his quotes and demands form the risky asset. The objective for the dealer is to set his quotes and determine the demands for the risky asset to maximize a negative exponential utility function[3] defined over nominal wealth at the close of period two.

$$\text{MAX} \quad E[-\exp(-\theta W_{i2} | \Omega_i)] \qquad \text{Eq. A1.3}$$

$$W_{i2} = W_{i0} + C_i(P_{i1} - P'_{i1}) + (D_{i1} + E[T'_{i1}|\Omega_{Ti1}])(P'_{i2} - P'_{i1}) + (D_{i2} + E[T'_{i2}|\Omega_{Ti2}])(V - P'_{i2}) - T'_{i1}(P'_{i2} - P_{i1}) - T'_{i2}(V - P_{i2}) \qquad \text{Eq. A1.4}$$

Therefore, the final wealth of the dealer is based on the following:

a) The profit made by the dealer when repurchasing (reselling) the amount purchased (soled) by the customer. For example, the dealer sells to the customer at P_{i1} and buys the same quantity back from another dealer at P'_{i1}.

$$C_i(P_{i1} - P'_{i1})$$

b) The capital gains from hedging against incoming orders from other dealers in period one and period two.

$$(D_{i1} + E[T'_{i1}|\Omega_{Ti1}])(P'_{i2} - P'_{i1}) + (D_{i2} + E[T'_{i2}|\Omega_{Ti2}])(V - P'_{i2})$$

c) The position disturbances due to inventory shocks, since dealers trade simultaneously. When dealer i decides on his outgoing orders, T_{i1}, he does not know the incoming orders, T'_{i1}, in the same period, because these are placed simultaneously.

$$T'_{i1}(P'_{i2} - P_{i1}) - T'_{i2}(V - P_{i2})$$

Where, V, is the payoff on the risky asset at the end of period two, P_i is the dealers quote, and P'_i a quote or trade received by dealer i.

Dealer Equilibrium Trading Strategies

Finally, Lyons in his model defines the dealer equilibrium trading strategies. In order to do so, he first defines the equilibrium quoting strategies in period one and period two. The assumption here is that quotes must be the same across dealers at any given time otherwise arbitrage opportunities will arise and quotes must be based on common information.

In period one, there is only one piece of information (the signal S) therefore, the quoting strategy in period one will be:

$$P_1 = \Lambda_s S \qquad \text{Eq. A1.5}$$

where Λ_s, is a coefficient that measures the size of the signal and produces an unbiased estimate of the value V conditional on S.

In period two, quoting strategy will be the same as in period one plus that in period two, public information available, includes also the interdealer order flow X in addition to the public signal. As was explained earlier, the dealer will pass his undesired quantity to another dealer according to the position disturbance T'_{i1}.

$$P_2 = \Lambda_2 S\, P_1 + \Lambda_x X \qquad \text{Eq.A1.6}$$

X's (interdealer orders) role is very important here. As Lyons notes "Order flow X does not convey all of the information (it conveys some), so P_2 does not fully impound all of that information. Any private information not reflected in P_2 becomes a basis for speculative demands in period two".

From equations (5) and (6) the optimal trading strategy for both periods for all dealers is the following:

$$T_{i1} = \beta_{11}C_i + \beta_{21}S_i + \beta_{31}S - \beta_{41}P_1 \qquad \text{Eq.A1.7}$$

$$T_{i2} = \beta_{12}C_i + \beta_{22}S_i + \beta_{32}S - \beta_{42}T'_{i1} + \beta_{52}X - \beta_{62}P_2 \qquad \text{Eq.A1.8}$$

Appendix 2

Ding (1999) models a market where dealers (M active dealers) and customers are the only participants. Below I present the details of the model.

Before describing how the optimal quotes are derived lets explain some notations that are used in the model.

$p^0 + \alpha_i$: ask price

$p^0 - b_i$: bid price (a symmetric form of bid-ask prices is considered)

Q: potential order size to dealer i.

I_i: dealer i's inventory change

F: fixed costs

z: expected price change of FX

If a new order hits the dealer and dealer quotes bid-ask prices, there are three possible scenarios. First, scenario is that the quotes are note accepted therefore no transaction occurs. Second, the dealers quotes are accepted and he sells Q at the ask price. Third, the dealers quotes are accepted and he buys Q at the bid price.

Dealer i's wealth at the end of each period according to the above possible outcomes are:

- Quotes not accepted

$$W_i(0) = C_i - \bar{F}_i + I_i(p^0 + z)$$

- Ask quote accepted

$$W_i(\alpha_i) = C_i - \bar{F}_i + (I_i - Q)(P^0 + z) + (p^0 + \alpha_i)Q$$

- Bid quote accepted

$$W_i(b_i) = C_i - \bar{F}_i + (I_i + Q)(P^0 + z) + (p^0 - b_i)Q$$

Each of the above outcomes should be indifferent to the dealer therefore his reservation quotes should make the following equation to hold.

$$E(U(W(0))|S_i) = E(U(W(\alpha^r_i))|S_i) = E(U(W(b^r_i))|S_i) \qquad \text{Eq.A2.1}$$

where S_i is the information set of dealer i.

It is clear then, that the dealer must set optimal bid ask prices to maximize expected utility.

Optimal quotes

Ding discusses the optimal ask quote and optimal bid quote both for the interdealer market and the customer market. The approach is similar to each case and is based on the estimation of the probability π_α, which is the probability that dealer i's ask quote is accepted and order is served by him. The optimal quote derivation therefore becomes a question of how π_α can be estimated. The rationale behind it lays in the relationship between best available price in the market (lowest ask price) and dealer inventory levels. In particular, if dealer i is chosen to be bought from, it means that his ask price is lower that any other's (electronic interdealer dealing system like Reuters 2000-1 displays real time best bid-ask prices). The probability then, that dealer i's quote is accepted is equivalent to the probability that his ask price is lowest among the dealers. Moving that a step further, one can conclude that this probability now (his ask price is lowest among the dealers) is equal with the probability that his inventory is larger than others. The explanation is that if a dealer has the highest undesirable inventory he must offer the lowest price to lower this inventory and bring his position to the "ideal" one. Taking all the above assumptions and consideration together and applying them for the bid quote, as well as the bid-ask quotes in the customer market, Ding derives the middle points of the quotes and spreads for both the interdealer market and customer market.

Interdealer market:

$$P_i^{1,d} = \frac{P^0 + \alpha_i^d + (P^0 - b_i^d)}{2} = P^0 - A\sigma^2(1 - 1/M)I_i + E(z|S_i) \qquad \text{Eq.A2.2}$$

$$S_i^d = (P^0 - \alpha_i^d) - (P^0 - b_i^d) = A\sigma^2(Q + 2R/M) \qquad \text{Eq.A2.3}$$

Customer market:

$$P_i^{1,c} = \frac{P^0 + \alpha_i^c + (P^0 - b_i^c)}{2} = P^0 - A\sigma^2(1 - 1/M)I_i + E(z|S_i) \qquad \text{Eq.A2.4}$$

$$S_i^c = (P^0 - \alpha_i^c) - (P^0 - b_i^c) = A\sigma^2(Q + 2R/M + 2f(\delta_i c)/M) \qquad \text{Eq.A2.5}$$

The effect of order flow can be written as:

$$\Delta P_t = r_t + \beta_1 O^c + \beta_2 O^d \qquad \text{Eq.A2.6}$$

Where $\beta_1 = [A\sigma^2(1 - 1/M) + \alpha_1]$ and $\beta_2 = [A\sigma^2(1 - 1/M) + \alpha_2]$ $\quad 0<\beta_1< \beta_2$

O^c: customers to dealer transactions
O^d: interdealer transactions

Appendix 3

Chakrabarti (2000) builds a model of bid-ask spreads in the foreign exchange market based on the idea that dealers learn in a Bayesian fashion about the excess demand situation from one other's quotes and their inventory positions (their overnight costs).

The objective function of a representative dealer at the beginning of a trading is:

$$\tilde{U} = E_0\{\Sigma\ [\alpha_t S_t - b_t B_t - \kappa Q_t^2 var_t(p)]\} + p_0 Q_T - V_0 Q_0 - \lambda Q_T^2 var_T(p), \qquad \text{Eq. A3.1}$$

with t going from 0 to T.

where

a= ask price, or the reserve selling price for the caller

b = bid price, or the reserve buying price of the caller.

S = quantity sold

B = quantity bought

Q= the inventory of deutsche mark

Q_T= the expected end-of-day own-account inventory of the dealer.

T= measure of time in the model

v= market clearing exchange rate. The rate at which the supply of deutsche marks equals the demand for deutsche marks among the customers of all banks, such that the net excess demand for deutsche marks is zero.

V_0= the observed price of deutsche marks at the beginning of the day. It can be the observed closing price of another financial centre.

p= the dealers estimate of v in terms of the probability distribution of an estimating variable, p, a dynamic distribution that gets updated every time a dealer receives new quote.

p= expected value of p at time 0.

The dealer is faced with two inventory risks. The risk of taking a position at any point in day until he receives or succeeds in making another call and the risk of holding an inventory position overnight. Obviously, the risk of holding inventory overnight is much higher due to the longer time period, therefore, the dealer will set a higher price. The letters k and λ in equation 1 represent the price of the risk associated in these two cases. The dealer will set the ask and bid, so as to maximize U.

Appendix 4

Chakrabarti (2000) builds a model of bid-ask spreads in the foreign exchange market based on the idea that dealers learn in a Bayesian fashion about the excess demand situation from one other's quotes and their inventory positions (their overnight costs). Below I present the details of the model.

Let us consider that the liquidity traders constitute the proportion 1-λ of the total market participants. Informed traders receive some information about the true value of the exchange rate, s_t.

At time t-1, a market making trader will set bid-ask quotes, B_t and A_t, good for trading at time t. The bid-ask spread is assumed to be set symmetrically around the known fundamental price prevailing at the time of quote formation.

$$A_t = s_{t-1} + k_{t,t-1} \quad \text{Eq. A4.1}$$

$$B_t = s_{t-1} + k_{t,t-1} \quad \text{Eq. A4.2}$$

Therefore, the quoted spread for trades at time t is

$K_t = A_t – B_t = 2k_{t,t-1}$ and depends on time t-1 information only.

Then the authors determine the expected profits and losses, from trading with uninformed traders and informed traders respectively.

The expected profit from trading with liquidity-motivated traders is

$$E_{t-1}(\pi_t^i) = 2[k_{t,t-1} - \sigma_t E(Z_t \mid k_{t,t-1}\, \sigma_t^{-1} < Z_t)][1-P(Z_t < k_{t,t-1}\, \sigma_t^{-1})]<0 \quad \text{Eq. A4.3}$$

The expected lose from trading with informed traders is

$$E_{t-1}(\pi_t^u) = E_{t-1}(1/2(A_t – s_t) + ½(s_t – B_t)) = k_{t,t-1} >0 \quad \text{Eq. A4.4}$$

Therefore, by combining the above two equations one can derive the expected profit for the market maker conditional on time t-1 information:

$$E_{t-1}(\pi_t) = 2\lambda[k_{t,t-1} - \sigma_t E(Z_t \mid Z_t > k_{t,t-1}\, \sigma_t^{-1})][1-P(Z_t < k_{t,t-1}\, \sigma_t^{-1})] + (1 - \lambda)k_{t,t-1} \quad \text{Eq. A4.5}$$

In equilibrium, competition from other banks or market-makers will drive this expected profit to zero. Expressing this zero profit condition in terms of the total spread, yields

$$K_t = \sigma_t 4\lambda E(Z_t \mid Z_t > k_{t,t-1}\, \sigma_t^{-1})][1-P(Z_t < k_{t,t-1}\, \sigma_t^{-1})] \times [1 + \lambda - 2\lambda P(Z_t < k_{t,t-1}\, \sigma_t^{-1})]^{-1} \quad \text{Eq. A4.6}$$

Since the conditional expectation and probabilities on the right-hand side of the above equation only depend on the time t-1 information set through $k_{t,t-1}$ σ_t^{-1}, it follows that in equilibrium the spread must move proportional to the conditional standard deviation of the true fundamental value of the exchange rate.

Appendix 5

Table A5.1: Summary Statistics for Quoted Spread, Sample Period 1-3

Summary statistics for the daily mean quoted spread (Periods 1-3) of US/JP, GB/US and EU/US exchange rates for different time zones. Period 1 sample extends from 01.01.1995 to 31.05.1997. The results are based on 630 daily mean spreads. Period 2 sample extends from 01.06.1997 to 31.12.1998. The results are based on 414 daily mean spreads. Period 3 sample extends from 01.01.1999 to 31.12.2005 (for the EU/US from 01.01.2001). The results are based on 1586 daily mean spreads (1066 for the EU/US). The daily mean spreads were calculated based on the last bid-ask quotes recorded at 5-minute intervals, between 8:00am and 5:00pm local time, obtained from Olsen.

Table A5.2: Summary Statistics for Relative Spread, Sample Period 1-3

Summary statistics for the daily mean relative spread (Periods 1-3) of US/JP, GB/US and EU/US exchange rates for different time zones. Period 1 sample extends from 01.01.1995 to 31.05.1997. The results are based on 630 daily mean spreads. Period 2 sample extends from 01.06.1997 to 31.12.1998. The results are based on 414 daily mean spreads. Period 3 sample extends from 01.01.1999 to 31.12.2005(for the EU/US from 01.01.2001). The results are based on 1586 daily mean spreads (1066 for the EU/US). The daily mean relative spreads were calculated based on the difference of the logarithm of the ask price and the logarithm of the bid price. The logarithmic bid and ask values are based on the last bid-ask quotes recorded at 5-minute intervals, between 8:00am and 5:00pm local time, obtained from Olsen.

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Table A5.3: Summary Statistics for Daily Number of Quote Revisions, Sample Period 1-3

Summary statistics for the daily mean number of quote revisions (Period s 1-3) of US/JP, GB/US and EU/US exchange rates for different time zones. Period 1 sample extends from 01.01.1995 to 31.05.1997. The results are based on 630 daily mean quote revisions. Period 2 sample extends from 01.06.1997 to 31.12.1998. The results are based on 414 daily mean quote revisions. Period 3 sample extends from 01.01.1999 to 31.12.2005 (for the EU/US from 01.01.2001). The results are based on 1586 daily mean quote revisions (1066 for the EU/US). The daily mean quote revisions were calculated based on the number of quote revisions recorded in 5-minute intervals, between 8:00am and 5:00pm local time, obtained from Olsen.

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Table A5.4: Intraday Mean Quoted Spread, Period 1 Sample

Intraday quarter-hour mean quoted spread (Period 1, mean spreads X 100) of JP/US and GB/US exchange rates for different time zones calculated based on the last bid-ask quotes recorded at 5-minute intervals, between 8:00am and 5:00pm local time, obtained from Olsen. Period 1 sample extends from 01.01.1995 to 31.05.1997. Interval 1 covers the trading quarter between 8:00am-8:15am and interval 36 4:45pm to 5:00pm

Table A5.5: Intraday Mean Relative Spread, Period 1 Sample

Intraday quarter-hour mean relative spread (Period 1, mean spreads X 100) of JP/US and GB/US exchange rates for different time zones calculated based on the last bid-ask quotes recorded at 5-minute intervals, between 8:00am and 5:00pm local time, obtained from Olsen. Period 1 sample extends from 01.01.1995 to 31.05.1997. Interval 1 covers the trading quarter between 8:00am-8:15am and interval 36 4:45pm to 5:00pm

Table A5.6: Intraday Quoted Spread Variance, Period 1 Sample

Intraday quarter-hour quoted spread variance (Period 1, variance X 1,000,000) of JP/US and GB/US exchange rates for different time zones calculated based on the last bid-ask quotes recorded at 5-minute intervals, between 8:00am and 5:00pm local time, obtained from Olsen. Period 1 sample extends from 01.01.1995 to 31.05.1997. Interval 1 covers the trading quarter between 8:00am-8:15am and interval 36 between 4:45pm to 5:00pm.

Table A5.7: Intraday Relative Spread Variance, Period 1 Sample

Intraday quarter-hour relative spread variance (Period 1, variance X 1,000,000) of JP/US and GB/US exchange rates for different time zones calculated based on the last bid-ask quotes recorded at 5-minute intervals, between 8:00am and 5:00pm local time, obtained from Olsen. Period 1 sample extends from 01.01.1995 to 31.05.1997. Interval 1 covers the trading quarter between 8:00am-8:15am and interval 36 between 4:45pm to 5:00pm.

	UK Time Zone		US Time Zone		ASIA Time Zone	
Interval	JP/US	GB/US	JP/US	GB/US	JP/US	GB/US
1(8:15)	0.0158	0.0043	0.0138	0.0058	0.0118	0.0045
2(8:30)	0.0154	0.0046	0.0142	0.0056	0.0119	0.0043
3(8:45)	0.0149	0.0045	0.0139	0.0057	0.0160	0.0076
4(9:00)	0.0153	0.0048	0.0148	0.0050	0.0170	0.0085
5(9:15)	0.0156	0.0044	0.0140	0.0043	0.0170	0.0082
6(9:30)	0.0159	0.0046	0.0143	0.0044	0.0179	0.0083
7(9:45)	0.0151	0.0048	0.0143	0.0045	0.0173	0.0100
8(10:00)	0.0148	0.0046	0.0146	0.0041	0.0199	0.0088
9(10:15)	0.0141	0.0046	0.0139	0.0053	0.0186	0.0092
10(10:30)	0.0146	0.0048	0.0138	0.0047	0.0187	0.0091
11(10:45)	0.0140	0.0047	0.0138	0.0044	0.0188	0.0088
12(11:00)	0.0150	0.0048	0.0129	0.0046	0.0204	0.0077
13(11:15)	0.0143	0.0047	0.0138	0.0046	0.0199	0.0092
14(11:30)	0.0148	0.0044	0.0146	0.0045	0.0206	0.0075
15(11:45)	0.0151	0.0048	0.0156	0.0047	0.0191	0.0096
16(12:00)	0.0138	0.0050	0.0159	0.0054	0.0190	0.0081
17(12:15)	0.0153	0.0045	0.0174	0.0054	0.0178	0.0071
18(12:30)	0.0138	0.0046	0.0162	0.0061	0.0171	0.0066
19(12:45)	0.0139	0.0049	0.0157	0.0063	0.0148	0.0064
20(13:00)	0.0150	0.0049	0.0170	0.0059	0.0161	0.0064
21(13:15)	0.0134	0.0045	0.0176	0.0057	0.0160	0.0060
22(13:30)	0.0139	0.0046	0.0159	0.0058	0.0166	0.0070
23(13:45)	0.0136	0.0046	0.0162	0.0056	0.0189	0.0072
24(14:00)	0.0148	0.0048	0.0165	0.0069	0.0187	0.0085
25(14:15)	0.0140	0.0045	0.0163	0.0065	0.0175	0.0081
26(14:30)	0.0143	0.0044	0.0164	0.0059	0.0194	0.0075
27(14:45)	0.0142	0.0045	0.0160	0.0064	0.0202	0.0074
28(15:00)	0.0145	0.0042	0.0171	0.0059	0.0194	0.0081
29(15:15)	0.0139	0.0053	0.0176	0.0062	0.0190	0.0076
30(15:30)	0.0137	0.0047	0.0160	0.0060	0.0183	0.0060
31(15:45)	0.0138	0.0044	0.0157	0.0060	0.0190	0.0058
32(16:00)	0.0129	0.0046	0.0162	0.0061	0.0184	0.0057
33(16:15)	0.0138	0.0045	0.0174	0.0061	0.0166	0.0045
34(16:30)	0.0146	0.0045	0.0142	0.0070	0.0154	0.0050
35(16:45)	0.0156	0.0047	0.0139	0.0054	0.0152	0.0045
36(17:00)	0.0158	0.0053	0.0123	0.0061	0.0161	0.0048

Table A5.8: Intraday Mean Number of Quote Revisions, Period 1 Sample

Intraday quarter-hour mean number of quote revisions (full sample) of JP/US, GB/US and EU/US exchange rates for different time zones calculated based on the number of quote revisions recorded in 5-minute intervals, between 8:00am and 5:00pm local time, obtained from Olsen. For the JP/US and the GB/US the full sample extends from 01.01.1995 to 31.01.2005. For the EU/US exchange rate the sample is from 01.01.2001 to 31.01 2005. Interval 1 covers the trading quarter between 8:00am-8:15am and interval 36 between 4:45pm to 5:00pm

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Table A5.9: Intraday Mean Quoted Spread, Period 2 Sample

Intraday quarter-hour mean quoted spread (Period 1, mean spreads X 100) of JP/US and GB/US exchange rates for different time zones calculated based on the last bid-ask quotes recorded at 5-minute intervals, between 8:00am and 5:00pm local time, obtained from Olsen. Period 2 sample extends from 01.06.1997 to 31.12.1998. Interval 1 covers the trading quarter between 8:00am-8:15am and interval 36 between 4:45pm to 5:00pm.

Table A5.10: Intraday Mean Relative Spread, Period 2 Sample

Intraday quarter-hour mean relative spread (Period 1, mean spreads X 100) of JP/US and GB/US exchange rates for different time zones calculated based on the last bid-ask quotes recorded at 5-minute intervals, between 8:00am and 5:00pm local time, obtained from Olsen. Period 2 sample extends from 01.06.1997 to 31.12.1998. Interval 1 covers the trading quarter between 8:00am-8:15am and interval between 36 4:45pm to 5:00pm.

Table A5.11: Intraday Quoted Spread Variance, Period 2 Sample

Intraday quarter-hour quoted spread variance (Period 2, variance X 1,000,000) of JP/US and GB/US exchange rates for different time zones calculated based on the last bid-ask quotes recorded at 5-minute intervals, between 8:00am and 5:00pm local time, obtained from Olsen. Period 2 sample extends from 01.06.1997 to 31.12.1998. Interval 1 covers the trading quarter between 8:00am-8:15am and interval 36 between 4:45pm to 5:00pm.

Table A5.12: Intraday Relative Spread Variance, Period 2 Sample

Intraday quarter-hour relative spread variance (Period 2, variance X 1,000,000) of JP/US and GB/US exchange rates for different time zones calculated based on the last bid-ask quotes recorded at 5-minute intervals, between 8:00am and 5:00pm local time, obtained from Olsen. Period 2 sample extends from 01.06.1997 to 31.12.1998. Interval 1 covers the trading quarter between 8:00am-8:15am and interval 36 between 4:45pm to 5:00pm.

Table A5.13: Intraday Mean Number of Quote Revisions, Period 2 Sample

Intraday quarter-hour mean number of quote revisions (full sample) of JP/US and GB/US exchange rates for different time zones calculated based on the number of quote revisions recorded in 5-minute intervals, between 8:00am and 5:00pm local time, obtained from Olsen. Period 2 sample extends from 01.06.1997 to 31.12.1998. Interval 1 covers the trading quarter between 8:00am-8:15am and interval 36 between 4:45pm to 5:00pm.

Table A5.14: Intraday Mean Quoted Spread, Period 3 Sample

Intraday quarter-hour mean quoted spread (Period 3, mean spreads X 100) of US/JP, GB/US and EU/US exchange rates for different time zones calculated based on the last bid-ask quotes recorded at 5-minute intervals, between 8:00am and 5:00pm local time, obtained from Olsen. Period 3 sample extends from 01.01.1999 to 31.12.2005 (for the EU/US from 01.01.2001). Interval 1 covers the trading quarter between 8:00am-8:15am and interval 36 between 4:45pm to 5:00pm.

Table A5.15: Intraday Mean Relative Spread, Period 3 Sample

Intraday quarter-hour mean relative spread (Period 3, mean spreads X 10,000) of US/JP, GB/US and EU/US exchange rates for different time zones calculated based on the last bid-ask quotes recorded at 5-minute intervals, between 8:00am and 5:00pm local time, obtained from Olsen. Period 3 sample extends from 01.01.1999 to 31.12.2005 (for the EU/US from 01.01.2001). Interval 1 covers the trading quarter between 8:00am-8:15am and interval 36 between 4:45pm to 5:00pm.

Table A5.16: Intraday Quoted Spread Variance, Period 3 Sample

Intraday quarter-hour quoted spread variance (Period 3, variance X 1,000,000) of US/JP, GB/US and EU/US exchange rates for different time zones calculated based on the last bid-ask quotes recorded at 5-minute intervals, between 8:00am and 5:00pm local time, obtained from Olsen. Period 3 sample extends from 01.01.1999 to 31.12.2005 (for the EU/US from 01.01.2001). Interval 1 covers the trading quarter between 8:00am-8:15am and interval 36 between 4:45pm to 5:00pm.

Table A5.17: Intraday Relative Spread Variance, Period 3 Sample

Intraday quarter-hour relative spread variance (Period 3, mean spreads X 1,000,000) of US/JP, GB/US and EU/US exchange rates for different time zones calculated based on the last bid-ask quotes recorded at 5-minute intervals, between 8:00am and 5:00pm local time, obtained from Olsen. Period 3 sample extends from 01.01.1999 to 31.12.2005 (for the EU/US from 01.01.2001). Interval 1 covers the trading quarter between 8:00am-8:15am and interval 36 between 4:45pm to 5:00pm.

Table A5.18: Intraday Mean Number of Quote Revisions, Period 3 Sample

Intraday quarter-hour mean number of quote revisions (full sample) of JP/US, GB/US and EU/US exchange rates for different time zones calculated based on the number of quote revisions recorded in 5-minute intervals, between 8:00am and 5:00pm local time, obtained from Olsen. Period 3 sample extends from 01.01.1999 to 31.01.2005 (from 01.01.2001 for EU/US). Interval 1 covers the trading quarter between 8:00am-8:15am and interval 36 between 4:45pm to 5:00pm

Appendix 6

Panels A – I: Time Series Regressions for Daily Sample

(US, UK and Asia Time Zone, Period 1, 2 and 3 Sample)

Depended variables are daily mean quoted and relative spreads. The daily mean quoted spreads were calculated based on the last recorded bid and ask quotes at 5-minute intervals, between 8:00am and 5pm local time. The daily mean relative spreads were calculated based on the difference of the logarithm of the ask price and the logarithm of the bid price. The logarithmic bid and ask values are based on the last bid-ask quotes recorded at 5-minute intervals, between 8:00am and 5:00pm local time. Explanatory variables are the number of quote revision: mean quote revisions were calculated based on the number of quote revisions recorded in 5-minute intervals, between 8:00am and 5:00pm local time; Interest rate differential between Eurodollar overnight deposit rates (short) and Eurodollar one month deposit rate (long); *Volatility*: the difference between the highest ask price and lowest bid price during a trading day; *Preceding Holiday*: 1.0 if a trading day satisfies the following conditions: (1) if holiday falls on Monday, then the preceding Friday, (2) if any holiday falls on another weekday, then the preceding day, and 0 otherwise; *Post Holiday*: 1.0 if a trading day satisfies the following conditions: (1) if holiday falls on Friday, then the following Monday, (2) if any holiday falls on another weekday, then the following day, and 0 otherwise; *Last Day of Month*: 1.0 if the last trading day of the month, and 0 otherwise; *Monday/Friday*: 1.0 if the trading day is a Monday/Friday and 0 otherwise; *IR(0):* 1.0 on the day of an interest rate announcement, and 0 otherwise; *IR(1-2)*: 1.0 on the two trading days prior to an interest rate announcement, and 0 otherwise; *GDPP(0)*: 1.0 on the day of a GDP (preliminary) announcement, and 0 otherwise; *GDPP(1-2)*: 1.0 on the two trading days prior to a GDP (preliminary) announcement, and 0 otherwise; *CPI(0), CPI(1-2), TB(0), TB(1-2))*: Defined as for GDP but for CPI and TB respectively; *Multiplicative Dummies:* Friday X Quote Revisions (or Volatility): 1.0 if the trading day is Friday, and 0 otherwise; Prec. Holiday X Quote Revisions (or Volatility): 1.0 if a trading day satisfies the following conditions: (1) if holiday falls on Monday, then the preceding Friday, (2) if any holiday falls on another weekday, then the preceding day, and 0 otherwise; *Lagged Spread*: the previous spread observation; *DFD (Data Feeder Dummies), DFD2:* 02Apr01 - 12Sep01 (Reuters and Alt1, this is the period for which the two data feeders overlap); *DFD3:* 25Mar01 - 11May01 (Reuters, Alt1 and Alt2, this is the period for which the three data feeders overlap)*; DFD4:* 03Sep01 - 12Sep01 (Reuters, Alt1, Alt2 and Oanda, this is the period for which the four data feeders overlap); *DFD5:* 14Aug01 - 12Sep01 (Reuters, Alt1, Alt2, Oanda, and Tenfore1, this is the period for which the five data feeders overlap); *DFD6:* 26Nov - 31Jan05 (Oanda,Tenfore1 and Tenfore2, this is the period for which these data feeders overlap); α_o: the constant in the conditional variance equation; α_1 : the coefficient of the past squared residuals of the conditional variance; β_1: the coefficient of the past values of the conditional variance.

Panel A: US Time Zone, Period 1 Sample								
	Quoted Spread				Relative Spread			
	JP/US		GB/US		JP/US		GB/US	
Parameter	Estimate	P-value	Estimate	P-value	Estimate	P-value	Estimate	P-value
Number of Quote Revisions	-0.0035112600	[.097]**	-0.0000901400	[.004]*	-0.0000088382	[.332]	-0.0000260821	[.003]*
Interest Rate	-0.7212690000	[.049]*	-0.0056036900	[.084]**	-0.0014053400	[.384]	-0.0015563800	[.080]
Volatility	0.0061599700	[.000]*	0.0046368400	[.000]*	0.0000226231	[.000]*	0.0011580900	[.000]*
Seasonality (US)								
Preceding Holiday:								
US only	0.0077426300	[.654]	0.0002684290	[.030]*	0.0000298743	[.633]	0.0000625059	[.058]**
Common	-0.0069880400	[.389]	-0.0001982320	[.000]*	-0.0000319751	[.310]	-0.0000516105	[.000]*
Post Holiday:								
US only	-0.0032070200	[.011]	-0.0000216958	[.088]**	-0.0000165491	[.005]*	-0.0000065728	[.086]**
Common	-0.0051121900	[.222]	-0.0000400924	[.395]	-0.0000270241	[.199]	-0.0000112919	[.362]
Last Day of Month	0.0007621810	[.461]	0.0000122693	[.448]	0.0000023161	[.624]	0.0000035553	[.146]
Monday	-0.0014905000	[.017]	-0.0000049018	[.389]	-0.0000077353	[.008]*	-0.0000011927	[.404]
Friday	0.0176180000	[.001]*	0.0000163665	[.799]	0.0000773098	[.001]*	0.0000042367	[.814]
Macroeconomic Ann. (US)								
GDP preliminary: GDPP(0)	-0.0009478120	[.428]	0.0000062671	[.728]	-0.0000022295	[.626]	0.0000000748	[.983]
GDP preliminary: GDPP(1-2)	0.0007541540	[.655]	0.0000016368	[.897]	0.0000026637	[.733]	-0.0000003084	[.902]
Consumer Price Index: CPI (0)	-0.0012054600	[.220]	-0.0000038972	[.660]	-0.0000030761	[.457]	-0.0000012431	[.610]
Consumer Price Index: CPI (1-2)	-0.0005593500	[.445]	0.0000080632	[.101]	-0.0000016410	[.615]	0.0000021524	[.096]**
Federal Fund Rate: IR (0)	0.0041008500	[.033]*	0.0000204988	[.460]	0.0000200486	[.014]*	0.0000074987	[.106]
Federal Fund Rate: IR (1-2)	0.0001050840	[.918]	-0.0000011497	[.900]	0.0000018202	[.714]	-0.0000003531	[.890]
Trade Balance:TB (0)	0.0001670660	[.876]	0.0000121218	[.261]	-0.0000001579	[.973]	0.0000037683	[.243]
Trade Balance:TB (1-2)	0.0005547600	[.479]	-0.0000128955	[.070]**	0.0000015229	[.681]	-0.0000036567	[.073]**
Multiplicative Dummies								
Friday X Quote Revisions	-0.0123690000	[.008]*	-0.0000186880	[.728]	-0.0000530927	[.009]*	-0.0000058726	[.677]
Prec. Holiday X Quote Revisions	-0.0062852400	[.679]	-0.0002661250	[.004]*	-0.0000249011	[.645]	-0.0000633804	[.010]*
Friday X Volatility	-0.0012321800	[.447]	0.0004976820	[.709]	-0.0000073314	[.298]	0.0002978750	[.210]
Prec. Holiday X Volatility	0.0032134400	[.174]	0.0078521600	[.124]	0.0000170436	[.066]**	0.0019948100	[.112]
Lagged Spread	0.6313630000	[.000]*	0.5341730000	[.000]	0.8496680000	[.000]*	0.4971450000	[.000]*
α_0	0.0000050918	[.026]*	0.0000000012	[.000]	0.0000000001	[.096]**	0.0000000001	[.000]*
α_1	0.1039540000	[.197]	0.4940280000	[.005]*	0.1321770000	[.046]*	0.5113370000	[.002]*
β_1	0.7326690000	[.000]*	0.1981060000	[.132]	0.7044880000	[.000]*	0.1367550000	[.224]
Intercept	0.0242610000		0.0004342650		0.0000363789		0.0001300420	
Adjusted R-squared	0.591452		0.439399		0.807251		0.414111	
a: resutls estimated with OLS, *: 5 percent level of significance, **: 10 percent level of significance								

Panel B: UK Time Zone, Period 1 Sample								
	Quoted Spread				Relative Spread			
	JP/US		GB/US		JP/US		GB/US	
Parameter	Estimate	P-value	Estimate	P-value	Estimate	P-value	Estimate	P-value
Number of Quote Revisions	0.0043670200	[.003]*	0.0000398029	[.006]*	0.0000107829	[.062]**	0.0000118998	[.000]*
Interest Rate	-1.4772600000	[.000]*	-0.0043232700	[.087]	-0.0048943900	[.009]*	-0.0018241900	[.003]*
Volatility	0.0037046000	[.000]*	0.0019892400	[.000]*	0.0000158152	[.000]*	0.0004042800	[.003]*
Seasonality (UK)								
Preceding Holiday:								
UK only	-0.0164530000	[.073]**	-0.0003574400	[.038]	-0.0000637038	[.124]	-0.0000990437	[.071]**
Common	-0.0058350100	[.154]	-0.0000154996	[.764]	-0.0000463861	[.005]*	-0.0000021065	[.854]
Post Holiday:								
UK only	0.0020508900	[.369]	0.0000167286	[.454]	0.0000074720	[.372]	0.0000035845	[.517]
Common	0.0037497500	[.513]	0.0000252352	[.414]	0.0000124731	[.672]	0.0000044229	[.567]
Last Day of Month	0.0015919200	[.044]*	0.0000120331	[.088]**	0.0000049655	[.120]	0.0000030341	[.085]**
Monday	-0.0005182500	[.377]	0.0000022288	[.649]	-0.0000034086	[.169]	0.0000008473	[.514]
Friday	0.0210160000	[.000]*	0.0000937646	[.129]	0.0001023020	[.000]*	0.0000185091	[.144]
Macroeconomic Ann. (UK)								
GDP preliminary: GDPP(0)	0.0010501700	[.594]	-0.0000292275	[.019]*	0.0000063896	[.452]	-0.0000063973	[.049]*
GDP preliminary: GDPP(1-2)	-0.0003147150	[.793]	0.0000225735	[.001]*	-0.0000009155	[.851]	0.0000068915	[.000]*
Consumer Price Index: CPI (0)	0.0005577270	[.604]	-0.0000292347	[.013]*	0.0000180935	[.010]*	-0.0000087597	[.000]*
Consumer Price Index: CPI (1-2)	-0.0006764810	[.706]	-0.0000053475	[.779]	0.0000063976	[.414]	-0.0000033825	[.564]
Federal Fund Rate: IR (0)	-0.0029931200	[.143]	-0.0000036192	[.911]	0.0000010194	[.934]	-0.0000062195	[.428]
Federal Fund Rate: IR (1-2)	-0.0009374950	[.641]	-0.0000341349	[.101]	0.0000045982	[.581]	-0.0000088657	[.057]**
Trade Balance:TB (0)	-0.0027590500	[.005]*	-0.0000149037	[.496]	-0.0000007122	[.915]	-0.0000067011	[.239]
Trade Balance:TB (1-2)	-0.0019539300	[.209]	-0.0000274782	[.021]*	0.0000021721	[.733]	-0.0000096587	[.002]*
Multiplicative Dummies								
Friday X Quote Revisions	-0.0154620000	[.000]*	-0.0000489920	[.264]	-0.0000727288	[.000]*	-0.0000085505	[.337]
Prec. Holiday X Quote Revisions	0.0149390000	[.024]*	0.0001840770	[.149]	0.0000534479	[.067]**	0.0000545760	[.140]
Friday X Volatility	0.0007051280	[.556]	-0.0023024600	[.065]**	-0.0000021395	[.746]	-0.0005929870	[.053]**
Prec. Holiday X Volatility	-0.0031058000	[.537]	0.0043629400	[.396]	-0.0000054297	[.856]	0.0007153460	[.485]
Lagged Spread	0.5831030000	[.000]*	0.6496560000	[.000]*	0.8314400000	[.000]*	0.5040070000	[.000]*
α_0	0.0000223319	[.102]	0.0000000002	[.610]	0.0000000003	[.005]*	0.0000000000	[.576]
α_1	0.1214930000	[.097]**	0.1264540000	[.305]	0.2917630000	[.008]*	0.0901250000	[.391]
β_1	0.0973980000	[.843]	0.8115330000	[.001]*	0.3140770000	[.115]	0.8646540000	[.000]*
Intercept	0.0223720000		0.0002156860		0.0000270536		0.0000920382	
Adjusted R-squared	0.472171		0.476472		0.757052		0.363815	

*: 5 percent level of significance, **: 10 percent level of significance

Panel C: ASIA Time Zone, Period 1 Sample								
	Quoted Spread				Relative Spread			
	JP/US		GB/US		JP/US		GB/US[a]	
Parameter	Estimate	P-value	Estimate	P-value	Estimate	P-value	Estimate	P-value
Number of Quote Revisions	-0.0025645900	[.216]	-0.0000832533	[.052]*	-0.0000211201	[.270]	-0.0000146697	[.000]*
Interest Rate	-0.7464580000	[.089]**	-0.0129230000	[.133]	-0.0047536500	[.355]	-0.0061054600	[.000]*
Volatility	0.0019020700	[.005]*	0.0045213600	[.000]*	0.0000211236	[.000]*	0.0025947100	[.000]*
Seasonality (ASIA)								
Preceding Holiday:								
ASIA only	-0.0074585300	[.330]	-0.0000340524	[.793]	0.0000042167	[.876]	-0.0000447570	[.158]
Common	-0.0001638970	[.976]	-0.0001487840	[.162]	-0.0000190654	[.574]	0.0000114642	[.460]
Post Holiday:								
ASIA only	-0.0011834000	[.328]	0.0000108345	[.421]	0.0000160007	[.000]*	-0.0000040502	[.297]
Common	-0.0063272900	[.126]	-0.0000576498	[.405]	-0.0001334970	[.047]*	0.0000050991	[.670]
Last Day of Month	0.0014819400	[.212]	0.0000121781	[.334]	0.0000002829	[.959]	-0.0000030231	[.461]
Monday	-0.0020567400	[.002]*	-0.0000179430	[.012]*	0.0000005165	[.842]	0.0000015100	[.479]
Friday	0.0137290000	[.003]*	0.0001166530	[.167]	0.0000395085	[.205]	0.0000433810	[.000]*
Macroeconomic Ann. (ASIA)								
GDP preliminary: GDPP(0)	0.0016860400	[.438]	0.0000217068	[.021]*	0.0000096080	[.257]	0.0000123847	[.225]
GDP preliminary: GDPP(1-2)	0.0047392600	[.093]**	-0.0000047680	[.809]	0.0000136150	[.042]*	0.0000071327	[.324]
Consumer Price Index: CPI (0)	0.0006580960	[.629]	-0.0000267817	[.071]**	-0.0000060049	[.284]	-0.0000045764	[.298]
Consumer Price Index: CPI (1-2)	-0.0013447100	[.158]	0.0000058822	[.733]	0.0000048833	[.140]	0.0000049611	[.088]**
Federal Fund Rate: IR (0)	0.0000742193	[.979]	-0.0000063023	[.753]	0.0000174745	[.236]	-0.0000293336	[.002]*
Federal Fund Rate: IR (1-2)	0.0037437600	[.047]	0.0000254830	[.070]**	0.0000101206	[.383]	-0.0000046588	[.477]
Trade Balance:TB (0)	0.0043249600	[.071]**	0.0000414947	[.014]*	0.0000103588	[.347]	0.0000071328	[.434]
Trade Balance:TB (1-2)	-0.0003046120	[.842]	0.0000126301	[.469]	0.0000099993	[.276]	-0.0000035421	[.579]
Multiplicative Dummies								
Friday X Quote Revisions	-0.0101250000	[.012]*	-0.0000824199	[.216]	-0.0000378161	[.135]	-0.0000234556	[.014]*
Prec. Holiday X Quote Revisions	0.0046376500	[.462]	0.0000313056	[.729]	0.0000013649	[.953]	0.0000419101	[.088]**
Friday X Volatility	0.0020647100	[.225]	-0.0015079400	[.374]	0.0000193652	[.001]*	-0.0016806000	[.017]*
Prec. Holiday X Volatility	0.0043410000	[.074]**	0.0003846900	[.882]	-0.0000037049	[.552]	-0.0006798750	[.502]
Lagged Spread	0.6346670000	[.000]*	0.5555790000	[.000]*	0.8261740000	[.000]*	0.3964730000	[.000]*
α_0	0.0000008316	[.648]	0.0000000011	[.002]*	0.0000000001	[.227]		
α_1	0.0280100000	[.270]	0.4558400000	[.117]	0.2202390000	[.041]*		
β_1	0.9480190000	[.000]*	0.3548870000	[.081]**	0.6706810000	[.000]*		
Intercept	0.0254960000		0.0004264510		0.0000581583		0.0001316960	
Adjusted R-squared	0.550993		0.373809		0.852997		0.404771	

a: resutls estimated with OLS, *: 5 percent level of significance, **: 10 percent level of significance

Panel D: US Time Zone, Period 2 Sample								
	Quoted Spread				Relative Spread			
	JP/US[a]		GB/US		JP/US		GB/US	
Parameter	Estimate	P-value	Estimate	P-value	Estimate	P-value	Estimate	P-value
Number of Quote Revisions	-0.0021081600	[.314]	-0.0000617551	[.000]*	0.0000068202	[.408]	-0.0000149839	[.002]*
Interest Rate	-0.3394780000	[.551]	0.0060457400	[.378]	0.0015595800	[.405]	0.0016153200	[.380]
Volatility	0.0029918800	[.000]*	0.0023829800	[.004]*	0.0000091433	[.000]*	0.0005610200	[.010]*
Seasonality (US)								
Preceding Holiday:								
USonly	-0.0219350000	[.097]**	-0.0004235330	[.019]*	-0.0000724768	[.238]	-0.0001126540	[.022]*
Common	0.0078199100	[.114]	-0.0001332140	[.000]*	0.0000349109	[.415]	-0.0000334374	[.000]*
Post Holiday:								
US only	0.0008895120	[.548]	-0.0000122170	[.617]	0.0000047782	[.465]	-0.0000037819	[.547]
Common	-0.0039448900	[.504]	0.0000043641	[.839]	-0.0000171653	[.003]*	0.0000023527	[.666]
Last Day of Month	0.0010491300	[.477]	0.0000293550	[.017]*	0.0000011987	[.814]	0.0000077120	[.020]*
Monday	-0.0005502220	[.486]	-0.0000084991	[.326]	-0.0000030064	[.265]	-0.0000020067	[.374]
Friday	0.0061510300	[.084]**	0.0000797492	[.046]*	0.0000281511	[.060]**	0.0000215429	[.045]*
Macroeconomic Ann. (US)								
GDP preliminary: GDPP(0)	-0.0005811940	[.807]	-0.0000136874	[.637]	-0.0000025290	[.777]	-0.0000042212	[.601]
GDP preliminary: GDPP(1-2)	0.0007178200	[.670]	-0.0000009125	[.940]	0.0000010116	[.855]	-0.0000001184	[.969]
Consumer Price Index: CPI (0)	-0.0006841900	[.632]	0.0000232997	[.085]**	-0.0000025626	[.610]	0.0000061937	[.095]**
Consumer Price Index: CPI (1-2)	0.0007223260	[.473]	0.0000038890	[.679]	0.0000015645	[.670]	0.0000006099	[.801]
Federal Fund Rate: IR (0)	0.0012238400	[.464]	-0.0000201280	[.271]	0.0000038045	[.238]	-0.0000058410	[.234]
Federal Fund Rate: IR (1-2)	0.0003839960	[.753]	-0.0000032035	[.779]	-0.0000004634	[.906]	-0.0000015257	[.635]
Trade Balance:TB (0)	0.0017374400	[.206]	-0.0000057458	[.638]	0.0000064785	[.106]	-0.0000022724	[.469]
Trade Balance:TB (1-2)	0.0014718400	[.158]	-0.0000007506	[.936]	0.0000030780	[.400]	-0.0000003195	[.903]
Multiplicative Dummies								
Friday X Quote Revisions	-0.0016187500	[.573]	-0.0000630666	[.046]*	-0.0000147372	[.195]	-0.0000170796	[.047]*
Prec. Holiday X Quote Revisions	0.0222030000	[.049]*	0.0004241960	[.005]*	0.0000872750	[.095]**	0.0001133690	[.006]*
Friday X Volatility	-0.0022728300	[.054]**	-0.0004188340	[.766]	-0.0000046720	[.232]	-0.0000789884	[.829]
Prec. Holiday X Volatility	-0.0030045000	[.079]**	-0.0085984700	[.049]*	-0.0000190100	[.015]*	-0.0024281900	[.030]*
Lagged Spread	0.4306920000	[.000]*	0.4994420000	[.000]*	0.5603670000	[.000]*	0.5072390000	[.000]*
α_0			0.0000000011	[.004]*	0.0000000003	[.004]*	0.0000000001	[.010]*
α_1			0.3243340000	[.007]*	0.2865450000	[.028]*	0.3148330000	[.012]*
β_1			0.4413280000	[.002]*	0.0311700000	[.892]	0.4469030000	[.005]*
Intercept	0.0384000000		0.0004593380		0.0000839106		0.0001178520	
Adjusted R-squared	0.291202		0.249283		0.321631		0.245068	
a: resutls estimated with OLS, *: 5 percent level of significance, **: 10 percent level of significance								

Panel E: UK Time Zone, Period 2 Sample								
	Quoted Spread				Relative Spread			
	JP/US		GB/US		JP/US[a]		GB/US	
Parameter	Estimate	P-value	Estimate	P-value	Estimate	P-value	Estimate	P-value
Number of Quote Revisions	0.0073673100	[.000]*	0.0000747314	[.578]	0.0000208872	[.000]*	0.0000172323	[.002]*
Interest Rate	-1.4832900000	[.005]*	0.0016787700	[.965]	-0.0020599500	[.297]	0.0016127500	[.547]
Volatility	0.0006325690	[.053]**	0.0006329540	[.490]	0.0000017080	[.194]	0.0001803390	[.461]
Seasonality (UK)								
Preceding Holiday:								
UK only	-0.0435620000	[.031]*	-0.0003255760	[.521]	-0.0001743800	[.002]*	-0.0000580251	[.366]
Common	0.0083228000	[.501]	-0.0001094460	[.126]	0.0000732198	[.000]*	-0.0000200433	[.032]
Post Holiday:								
UK only	-0.0015934900	[.426]	-0.0000058815	[.785]	0.0000003070	[.967]	-0.0000022358	[.586]
Common	0.0117130000	[.000]*	0.0002147410	[.199]	0.0000413759	[.062]**	0.0000640454	[.000]*
Last Day of Month	-0.0005257260	[.744]	0.0000156752	[.154]	-0.0000012619	[.808]	0.0000035031	[.055]**
Monday	-0.0004643360	[.523]	-0.0000028366	[.824]	-0.0000016576	[.545]	-0.0000005594	[.711]
Friday	-0.0019868200	[.665]	0.0002789800	[.452]	-0.0000126267	[.471]	0.0000641819	[.000]*
Macroeconomic Ann. (UK)								
GDP preliminary: GDPP(0)	0.0030133700	[.175]	-0.0000033657	[.957]	0.0000088101	[.519]	-0.0000009126	[.760]
GDP preliminary: GDPP(1-2)	0.0005970070	[.641]	0.0000081968	[.698]	0.0000023585	[.799]	0.0000033886	[.424]
Consumer Price Index: CPI (0)	-0.0036235400	[.078]**	-0.0000200811	[.463]	-0.0000067761	[.511]	-0.0000063259	[.035]*
Consumer Price Index: CPI (1-2)	-0.0002134810	[.910]	-0.0000134995	[.453]	-0.0000038930	[.672]	-0.0000045712	[.205]
Federal Fund Rate: IR (0)	-0.0021630200	[.041]*	-0.0000060112	[.908]	-0.0000062436	[.220]	-0.0000031117	[.251]
Federal Fund Rate: IR (1-2)	0.0001546880	[.828]	-0.0000003283	[.992]	0.0000008093	[.826]	0.0000003904	[.810]
Trade Balance:TB (0)	0.0006323550	[.680]	0.0000112376	[.569]	-0.0000005433	[.954]	0.0000022504	[.540]
Trade Balance:TB (1-2)	0.0019873800	[.221]	0.0000076955	[.823]	0.0000022730	[.803]	0.0000019756	[.590]
Multiplicative Dummies								
Friday X Quote Revisions	0.0005300580	[.870]	-0.0001751860	[.466]	0.0000031183	[.801]	-0.0000406369	[.000]*
Prec. Holiday X Quote Revisions	0.0337870000	[.043]*	0.0001913090	[.508]	0.0001298250	[.007]*	0.0000335973	[.360]
Friday X Volatility	0.0012009600	[.199]	0.0001442310	[.956]	0.0000057224	[.156]	0.0000375446	[.924]
Prec. Holiday X Volatility	-0.0009893610	[.750]	0.0008400430	[.722]	-0.0000076525	[.412]	0.0000860464	[.877]
Lagged Spread	0.5503080000	[.000]*	0.5148640000	[.288]	0.6768600000	[.000]*	0.5630150000	[.000]*
α_0	0.0000139808	[.002]*	0.0000000005	[.912]			0.0000000000	[.601]
α_1	0.2283500000	[.085]**	0.2594550000	[.821]			0.1617130000	[.143]
β_1	0.3197210000	[.040]*	0.4274180000	[.916]			0.7479080000	[.012]*
Intercept	0.0241360000		0.0003081580		0.0000554168		0.0000735267	
Adjusted R-squared	0.424584		0.343681		0.542365		0.402323	
a: resutls estimated with OLS, *: 5 percent level of significance, **: 10 percent level of significance								

Panel F: ASIA Time Zone, Period 2 Sample								
	Quoted Spread				**Relative Spread**			
	JP/US		**GB/US**		**JP/US**		**GB/US**	
Parameter	Estimate	P-value	Estimate	P-value	Estimate	P-value	Estimate	P-value
Number of Quote Revisions	0.0003682050	[.859]	-0.0000400399	[.030]*	0.0000044597	[.777]	0.0000053741	[.381]
Interest Rate	-0.5970450000	[.280]	0.0081123500	[.357]	0.0000549096	[.986]	-0.0042078300	[.055]**
Volatility	0.0013961400	[.009]*	-0.0014121300	[.151]	0.0000115434	[.000]*	0.0010675400	[.024]*
Seasonality (ASIA)								
Preceding Holiday:								
ASIA only	0.0074996100	[.606]	0.0001093630	[.500]	-0.0000452440	[.235]	0.0000298514	[.519]
Common	0.0038443700	[.457]	-0.0001589050	[.000]*	-0.0000196804	[.210]	-0.0000131487	[.150]
Post Holiday:								
ASIA only	-0.0013632500	[.325]	0.0000224900	[.132]	0.0000161648	[.010]*	0.0000051435	[.229]
Common	-0.0024004700	[.689]	-0.0000355071	[.062]**	-0.0000029712	[.705]	0.0000173729	[.001]*
Last Day of Month	0.0025021800	[.102]	0.0000369468	[.010]*	-0.0000012451	[.827]	0.0000061982	[.170]
Monday	-0.0008523850	[.279]	-0.0000027726	[.754]	0.0000022579	[.451]	0.0000057113	[.020]*
Friday	0.0095437700	[.013]*	0.0000980006	[.023]*	0.0000110034	[.616]	0.0000327950	[.262]
Macroeconomic Ann. (ASIA)								
GDP preliminary: GDPP(0)	0.0024018200	[.413]	-0.0000250461	[.031]*	0.0000046919	[.460]	-0.0000051899	[.428]
GDP preliminary: GDPP(1-2)	0.0013389900	[.525]	0.0000190378	[.348]	-0.0000029883	[.439]	-0.0000051226	[.354]
Consumer Price Index: CPI (0)	-0.0028398000	[.088]**	-0.0000103361	[.548]	-0.0000003014	[.956]	-0.0000096697	[.084]
Consumer Price Index: CPI (1-2)	-0.0003736390	[.725]	0.0000083007	[.466]	0.0000031626	[.412]	0.0000045636	[.202]
Federal Fund Rate: IR (0)	0.0036055200	[.009]*	0.0000143463	[.210]	-0.0000025462	[.561]	0.0000029895	[.618]
Federal Fund Rate: IR (1-2)	0.0023418200	[.019]*	0.0000157899	[.037]*	-0.0000025614	[.488]	-0.0000040219	[.193]
Trade Balance:TB (0)	0.0018028700	[.494]	-0.0000057882	[.836]	-0.0000057503	[.134]	-0.0000081728	[.097]
Trade Balance:TB (1-2)	0.0005208380	[.781]	-0.0000019899	[.883]	-0.0000070719	[.104]	0.0000018053	[.696]
Multiplicative Dummies								
Friday X Quote Revisions	-0.0047259000	[.101]	-0.0000814511	[.008]*	-0.0000035193	[.835]	-0.0000186483	[.425]
Prec. Holiday X Quote Revisions	-0.0087046400	[.471]	-0.0000488334	[.706]	0.0000409666	[.231]	-0.0000129976	[.699]
Friday X Volatility	-0.0012018400	[.199]	0.0017817900	[.493]	-0.0000016499	[.701]	-0.0005384930	[.514]
Prec. Holiday X Volatility	0.0028989900	[.202]	-0.0067897000	[.193]	-0.0000041139	[.683]	-0.0017136100	[.201]
Lagged Spread	0.4326000000	[.000]*	0.4762460000	[.000]*	0.6738710000	[.000]*	0.5460940000	[.000]*
α_0			0.0000000012	[.070]**	0.0000000002	[.608]	0.0000000001	[.002]*
α_1			0.2711640000	[.048]*	0.0585050000	[.583]	0.2088610000	[.064]
β_1			0.4707440000	[.038]*	0.4425190000	[.672]	0.5970770000	[.000]*
Intercept	0.0368090000		0.0004739880		0.0000616945		0.0000834179	
Adjusted R-squared	0.268549		0.233721		0.511313		0.315216	
a: resutls estimated with OLS, *: 5 percent level of significance, **: 10 percent level of significance								

Panel G: US Time Zone, Period 3 Sample

	Quoted Spread						Relative Spread					
	JP/US[a]		GB/US		EU/US		JP/US		GB/US		EU/US	
Parameter	Estimate	P-value	Estimate	P-value	Estimate	P-value	Estimate	P-value	Estimate	P-value	Estimate	P-value
Number of Quote Revisions	-0.0086141500	[.000]*	-0.0001081010	[.000]*	-0.0000937277	[.000]*	-0.0000249797	[.000]*	-0.0000243106	[.000]*	-0.0000384866	[.000]*
Interest Rate	-0.9835540000	[.000]*	-0.0057229000	[.015]*	-0.0081215400	[.001]*	-0.0003973590	[.618]	-0.0031520900	[.000]*	-0.0027673900	[.001]*
Volatility	0.0007583600	[.083]**	0.0006526990	[.027]*	0.0005132670	[.107]	-0.0000000216	[.989]	0.0000559760	[.429]	0.0001413140	[.231]
Seasonality (US)												
Preceding Holiday:												
USonly	0.0104980000	[.012]*	0.0001068600	[.052]**	-0.0000566801	[.650]	0.0000342943	[.056]**	0.0000317959	[.053]**	-0.0000317281	[.627]
Common	0.0090904500	[.000]*	0.0000662112	[.002]*	0.0000430060	[.604]	0.0000332231	[.000]*	0.0000134675	[.050]*	0.0000400077	[.470]
Post Holiday:												
US only	-0.0018004100	[.002]*	-0.0000193526	[.000]*	-0.0000202563	[.000]*	-0.0000052714	[.009]*	-0.0000056233	[.000]*	-0.0000123908	[.000]*
Common	-0.0073213600	[.015]*	-0.0000129853	[.361]	0.0000339847	[.367]	-0.0000143631	[.259]	-0.0000094634	[.037]*	0.0000054822	[.739]
Last Day of Month	0.0001956620	[.742]	0.0000057207	[.360]	0.0000055024	[.350]	0.0000007274	[.727]	0.0000017969	[.264]	0.0000029543	[.161]
Monday	-0.0027404100	[.000]*	-0.0000210488	[.000]*	-0.0000139633	[.000]*	-0.0000085172	[.000]*	-0.0000061982	[.000]*	-0.0000093460	[.000]*
Friday	-0.0100930000	[.019]*	-0.0000200231	[.329]	0.0000396002	[.305]	-0.0000352618	[.022]*	-0.0000054734	[.405]	0.0000277935	[.103]
Macroeconomic Ann. (US)												
GDP preliminary: GDPP(0)	-0.0002803810	[.750]	-0.0000061483	[.498]	0.0000065926	[.332]	-0.0000013081	[.669]	-0.0000012013	[.631]	0.0000023492	[.357]
GDP preliminary: GDPP(1-2)	-0.0006075040	[.317]	-0.0000125286	[.041]*	0.0000016616	[.808]	-0.0000019119	[.391]	-0.0000034322	[.038]*	0.0000000647	[.979]
Consumer Price Index: CPI (0)	-0.0000984275	[.831]	-0.0000028916	[.442]	0.0000009138	[.838]	-0.0000014881	[.432]	-0.0000005808	[.574]	0.0000012108	[.529]
Consumer Price Index: CPI (1-2)	0.0002595240	[.497]	0.0000037282	[.211]	0.0000047538	[.160]	0.0000010549	[.474]	0.0000010106	[.162]	0.0000021106	[.201]
Federal Fund Rate: IR (0)	-0.0002630850	[.709]	-0.0000079278	[.246]	0.0000010478	[.828]	-0.0000011395	[.695]	-0.0000017195	[.276]	-0.0000000830	[.963]
Federal Fund Rate: IR (1-2)	-0.0001217610	[.808]	0.0000006156	[.893]	-0.0000001229	[.976]	0.0000008639	[.679]	0.0000000362	[.975]	-0.0000001302	[.941]
Trade Balance:TB (0)	-0.0000987052	[.798]	0.0000066785	[.189]	-0.0000057690	[.238]	-0.0000001737	[.921]	0.0000020801	[.115]	-0.0000024495	[.278]
Trade Balance:TB (1-2)	-0.0003043570	[.403]	-0.0000080231	[.019]*	-0.0000025887	[.430]	-0.0000014996	[.286]	-0.0000017030	[.035]*	-0.0000008002	[.525]
Multiplicative Dummies												
Friday X Quote Revisions	0.0069597300	[.002]*	0.0000252300	[.017]*	-0.0000062573	[.741]	0.0000257274	[.001]*	0.0000064445	[.048]*	-0.0000087947	[.277]
Prec. Holiday X Quote Revisions	-0.0043196100	[.040]	-0.0000514486	[.056]	0.0000270359	[.660]	-0.0000128010	[.164]	-0.0000157876	[.050]*	0.0000133773	[.672]
Friday X Volatility	-0.0011478100	[.172]	-0.0006305900	[.294]	0.0005470960	[.373]	-0.0000037568	[.223]	-0.0001606460	[.274]	0.0002383890	[.291]
Prec. Holiday X Volatility	-0.0015474400	[.353]	0.0007523220	[.493]	-0.0001995500	[.898]	-0.0000072369	[.375]	0.0003002380	[.274]	0.0003186480	[.618]
Lagged Spread	0.5671430000	[.000]*	0.5518540000	[.000]*	0.4509600000	[.000]*	0.5312310000	[.000]*	0.6942310000	[.000]*	0.7142150000	[.000]*
Data Feeder Dummies												
DDF2	-0.0040761200	[.000]*	-0.0000732792	[.000]*	-0.0000130680	[.199]	-0.0000267200	[.000]*	-0.0000120339	[.000]*	-0.0000032416	[.342]
DDF3	0.0037175200	[.013]*	0.0000240420	[.312]	0.0000054475	[.504]	0.0000162707	[.002]*	0.0000051212	[.454]	-0.0000013376	[.712]
DDF4	0.0038965600	[.424]	0.0000955609	[.078]**	0.0000626466	[.030]*	0.0000228772	[.087]**	0.0000274530	[.098]**	0.0000292976	[.035]*
DDF5	0.0017338600	[.355]	0.0000532255	[.133]	0.0000326565	[.014]*	0.0000102646	[.061]**	0.0000087880	[.424]	0.0000112620	[.123]
DDF6	-0.0082340300	[.000]*	-0.0000542576	[.000]*	-0.0000300183	[.002]*	-0.0000416016	[.000]*	-0.0000126570	[.000]**	-0.0000151810	[.002]**
α_0	0.0000000166	[.719]	0.0000000000	[.379]	0.0000000002	[.001]*	0.0000000000	[.226]	0.0000000000	[.376]	0.0000000000	[.304]
α_1	0.0271350000	[.087]	0.1214520000	[.023]*	0.2648040000	[.000]*	0.1535420000	[.008]*	0.1334650000	[.015]*	0.2704100000	[.015]*
β_1	0.9716280000	[.000]*	0.8926620000	[.000]*	0.6026560000	[.000]*	0.8021390000	[.000]*	0.8844340000	[.000]*	0.7062660000	[.000]*
Intercept	0.0423050000		0.0004804990		0.0004131370		0.0001604570		0.0000994448		0.0001347030	
Adjusted R-squared	0.86953		0.830575		0.577239		0.87838		0.850888		0.811845	

*: 5 percent level of significance, **: 10 percent level of significance

Panel H: UK Time Zone, Period 3 Sample												
	Quoted Spread						Relative Spread					
	JP/US[a]		GB/US		EU/US		JP/US		GB/US		EU/US	
Parameter	Estimate	P-value	Estimate	P-value	Estimate	P-value	Estimate	P-value	Estimate	P-value	Estimate	P-value
Number of Quote Revisions	-0.0080393200	[.000]*	-0.0001340700	[.000]*	-0.0000443570	[.002]*	-0.0000261335	[.000]*	-0.0000393229	[.000]*	-0.0000386896	[.099]**
Interest Rate	-0.1378520000	[.535]	0.0060855400	[.022]*	-0.0034358300	[.178]	0.0024411800	[.003]*	-0.0015616100	[.032]*	-0.0022283900	[.056]**
Volatility	0.0012187400	[.001]*	0.0011214000	[.002]*	0.0001400960	[.750]	0.0000036366	[.016]*	0.0001249680	[.131]	0.0002976710	[.102]
Seasonality (UK)												
Preceding Holiday:												
UK only	0.0058413800	[.332]	-0.0000887859	[.160]	0.0000332000	[.761]	0.0000391401	[.090]**	-0.0000254196	[.189]	0.0000222558	[.487]
Common	0.0021050000	[.364]	0.0000742402	[.006]*	0.0002007090	[.000]*	0.0000101320	[.348]	0.0000171457	[.051]**	-0.0000131724	[.755]
Post Holiday:												
UK only	-0.0012020900	[.133]	-0.0000163130	[.160]	-0.0000252705	[.200]	-0.0000024973	[.457]	-0.0000051194	[.027]*	-0.0000161219	[.000]*
Common	-0.0076209300	[.001]*	0.0000159376	[.413]	-0.0000351747	[.282]	-0.0000032112	[.800]	0.0000006478	[.858]	-0.0000149601	[.085]**
Last Day of Month	-0.0001448320	[.809]	0.0000072160	[.223]	-0.0000001896	[.976]	-0.0000008198	[.717]	0.0000023031	[.133]	0.0000003158	[.888]
Monday	-0.0004910360	[.160]	-0.0000089623	[.020]*	0.0000000529	[.987]	-0.0000012462	[.390]	-0.0000034795	[.000]*	-0.0000025723	[.397]
Friday	-0.0026731400	[.163]	0.0000327029	[.001]*	0.0000011202	[.865]	-0.0000121688	[.223]	0.0000018119	[.510]	-0.0000057578	[.083]**
Macroeconomic Ann. (UK)												
GDP preliminary: GDPP(0)	-0.0007692440	[.400]	0.0000000609	[.993]	-0.0000085295	[.287]	-0.0000024438	[.489]	-0.0000000463	[.981]	-0.0000022863	[.527]
GDP preliminary: GDPP(1-2)	0.0001620660	[.769]	0.0000059973	[.270]	0.0000007550	[.863]	0.0000004120	[.839]	0.0000014764	[.362]	-0.0000007558	[.787]
Consumer Price Index: CPI (0)	0.0000396352	[.942]	0.0000111719	[.020]*	-0.0000014622	[.692]	-0.0000007091	[.758]	0.0000023654	[.030]*	-0.0000004253	[.815]
Consumer Price Index: CPI (1-2)	-0.0003562700	[.398]	-0.0000046268	[.344]	0.0000056204	[.194]	-0.0000015838	[.334]	-0.0000015759	[.150]	0.0000015115	[.323]
Federal Fund Rate: IR (0)	0.0003540950	[.482]	0.0000098663	[.178]	-0.0000040647	[.533]	0.0000012006	[.541]	0.0000008239	[.565]	-0.0000028624	[.291]
Federal Fund Rate: IR (1-2)	-0.0006497800	[.076]**	0.0000030638	[.474]	-0.0000050561	[.135]	-0.0000031427	[.029]*	0.0000007218	[.512]	-0.0000018384	[.186]
Trade Balance:TB (0)	-0.0008728450	[.118]	-0.0000113911	[.135]	-0.0000010195	[.854]	-0.0000027332	[.217]	-0.0000025406	[.130]	-0.0000027550	[.232]
Trade Balance:TB (1-2)	0.0000138122	[.968]	-0.0000104417	[.045]*	0.0000009963	[.759]	0.0000002167	[.869]	-0.0000018816	[.097]**	-0.0000000681	[.960]
Multiplicative Dummies												
Friday X Quote Revisions	0.0015746900	[.126]	-0.0000064161	[.297]	0.0000046000	[.256]	0.0000072483	[.161]	0.0000007233	[.651]	0.0000051073	[.004]*
Prec. Holiday X Quote Revisions	-0.0024962200	[.322]	0.0000343854	[.212]	-0.0000873684	[.037]*	-0.0000153008	[.072]**	0.0000106640	[.248]	-0.0000279479	[.080]**
Friday X Volatility	-0.0012702900	[.182]	-0.0006889540	[.170]	-0.0005102600	[.415]	-0.0000054073	[.222]	-0.0001270900	[.310]	-0.0004625240	[.055]**
Prec. Holiday X Volatility	0.0009273570	[.755]	-0.0011147900	[.714]	0.0142430000	[.004]*	-0.0000028467	[.830]	-0.0004308040	[.557]	0.0040586100	[.104]
Lagged Spread	0.5574730000	[.000]*	0.4546770000	[.000]*	0.5569270000	[.000]*	0.5443410000	[.000]*	0.5171700000	[.000]*	0.6868850000	[.000]*
Data Feeder Dummies												
DDF2	-0.0040958000	[.000]*	-0.0000757401	[.000]*	0.0000046205	[.514]	-0.0000227975	[.000]*	-0.0000146954	[.000]*	0.0000006901	[.942]
DDF3	0.0015817300	[.189]	0.0000288049	[.088]**	0.0000026772	[.778]	0.0000064235	[.116]	0.0000047496	[.362]	0.0000003165	[.960]
DDF4	0.0032232100	[.368]	0.0000220858	[.445]	0.0000304601	[.111]	0.0000126094	[.357]	0.0000068556	[.380]	0.0000149759	[.133]
DDF5	0.0023897800	[.101]	0.0000836869	[.000]*	0.0000082744	[.329]	0.0000093821	[.084]**	0.0000218553	[.000]*	0.0000038047	[.452]
DDF6	-0.0075795500	[.000]*	-0.0000522609	[.001]*	-0.0000310896	[.000]*	-0.0000342283	[.000]*	-0.0000149035	[.000]*	-0.0000200195	[.215]
α_0	0.0000000189	[.523]	0.0000000000	[.384]	0.0000000005	[.041]*	0.0000000000	[.348]	0.0000000000	[.282]	0.0000000000	[.203]
α_1	0.0426660000	[.053]	0.2294280000	[.073]*	0.4444800000	[.031]*	0.0467820000	[.003]*	0.1774510000	[.041]*	0.3446710000	[.000]*
β_1	0.9592120000	[.000]*	0.8249390000	[.000]*	0.2888070000	[.247]	0.9548600000	[.000]*	0.8577360000	[.000]*	0.6480910000	[.000]*
Intercept	0.0400630000		0.0005670960		0.0002655990		0.0001498910		0.0001539780		0.0001428160	
Adjusted R-squared	0.821427		0.784782		0.522469		0.834776		0.81024		0.792592	
*: 5 percent level of significance, **: 10 percent level of significance												

Panel I: ASIA Time Zone, Period 3 Sample												
	Quoted Spread						Relative Spread					
	JP/US[a]		GB/US		EU/US		JP/US		GB/US		EU/US	
Parameter	Estimate	P-value	Estimate	P-value	Estimate	P-value	Estimate	P-value	Estimate	P-value	Estimate	P-value
Number of Quote Revisions	-0,0086114000	[.000]*	-0,0001075910	[.000]*	-0,0000918214	[.000]*	-0,0000228392	[.000]*	-0,0000149689	[.000]*	-0,0000271225	[.000]*
Interest Rate	-1,0342300000	[.000]*	-0,0058108100	[.025]*	-0,0105530000	[.000]*	-0,0041077600	[.000]*	-0,0038433800	[.000]*	-0,0060454900	[.000]*
Volatility	0,0000684633	[.864]	0,0000627739	[.877]	-0,0001849150	[.716]	-0,0000015700	[.360]	-0,0004229900	[.000]*	-0,0003438430	[.126]
Seasonality (ASIA)												
Preceding Holiday:												
ASIA only	0,0031924600	[.345]	0,0000205351	[.666]	-0,0000091389	[.933]	-0,0000112521	[.484]	0,0000138063	[.160]	-0,0000454426	[.241]
Common	0,0107020000	[.000]*	0,0000828166	[.000]*	0,0000485268	[.602]	0,0000402405	[.000]*	-0,0000047626	[.545]	-0,0000395493	[.177]
Post Holiday:												
ASIA only	-0,0003376090	[.558]	-0,0000093614	[.049]*	-0,0000091129	[.056]**	-0,0000037168	[.052]**	-0,0000051608	[.000]*	-0,0000046735	[.034]*
Common	-0,0081940700	[.006]	-0,0000186782	[.168]	0,0000226009	[.535]	0,0000078830	[.260]	-0,0000004389	[.910]	0,0000014612	[.934]
Last Day of Month	0,0004602090	[.455]	0,0000043197	[.471]	0,0000060724	[.339]	0,0000050552	[.032]*	0,0000015790	[.292]	-0,0000035809	[.143]
Monday	-0,0027734400	[.000]*	-0,0000216313	[.000]*	-0,0000121740	[.000]*	0,0000130718	[.000]*	0,0000020816	[.009]*	0,0000065395	[.000]*
Friday	-0,0103730000	[.022]**	-0,0000070513	[.734]	0,0000097610	[.789]	0,0000066683	[.487]	0,0000006930	[.889]	0,0000266697	[.147]
Macroeconomic Ann. (ASIA)												
GDP preliminary: GDPP(0)	-0,0009133670	[.297]	-0,0000086613	[.450]	-0,0000136778	[.086]**	0,0000041822	[.161]	-0,0000012302	[.629]	-0,0000055710	[.177]
GDP preliminary: GDPP(1-2)	-0,0000643030	[.911]	-0,0000049278	[.324]	-0,0000016968	[.668]	-0,0000023370	[.254]	0,0000002683	[.860]	-0,0000012705	[.534]
Consumer Price Index: CPI (0)	0,0002171150	[.773]	-0,0000033188	[.602]	-0,0000035916	[.554]	0,0000012817	[.631]	-0,0000023441	[.123]	0,0000005552	[.849]
Consumer Price Index: CPI (1-2)	0,0000560521	[.883]	0,0000017337	[.637]	0,0000086036	[.032]*	0,0000037058	[.024]*	0,0000007813	[.388]	0,0000052759	[.005]*
Federal Fund Rate: IR (0)	0,0004340280	[.305]	-0,0000029227	[.503]	0,0000023231	[.545]	0,0000022109	[.176]	0,0000004413	[.716]	0,0000010432	[.642]
Federal Fund Rate: IR (1-2)	0,0003162140	[.322]	0,0000013401	[.701]	0,0000001171	[.967]	0,0000006562	[.673]	-0,0000006700	[.394]	0,0000008437	[.540]
Trade Balance:TB (0)	-0,0005400540	[.418]	0,0000029951	[.629]	-0,0000050548	[.406]	-0,0000042316	[.072]**	-0,0000009734	[.522]	-0,0000000473	[.985]
Trade Balance:TB (1-2)	-0,0003334000	[.422]	-0,0000008256	[.835]	-0,0000026842	[.455]	-0,0000009841	[.558]	0,0000004496	[.623]	-0,0000039237	[.043]*
Multiplicative Dummies												
Friday X Quote Revisions	0,0066187200	[.002]*	0,0000223950	[.027]*	0,0000116092	[.499]	-0,0000025225	[.575]	-0,0000006567	[.768]	-0,0000107405	[.188]
Prec. Holiday X Quote Revisions	-0,0019214100	[.218]	-0,0000083476	[.696]	0,0000027968	[.956]	0,0000021610	[.776]	-0,0000078168	[.074]**	0,0000182034	[.290]
Friday X Volatility	0,0003596760	[.699]	-0,0016680800	[.031]*	-0,0002376160	[.867]	0,0000028600	[.415]	0,0002017470	[.235]	-0,0002801220	[.529]
Prec. Holiday X Volatility	0,0006237920	[.543]	0,0002651610	[.883]	0,0008106240	[.735]	0,0000074247	[.108]	0,0003032910	[.495]	0,0001178810	[.901]
Lagged Spread	0,5649460000	[.000]*	0,5365950000	[.000]*	0,4227210000	[.000]*	0,5412250000	[.000]*	0,7973540000	[.000]*	0,7453720000	[.000]*
Data Feeder Dummies												
DDF2	-0,0041299200	[.000]*	-0,0000764322	[.000]*	-0,0000142597	[.222]	-0,0000119788	[.012]*	-0,0000044724	[.142]	0,0000015320	[.762]
DDF3	0,0037180400	[.013]*	0,0000258859	[.253]	0,0000060164	[.429]	0,0000071288	[.133]	0,0000001893	[.978]	-0,0000062871	[.241]
DDF4	0,0043772700	[.432]	0,0001061000	[.055]*	0,0000639623	[.040]*	0,0000235094	[.308]	0,0000335521	[.101]	0,0000262826	[.108]
DDF5	0,0018457000	[.339]	0,0000478805	[.187]	0,0000316021	[.018]*	-0,0000100057	[.166]	0,0000103772	[.341]	0,0000008326	[.929]
DDF6	-0,0083479200	[.000]*	-0,0000589855	[.000]*	-0,0000319169	[.006]*	-0,0000397055	[.000]*	-0,0000043282	[.015]*	-0,0000137964	[.000]*
α_0	0,0000000148	[.755]	0,0000000000	[.392]	0,0000000002	[.002]*	0,0000000000	[.115]	0,0000000000	[.353]	0,0000000000	[.041]*
α_1	0,0283320000	[.095]**	0,1355900000	[.026]*	0,2383520000	[.000]*	0,0800000000	[.001]*	0,1094590000	[.005]*	0,2170970000	[.000]*
β_1	0,9705720000	[.000]*	0,8814970000	[.000]*	0,6409100000	[.000]*	0,9182330000	[.000]*	0,8991710000	[.000]*	0,7916450000	[.000]*
Intercept	0,0428260000		0,0004948310		0,0004246830		0,0001534380		0,0000651792		0,0001123430	
Adjusted R-squared	0,867427		0,828723		0,583974		0,832438		0,792799		0,81344	
*: 5 percent level of significance, **: 10 percent level of significance												

Panels J – R: Time Series Regressions for Intraday Sample

(US, UK and Asia Time Zone, Periods 1, 2 and 3 Sample)

Depended variables the last recorded bid and ask quotes at 5-minute intervals, between 8:00am and 5pm local time. The relative spreads were calculated based on the difference of the logarithm of the ask price and the logarithm of the bid price recorded at 5-minute intervals, between 8:00am and 5:00pm local time. Explanatory variables are the number of quote revision: number of quote revisions recorded in 5-minute intervals, between 8:00am and 5:00pm local time; Interest rate differential between Eurodollar overnight deposit rates (short) and Eurodollar one month deposit rate (long); *Volatility*: the squared result of the log of the exchange rate at time t+1 minus log of the exchange rate at time t, in 5-minute intervals; *Preceding Holiday*: 1.0 if a trading day satisfies the following conditions: (1) if holiday falls on Monday, then the last four hours of the active trading on Friday, (2) if any holiday falls on another weekday, then the last four hours of active trading of the preceding day, and 0 otherwise; *Post Holiday*: 1.0 if a trading day satisfies the following conditions: (1) if holiday falls on Friday, then the first four hours of active trading on following Monday, (2) if any holiday falls on another weekday, then the first four hours of active trading on the following day, and 0 otherwise; *Last Day of Month*: 1.0 if the last four hours of active trading on the last day of the month, and 0 otherwise; *Monday/Friday*: 1.0 if the first/last three hours of active trading day is on Monday/Friday, and 0 otherwise; *IR(Before):* 1.0 on the three hours before an interest rate announcement, and 0 otherwise; *IR(After)*: 1.0 on the three hours after an interest rate announcement, and 0 otherwise; *GDPP(Before)*: 1.0 on the three hours before a GDP (preliminary) announcement, and 0 otherwise; *GDPP(After)*: 1.0 on the three hours after a GDP (preliminary) announcement, and 0 otherwise; *CPI(Before), CPI(After), TB(Before), TB(After)*: Defined as for GDP but for CPI and TB respectively; *Multiplicative Dummies: Friday X Quote Revisions:* 1.0 if the trading day is a Friday, and 0 otherwise; *Prec. Holiday X Quote Revisions:* 1.0 if a trading day satisfies the following conditions: (1) if holiday falls on Monday, then the preceding Friday, (2) if any holiday falls on another weekday, then the preceding day, and 0 otherwise; *Friday X Quote Volatility:* 1.0 if the trading day is a Friday, and 0 otherwise; *Prec. Holiday X Quote Volatility:* 1.0 if a trading day satisfies the following conditions: (1) if holiday falls on Monday, then the preceding Friday, (2) if any holiday falls on another weekday, then the preceding day, and 0 otherwise; *Lagged Spread*: the previous spread observation; *DFD (Data Feeder Dummies), DFD2:* 02Apr01 - 12Sep01 (Reuters and Alt1, this is the period for which the two data feeders overlap); *DFD3:* 25Mar01 - 11May01 (Reuters, Alt1 and Alt2, this is the period for which the three data feeders overlap)*; DFD4:* 03Sep01 - 12Sep01 (Reuters, Alt1, Alt2 and Oanda, this is the period for which the four data feeders overlap); *DFD5:* 14Aug01 - 12Sep01 (Reuters, Alt1, Alt2, Oanda, and Tenfore1, this is the period for which the five data feeders overlap); *DFD6:* 26Nov - 31Jan05 (Oanda,Tenfore1 and Tenfore2, this is the period for which these data feeders overlap); α_o: the constant in the conditional variance equation; α_1 : the coefficient of the past squared residuals of the conditional variance; β_1: the coefficient of the past values of the conditional variance.

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Panel J: US Time Zone, Period 1 Sample: Intraday								
	Quoted Spread				Relative Spread			
	JP/US		GB/US		JP/US		GB/US	
Parameter	Estimate	P-value	Estimate	P-value	Estimate	P-value	Estimate	P-value
Number of Quote Revisions	0.0018230800	[.000]*	0.0000284137	[.000]*	-0.0000021532	[.094]**	0.0000078544	[.000]*
Interest Rate	-1.7860700000	[.000]*	-0.0044437200	[.118]	-0.0093956000	[.000]*	-0.0017442200	[.011]*
Volatility	399.0960000000	[.001]*	7.9608900000	[.117]	2.4784400000	[.000]*	1.7494800000	[.187]
Seasonality (US)								
Preceding Holiday:								
US only	-0.0003887650	[.766]	-0.0000447600	[.019]*	-0.0000062890	[.257]	-0.0000120796	[.008]*
Common	0.0110990000	[.000]*	0.0000971492	[.130]	0.0000359482	[.000]*	0.0000277157	[.010]
Post Holiday:								
US only	0.0033519600	[.000]*	0.0000047509	[.595]	0.0000134098	[.000]*	0.0000000100	[.997]
Common	0.0011818300	[.661]	0.0000253832	[.372]	-0.0000024204	[.820]	0.0000038923	[.589]
Last Day of Month	-0.0024377400	[.005]*	-0.0000027495	[.713]	-0.0000125648	[.000]*	-0.0000003998	[.848]
Monday	0.0002880690	[.331]	-0.0000009334	[.776]	-0.0000004220	[.752]	-0.0000004628	[.601]
Friday	0.0039377800	[.000]*	0.0000029009	[.713]	0.0000109933	[.001]*	0.0000005958	[.772]
Macroeconomic Ann. (US)								
GDP preliminary: GDPP(Before)	-0.0044657700	[.008]*	-0.0000058258	[.649]	-0.0000157403	[.030]*	-0.0000029868	[.396]
GDP preliminary: GDPP(After)	0.0031017300	[.054]**	0.0000183852	[.191]	0.0000123345	[.081]**	0.0000037539	[.307]
Consumer Price Index: CPI (Before)	-0.0037340100	[.000]*	-0.0000162473	[.046]*	-0.0000149035	[.000]*	-0.0000041982	[.060]
Consumer Price Index: CPI (After)	0.0029606300	[.001]*	0.0000154632	[.068]**	0.0000141109	[.000]*	0.0000041417	[.067]
Federal Fund Rate: IR (Before)	0.0006100580	[.615]	-0.0000252138	[.044]*	0.0000014110	[.775]	-0.0000072684	[.033]
Federal Fund Rate: IR (After)	-0.0031843700	[.006]*	0.0000077240	[.496]	-0.0000161934	[.000]*	0.0000019026	[.535]
Trade Balance:TB (Before)	-0.0026611400	[.008]*	-0.0000296275	[.002]*	-0.0000141226	[.001]*	-0.0000086491	[.001]
Trade Balance:TB (After)	0.0056604600	[.000]*	0.0000214036	[.007]*	0.0000233104	[.000]*	0.0000051831	[.016]
Multiplicative Dummies								
Friday X Quote Revisions	-0.0007936460	[.203]	0.0000031798	[.631]	-0.0000015002	[.585]	0.0000011968	[.486]
Prec. Holiday X Quote Revisions	0.0014525100	[.024]*	-0.0000031924	[.609]	0.0000056057	[.043]*	-0.0000019957	[.217]
Friday X Volatility	-253.9880000000	[.282]	-1.4556700000	[.863]	-1.2521400000	[.393]	-0.4579070000	[.839]
Prec. Holiday X Volatility	556.8780000000	[.078]**	33.0989000000	[.037]*	3.8718000000	[.103]	8.2057300000	[.055]
Lagged Spread	0.2241290000	[.000]*	0.2436940000	[.000]*	0.3101910000	[.000]*	0.2326160000	[.000]
α_0	0.0000490749	[.000]*	0.0000000060	[.000]*	0.0000000002	[.000]*	0.0000000005	[.000]
α_1	0.0726730000	[.000]*	0.0961090000	[.000]*	0.0454780000	[.000]*	0.0983430000	[.000]
β_1	0.8588390000	[.000]*	0.8154910000	[.000]*	0.9364220000	[.000]*	0.8083700000	[.000]
Intercept	0.0487920000		0.0005608530		0.0001885510		0.0001571330	
Adjusted R-squared	0.069288		0.090968		0.130076		0.084048	
*: 5 percent level of significance, **: 10 percent level of significance								

Panel K: UK Time Zone, Period 1 Sample: Intraday

	Quoted Spread				Relative Spread			
	JP/US		GB/US		JP/US		GB/US	
Parameter	Estimate	P-value	Estimate	P-value	Estimate	P-value	Estimate	P-value
Number of Quote Revisions	0,0007750290	[.063]**	0,0000739528	[.000]*	-0,0000160990	[.000]*	0,0000184392	[.000]*
Interest Rate	-2,9744800000	[.000]*	-0,0086799600	[.000]*	-0,0155980000	[.000]*	-0,0025224600	[.000]*
Volatility	168,2800000000	[.209]	16,0750000000	[.000]*	1,3074400000	[.065]	3,6055100000	[.001]*
Seasonality (UK)								
Preceding Holiday:								
UK only	-0,0058962600	[.000]*	-0,0000255854	[.076]**	-0,0000168752	[.005]*	-0,0000066061	[.102]
Common	0,0002505620	[.969]	0,0000177254	[.537]	-0,0000138098	[.475]	0,0000008865	[.906]
Post Holiday:								
UK only	0,0045178500	[.001]*	0,0000122763	[.393]	0,0000114295	[.072]**	0,0000027919	[.497]
Common	0,0009354060	[.747]	0,0000203080	[.506]	-0,0000014761	[.902]	0,0000020320	[.799]
Last Day of Month	0,0018696400	[.018]*	0,0000049730	[.532]	0,0000078824	[.020]*	0,0000009943	[.649]
Monday	0,0001070080	[.708]	0,0000121273	[.000]*	-0,0000008930	[.463]	0,0000030943	[.000]*
Friday	0,0029866300	[.005]*	-0,0000066841	[.563]	0,0000119962	[.015]*	-0,0000025330	[.430]
Macroeconomic Ann. (UK)								
GDP preliminary: GDPP(Before)	0,0007374240	[.610]	-0,0000142032	[.294]	0,0000048000	[.427]	-0,0000043162	[.244]
GDP preliminary: GDPP(After)	-0,0005223240	[.713]	-0,0000074593	[.581]	-0,0000020322	[.745]	-0,0000028227	[.441]
Consumer Price Index: CPI (Before)	-0,0036081600	[.110]	-0,0000397518	[.126]	0,0000097526	[.371]	-0,0000128420	[.068]**
Consumer Price Index: CPI (After)	-0,0012107200	[.625]	-0,0000208754	[.438]	0,0000137131	[.255]	-0,0000075650	[.314]
Federal Fund Rate: IR (Before)	0,0021064800	[.077]**	0,0000046429	[.721]	0,0000333977	[.000]*	0,0000007900	[.829]
Federal Fund Rate: IR (After)	0,0009319450	[.434]	-0,0000086284	[.467]	0,0000260488	[.000]*	-0,0000028427	[.392]
Trade Balance:TB (Before)	-0,0004990870	[.794]	-0,0000645668	[.001]*	0,0000291981	[.003]*	-0,0000200022	[.000]*
Trade Balance:TB (After)	-0,0059123700	[.002]*	-0,0000146862	[.479]	-0,0000004852	[.959]	-0,0000061525	[.271]
Multiplicative Dummies								
Friday X Quote Revisions	-0,0008735610	[.296]	0,0000107632	[.186]	-0,0000042242	[.265]	0,0000034389	[.126]
Prec. Holiday X Quote Revisions	0,0022238800	[.003]*	0,0000028525	[.664]	0,0000013891	[.647]	0,0000005157	[.770]
Friday X Volatility	608,8290000000	[.048]*	-6,5357200000	[.344]	3,5366700000	[.029]*	-1,2772900000	[.465]
Prec. Holiday X Volatility	159,3930000000	[.874]	25,0070000000	[.139]	11,1548000000	[.102]	4,5963500000	[.214]
Lagged Spread	0,0952470000	[.000]*	0,1139960000	[.000]*	0,1679930000	[.000]*	0,0994850000	[.000]*
α_0	0,0000114936	[.001]*	0,0000000019	[.002]*	0,0000000000	[.002]*	0,0000000001	[.002]*
α_1	0,0285990000	[.000]*	0,0259610000	[.000]*	0,0162720000	[.000]*	0,0280480000	[.000]*
β_1	0,9555770000	[.000]*	0,9437710000	[.000]*	0,9803660000	[.000]*	0,9450960000	[.000]*
Intercept	0,0652410000		0,0006199840		0,0002727770		0,0001764130	
Adjusted R-squared	0,016301		0,024856		0,055193		0,019756	
*: 5 percent level of significance, **: 10 percent level of significance								

Panel L: ASIA Time Zone, Period 1 Sample: Intraday								
	Quoted Spread				Relative Spread			
	JP/US		GB/US		JP/US		GB/US	
Parameter	Estimate	P-value	Estimate	P-value	Estimate	P-value	Estimate	P-value
Number of Quote Revisions	-0,0024908900	[.000]*	0,0000220868	[.000]*	-0,0000225227	[.000]*	0,0000055500	[.000]*
Interest Rate	-2,4203500000	[.000]*	-0,0304050000	[.000]*	-0,0128320000	[.000]*	-0,0085671300	[.000]*
Volatility	247,8910000000	[.171]	2,8999600000	[.042]*	1,0773800000	[.194]	0,7236650000	[.059]**
Seasonality (ASIA)								
Preceding Holiday:								
ASIA only	0,0036083200	[.001]*	-0,0000361382	[.002]*	0,0000132523	[.002]*	-0,0000080579	[.005]*
Common	-0,0092466000	[.000]*	0,0000858631	[.000]*	-0,0000436089	[.000]*	0,0000168235	[.000]*
Post Holiday:								
ASIA only	-0,0024342600	[.005]*	-0,0000339080	[.000]*	-0,0000132987	[.000]*	-0,0000098313	[.000]*
Common	-0,0069310900	[.008]*	0,0000502549	[.071]**	-0,0000343667	[.001]*	0,0000082342	[.304]
Last Day of Month	0,0035115600	[.000]*	0,0000088108	[.241]	0,0000146079	[.000]*	0,0000025354	[.223]
Monday	0,0009340210	[.003]*	0,0000112300	[.000]*	0,0000028313	[.048]*	0,0000030644	[.000]*
Friday	0,0018022100	[.010]*	0,0000253867	[.000]*	0,0000049213	[.122]	0,0000067362	[.000]*
Macroeconomic Ann. (ASIA)								
GDP preliminary: GDPP(Before)	0,0075584200	[.001]*	0,0000789673	[.005]*	0,0000423263	[.000]*	0,0000236618	[.004]*
GDP preliminary: GDPP(After)	0,0061167500	[.007]*	0,0000905979	[.254]	0,0000433139	[.000]*	0,0000277264	[.207]
Consumer Price Index: CPI (Before)	0,0036074700	[.000]*	0,0000247491	[.004]*	0,0000127512	[.003]*	0,0000063633	[.007]*
Consumer Price Index: CPI (After)	-0,0019546000	[.065]**	-0,0000252076	[.017]	-0,0000066525	[.130]	-0,0000068176	[.019]*
Federal Fund Rate: IR (Before)	0,0078427800	[.000]*	-0,0000618109	[.000]*	0,0000525806	[.000]*	-0,0000169101	[.001]*
Federal Fund Rate: IR (After)	0,0081490300	[.000]*	-0,0000249235	[.244]	0,0000518791	[.000]*	-0,0000069585	[.241]
Trade Balance:TB (Before)	0,0024781400	[.192]	0,0000232685	[.190]	0,0000408619	[.000]*	0,0000055333	[.253]
Trade Balance:TB (After)	0,0070738500	[.001]*	0,0000016711	[.952]	0,0000631820	[.000]*	-0,0000008066	[.913]
Multiplicative Dummies								
Friday X Quote Revisions	-0,0009797730	[.161]	-0,0000158537	[.015]*	-0,0000024747	[.413]	-0,0000040602	[.023]*
Prec. Holiday X Quote Revisions	-0,0011538900	[.125]	0,0000614524	[.000]*	-0,0000073226	[.012]*	0,0000147950	[.000]*
Friday X Volatility	-205,2230000000	[.333]	-1,2118000000	[.759]	-0,1229860000	[.907]	-0,3044140000	[.780]
Prec. Holiday X Volatility	444,0370000000	[.147]	-13,0350000000	[.367]	0,9620820000	[.457]	-3,1591600000	[.421]
Lagged Spread	0,2033080000	[.000]*	0,2066000000	[.000]*	0,2909460000	[.000]*	0,2048830000	[.000]*
α_0	0,0000813978	[.000]*	0,0000000004	[.013]*	0,0000000001	[.084]**	0,0000000000	[.013]*
α_1	0,0548550000	[.000]*	0,0220400000	[.000]*	0,0182340000	[.007]*	0,0220140000	[.000]*
β_1	0,8443320000	[.000]*	0,9737050000	[.000]*	0,9755050000	[.000]*	0,9738600000	[.000]*
Intercept	0,0560860000		0,0005934770		0,0002192450		0,0001641530	
Adjusted R-squared	0,059127		0,058793		0,132447		0,056921	
*: 5 percent level of significance, **: 10 percent level of significance								

Panel M: US Time Zone, Period 2 Sample: Intraday								
	Quoted Spread				Relative Spread			
	JP/US		GB/US		JP/US		GB/US	
Parameter	Estimate	P-value	Estimate	P-value	Estimate	P-value	Estimate	P-value
Number of Quote Revisions	0.0116260000	[.000]	0.0000332549	[.000]	0.0000413267	[.000]	0.0000087967	[.000]
Interest Rate	-1.1258600000	[.000]	0.0069560100	[.025]	0.0009034340	[.292]	0.0022323600	[.007]
Volatility	48.3207000000	[.127]	7.7633300000	[.097]	0.2009200000	[.041]	2.0477500000	[.083]
Seasonality (US)								
Preceding Holiday:								
US only	0.0004070920	[.699]	0.0000314418	[.143]	0.0000058269	[.099]	0.0000069532	[.258]
Common	0.0042778300	[.237]	-0.0001001620	[.111]	0.0000061718	[.656]	-0.0000251999	[.125]
Post Holiday:								
US only	0.0013711300	[.284]	0.0000221012	[.014]	0.0000061857	[.213]	0.0000055674	[.023]
Common	-0.0049272600	[.219]	-0.0000018090	[.960]	-0.0000240602	[.069]	0.0000008919	[.927]
Last Day of Month	0.0007876410	[.748]	-0.0000180393	[.385]	0.0000048705	[.630]	-0.0000060236	[.319]
Monday	0.0006689730	[.104]	0.0000081881	[.079]	0.0000021755	[.142]	0.0000021665	[.084]
Friday	0.0086971800	[.000]	0.0000565127	[.000]	0.0000275485	[.000]	0.0000149253	[.000]
Macroeconomic Ann. (US)								
GDP preliminary: GDPP(Before)	-0.0037122300	[.153]	0.0000098947	[.608]	-0.0000158771	[.053]	0.0000034346	[.506]
GDP preliminary: GDPP(After)	0.0002016810	[.926]	0.0000386246	[.012]	-0.0000033312	[.623]	0.0000110699	[.008]
Consumer Price Index: CPI (Before)	0.0001321100	[.913]	-0.0000103010	[.442]	0.0000009224	[.828]	-0.0000025244	[.474]
Consumer Price Index: CPI (After)	0.0040037700	[.000]	0.0000290628	[.004]	0.0000115436	[.005]	0.0000072041	[.009]
Federal Fund Rate: IR (Before)	-0.0006927850	[.653]	-0.0000491270	[.000]	-0.0000035484	[.496]	-0.0000134526	[.000]
Federal Fund Rate: IR (After)	0.0022815700	[.142]	-0.0000208710	[.349]	0.0000055076	[.284]	-0.0000069999	[.244]
Trade Balance:TB (Before)	-0.0013895100	[.219]	-0.0000079153	[.689]	-0.0000017188	[.670]	-0.0000023485	[.651]
Trade Balance:TB (After)	0.0049960700	[.000]	0.0000338689	[.000]	0.0000160452	[.000]	0.0000085725	[.000]
Multiplicative Dummies								
Friday X Quote Revisions	-0.0049869000	[.000]	-0.0000373294	[.000]	-0.0000161812	[.000]	-0.0000100152	[.000]
Prec. Holiday X Quote Revisions	0.0002402220	[.729]	-0.0000050119	[.385]	0.0000020289	[.389]	-0.0000015784	[.299]
Friday X Volatility	83.2688000000	[.492]	-0.7343420000	[.889]	0.1691640000	[.692]	-0.0896820000	[.949]
Prec. Holiday X Volatility	1049.2600000000	[.135]	49.1452000000	[.061]	3.5653400000	[.198]	11.9739000000	[.078]
Lagged Spread	0.1894810000	[.000]	0.3220070000	[.000]	0.1863010000	[.000]	0.3217990000	[.000]
α_0	0.0000491224	[.000]	0.0000000049	[.000]	0.0000000004	[.000]	0.0000000003	[.000]
α_1	0.0960260000	[.000]	0.1284200000	[.000]	0.0872810000	[.000]	0.1286010000	[.000]
β_1	0.8410770000	[.000]	0.7942620000	[.000]	0.8733420000	[.000]	0.8015850000	[.000]
Intercept	0.0428670000		0.0005148110		0.0001435380		0.0001350140	
Adjusted R-squared	0.091381		0.134745		0.100985		0.134864	
*: 5 percent level of significance, **: 10 percent level of significance								

Panel N: UK Time Zone, Period 2 Sample: Intraday								
	Quoted Spread				Relative Spread			
	JP/US		GB/US		JP/US		GB/US	
Parameter	Estimate	P-value	Estimate	P-value	Estimate	P-value	Estimate	P-value
Number of Quote Revisions	0.0119090000	[.000]*	0.0000753759	[.000]*	0.0000424459	[.000]*	0.0000204371	[.000]*
Interest Rate	-2.1406500000	[.000]*	0.0046093200	[.028]*	0.0003727840	[.664]	0.0017844900	[.001]*
Volatility	46.8349000000	[.399]	13.0921000000	[.118]	0.2116610000	[.287]	3.4573500000	[.107]
Seasonality (UK)								
Preceding Holiday:								
UK only	0.0016752600	[.462]	0.0000054026	[.743]	0.0000089792	[.195]	0.0000011179	[.795]
Common	-0.0074078800	[.065]**	-0.0001499090	[.000]*	-0.0000253754	[.035]*	-0.0000369646	[.000]*
Post Holiday:								
UK only	-0.0027616900	[.157]	0.0000172100	[.225]	-0.0000126207	[.048]*	0.0000037470	[.311]
Common	-0.0022101400	[.635]	0.0000103763	[.758]	-0.0000120122	[.503]	0.0000052395	[.557]
Last Day of Month	-0.0003277680	[.741]	0.0000147796	[.051]**	-0.0000026860	[.430]	0.0000030699	[.124]
Monday	-0.0001012730	[.777]	0.0000012365	[.663]	-0.0000012359	[.332]	0.0000003265	[.664]
Friday	-0.0001426060	[.945]	0.0001206980	[.000]*	0.0000148009	[.038]*	0.0000309738	[.000]*
Macroeconomic Ann. (UK)								
GDP preliminary: GDPP(Before)	-0.0044974000	[.039]*	0.0000351743	[.006]*	-0.0000126282	[.130]	0.0000083391	[.013]*
GDP preliminary: GDPP(After)	-0.0011408800	[.615]	-0.0000103364	[.517]	-0.0000029543	[.707]	-0.0000039973	[.339]
Consumer Price Index: CPI (Before)	0.0040180700	[.000]*	-0.0000266340	[.001]*	0.0000072829	[.028]*	-0.0000076212	[.000]*
Consumer Price Index: CPI (After)	0.0025351900	[.013]*	-0.0000068261	[.405]	0.0000041317	[.234]	-0.0000027222	[.210]
Federal Fund Rate: IR (Before)	-0.0020948000	[.050]*	-0.0000246251	[.008]*	-0.0000073108	[.052]*	-0.0000063148	[.010]*
Federal Fund Rate: IR (After)	-0.0015902400	[.147]	-0.0000059570	[.487]	-0.0000024698	[.521]	-0.0000013396	[.553]
Trade Balance:TB (Before)	-0.0003361870	[.823]	0.0000017543	[.869]	-0.0000072785	[.116]	-0.0000000300	[.991]
Trade Balance:TB (After)	0.0017382000	[.214]	-0.0000196788	[.073]**	-0.0000016882	[.707]	-0.0000053516	[.064]**
Multiplicative Dummies								
Friday X Quote Revisions	0.0001102070	[.939]	-0.0000750896	[.000]*	-0.0000106232	[.033]*	-0.0000193296	[.000]*
Prec. Holiday X Quote Revisions	0.0001204120	[.927]	0.0000021797	[.779]	-0.0000033589	[.395]	-0.0000000310	[.988]
Friday X Volatility	226.4160000000	[.692]	-10.7474000000	[.311]	0.6581020000	[.708]	-2.8935500000	[.291]
Prec. Holiday X Volatility	-998.1850000000	[.418]	25.1349000000	[.408]	-3.7969200000	[.369]	6.1094600000	[.436]
Lagged Spread	0.0805240000	[.000]*	0.0699270000	[.000]*	0.0996170000	[.000]*	0.0792510000	[.000]*
α_0	0.0000391236	[.000]*	0.0000000006	[.193]	0.0000000001	[.028]*	0.0000000000	[.182]
α_1	0.0355940000	[.000]*	0.0139130000	[.004]*	0.0254020000	[.000]*	0.0132590000	[.003]*
β_1	0.9128250000	[.000]*	0.9742240000	[.000]*	0.9691250000	[.000]*	0.9769850000	[.000]*
Intercept	0.0550670000		0.0007090570		0.0001771090		0.0001831540	
Adjusted R-squared	0.021463		0.016059		0.026702		0.018217	
*: 5 percent level of significance, **: 10 percent level of significance								

Panel O: ASIA Time Zone, Period 2 Sample: Intraday								
	Quoted Spread				Relative Spread			
	JP/US		GB/US		JP/US		GB/US	
Parameter	Estimate	P-value	Estimate	P-value	Estimate	P-value	Estimate	P-value
Number of Quote Revisions	0,0062562600	[.000]*	0,0000542887	[.000]*	0,0000216503	[.000]*	0,0000137308	[.000]*
Interest Rate	-2,9058600000	[.000]*	-0,0320490000	[.000]*	-0,0039207100	[.000]*	-0,0077046700	[.000]*
Volatility	-15,8494000000	[.500]	2,6125500000	[.517]	-0,0586360000	[.566]	0,9054420000	[.199]
Seasonality (ASIA)								
Preceding Holiday:								
ASIA only	0,0010336800	[.436]	0,0000293220	[.033]*	0,0000009115	[.843]	0,0000074109	[.013]*
Common	-0,0056402600	[.017]*	-0,0000115394	[.688]	-0,0000053872	[.492]	-0,0000039330	[.568]
Post Holiday:								
ASIA only	-0,0035883800	[.001]*	0,0000056679	[.606]	-0,0000089375	[.023]*	0,0000020006	[.437]
Common	-0,0052370900	[.124]	0,0000560647	[.116]	-0,0000234625	[.041]*	0,0000112767	[.304]
Last Day of Month	0,0022090300	[.022]*	0,0000266450	[.002]*	0,0000049288	[.139]	0,0000069289	[.004]*
Monday	0,0013863700	[.000]*	0,0000192361	[.000]*	0,0000041411	[.001]*	0,0000050038	[.000]*
Friday	0,0017707100	[.113]	0,0000121417	[.119]	0,0000060636	[.109]	0,0000052448	[.005]*
Macroeconomic Ann. (ASIA)								
GDP preliminary: GDPP(Before)	0,0058156300	[.007]*	-0,0000614395	[.025]*	0,0000123184	[.097]**	-0,0000168366	[.008]*
GDP preliminary: GDPP(After)	0,0006712390	[.776]	-0,0000339009	[.091]**	-0,0000023800	[.768]	-0,0000075220	[.164]
Consumer Price Index: CPI (Before)	-0,0011283400	[.307]	0,0000393488	[.000]*	-0,0000006986	[.857]	0,0000095421	[.000]*
Consumer Price Index: CPI (After)	-0,0019957800	[.160]	-0,0000296934	[.067]**	-0,0000039099	[.421]	-0,0000064004	[.033]*
Federal Fund Rate: IR (Before)	0,0066944800	[.000]*	-0,0000267334	[.014]*	0,0000172929	[.000]*	-0,0000057850	[.023]*
Federal Fund Rate: IR (After)	0,0024492600	[.022]	0,0000065865	[.457]	0,0000018793	[.604]	0,0000018601	[.442]
Trade Balance:TB (Before)	-0,0026209200	[.143]	0,0000654429	[.005]*	-0,0000113794	[.056]**	0,0000143823	[.035]*
Trade Balance:TB (After)	-0,0055865700	[.004]*	0,0000087071	[.854]	-0,0000205748	[.001]*	0,0000007118	[.948]
Multiplicative Dummies								
Friday X Quote Revisions	-0,0005011850	[.598]	-0,0000046788	[.516]	-0,0000016434	[.612]	-0,0000026412	[.145]
Prec. Holiday X Quote Revisions	0,0009848670	[.219]	-0,0000171808	[.098]**	0,0000079420	[.004]*	-0,0000053292	[.016]*
Friday X Volatility	205,8220000000	[.045]	5,6010100000	[.248]	0,5617290000	[.227]	1,6673500000	[.110]
Prec. Holiday X Volatility	-126,7050000000	[.251]	23,0449000000	[.013]*	-0,2199330000	[.674]	5,0521500000	[.030]*
Lagged Spread	0,1186810000	[.000]*	0,2055970000	[.000]*	0,1378870000	[.000]*	0,2056360000	[.000]*
α_0	0,0000378127	[.025]*	0,0000000035	[.283]	0,0000000002	[.007]*	0,0000000000	[.262]
α_1	0,0423520000	[.000]*	0,0540910000	[.079]**	0,0391120000	[.000]*	0,0128410000	[.011]*
β_1	0,9093280000	[.000]*	0,9074770000	[.000]*	0,9423620000	[.000]*	0,9854870000	[.000]*
Intercept	0,0568560000		0,0006110210		0,0001863130		0,0001596680	
Adjusted R-squared	0,029258		0,061256		0,033683		0,061293	
*: 5 percent level of significance, **: 10 percent level of significance								

Panel P: US Time Zone, Period 3 Sample: Intraday												
	Quoted Spread						**Relative Spread**					
	JP/US		**GB/US**		**EU/US**		**JP/US**		**GB/US**		**EU/US**	
Parameter	Estimate	P-value	Estimate	P-value	Estimate	P-value	Estimate	P-value	Estimate	P-value	Estimate	P-value
Number of Quote Revisions	-0.0114870000	[.000]*	-0.0001282380	[.000]*	-0.0001027870	[.000]*	-0.0000402945	[.000]*	-0.0000324074	[.000]*	-0.0000502273	[.000]*
Interest Rate	-1.4551200000	[.000]*	-0.0044327000	[.000]*	-0.0157100000	[.000]*	0.0007981910	[.017]*	-0.0057405200	[.000]*	-0.0138610000	[.000]*
Volatility	-29.3379000000	[.605]	-2.1170300000	[.510]	0.9095400000	[.193]	-0.2144410000	[.332]	-0.4921750000	[.505]	0.4959110000	[.091]**
Seasonality (US)												
Preceding Holiday:												
US only	0.0019267700	[.001]*	0.0000097603	[.041]*	0.0000264622	[.000]*	0.0000089506	[.000]*	0.0000006595	[.685]	0.0000044878	[.059]*
Common	0.0123970000	[.000]*	0.0001113810	[.000]*	0.0001104680	[.000]*	0.0000446055	[.000]*	0.0000356981	[.000]*	0.0000463793	[.000]*
Post Holiday:												
US only	-0.0003386290	[.450]	0.0000053722	[.292]	-0.0000064424	[.138]	-0.0000000579	[.974]	0.0000000330	[.982]	-0.0000033033	[.040]*
Common	0.0067151800	[.017]*	0.0000470497	[.001]*	0.0000046486	[.756]	0.0000228531	[.014]*	0.0000131490	[.002]*	-0.0000018158	[.806]
Last Day of Month	0.0010045300	[.036]*	0.0000026487	[.545]	0.0000120515	[.012]*	0.0000030921	[.071]**	-0.0000006527	[.590]	0.0000014254	[.444]
Monday	-0.0009920570	[.000]*	-0.0000088929	[.000]*	-0.0000051210	[.000]*	-0.0000030490	[.000]*	-0.0000025694	[.000]*	-0.0000032529	[.000]*
Friday	0.0024560100	[.000]*	-0.0000032719	[.473]	0.0000114768	[.152]	0.0000116589	[.000]*	-0.0000012102	[.394]	0.0000018502	[.611]
Macroeconomic Ann. (US)												
GDP preliminary: GDPP(Before)	0.0015298100	[.070]**	0.0000139911	[.421]	0.0000110053	[.179]	0.0000069609	[.026]*	0.0000013681	[.811]	-0.0000000283	[.993]
GDP preliminary: GDPP(After)	-0.0016375800	[.037]*	-0.0000088311	[.246]	-0.0000162443	[.019]*	-0.0000051025	[.082]**	-0.0000012371	[.539]	-0.0000030559	[.270]
Consumer Price Index: CPI (Before)	0.0007771680	[.086]**	0.0000001471	[.976]	0.0000102587	[.025]*	0.0000033418	[.053]**	-0.0000004930	[.704]	0.0000029142	[.106]
Consumer Price Index: CPI (After)	0.0000776007	[.858]	0.0000032779	[.387]	0.0000041795	[.367]	-0.0000009019	[.589]	0.0000014021	[.131]	0.0000041318	[.021]*
Federal Fund Rate: IR (Before)	-0.0012823700	[.021]*	-0.0000099768	[.047]*	-0.0000088775	[.042]*	-0.0000047444	[.033]*	-0.0000031639	[.017]*	-0.0000038491	[.031]*
Federal Fund Rate: IR (After)	0.0007336650	[.169]	-0.0000038588	[.476]	0.0000080169	[.122]	0.0000034199	[.093]**	-0.0000011376	[.419]	0.0000034565	[.083]**
Trade Balance:TB (Before)	0.0001148010	[.806]	-0.0000105601	[.043]*	0.0000085779	[.043]*	0.0000006190	[.729]	-0.0000027900	[.053]*	0.0000015184	[.365]
Trade Balance:TB (After)	0.0001725560	[.688]	0.0000064132	[.143]	-0.0000081652	[.067]**	-0.0000011301	[.504]	0.0000024635	[.040]*	-0.0000002825	[.874]
Multiplicative Dummies												
Friday X Quote Revisions	-0.0001850110	[.495]	0.0000096355	[.000]*	0.0000045716	[.240]	-0.0000019095	[.073]**	0.0000026739	[.000]*	0.0000031449	[.068]**
Prec. Holiday X Quote Revisions	-0.0001010080	[.563]	0.0000028666	[.221]	-0.0000020928	[.293]	0.0000002537	[.711]	0.0000005816	[.314]	-0.0000008495	[.291]
Friday X Volatility	-5.3118400000	[.974]	7.2465200000	[.234]	-1.2330200000	[.520]	-0.0088286100	[.989]	1.7968500000	[.279]	-0.4830850000	[.557]
Prec. Holiday X Volatility	-36.6730000000	[.953]	-8.0046300000	[.075]**	-1.5223400000	[.739]	0.0449720000	[.985]	3.0781000000	[.017]*	-0.1180540000	[.946]
Lagged Spread	0.1825990000	[.000]*	0.2032250000	[.000]*	0.0971640000	[.000]*	0.1816280000	[.000]*	0.2404110000	[.000]*	0.1344690000	[.000]*
Data Feeder Dummies												
DDF2	-0.0089229300	[.000]*	-0.0001452830	[.000]*	-0.0000320159	[.000]*	-0.0000450355	[.000]*	-0.0000309634	[.000]*	-0.0000022827	[.066]*
DDF3	0.0103010000	[.000]*	0.0000472559	[.000]*	0.0000202597	[.000]*	0.0000366958	[.000]*	0.0000095536	[.000]*	0.0000020297	[.200]
DDF4	0.0017903700	[.176]	-0.0000125616	[.375]	0.0000175471	[.358]	0.0000067355	[.156]	-0.0000050263	[.214]	0.0000106639	[.281]
DDF5	0.0037180100	[.000]*	0.0001102890	[.000]*	0.0000507010	[.000]*	0.0000164605	[.000]*	0.0000269522	[.000]*	0.0000156805	[.000]*
DDF6	-0.0162550000	[.000]*	-0.0001408600	[.000]*	-0.0000502301	[.000]*	-0.0000673234	[.000]*	-0.0000501959	[.000]*	-0.0000419404	[.000]*
α_0	0.0000036300	[.000]*	0.0000000005	[.000]*	0.0000000002	[.000]*	0.0000000001	[.000]*	0.0000000000	[.000]*	0.0000000000	[.000]*
α_1	0.0625800000	[.000]*	0.0855550000	[.000]*	0.0298330000	[.000]*	0.0636710000	[.000]*	0.0740170000	[.000]*	0.0235430000	[.000]*
β_1	0.9320270000	[.000]*	0.9073800000	[.000]*	0.9637520000	[.000]*	0.9282680000	[.000]*	0.9239690000	[.000]*	0.9758160000	[.000]*
Intercept	0.0707040000		0.0007711050		0.0005715350		0.0002655270		0.0002056040		0.0002611440	
Adjusted R-squared	0.296733		0.29578		0.107522		0.320047		0.319195		0.204047	
*: 5 percent level of significance, **: 10 percent level of significance												

Panel Q: UK Time Zone, Period 3 Sample: Intraday												
	Quoted Spread						Relative Spread					
	JP/US		GB/US		EU/US		JP/US		GB/US[a]		EU/US	
Parameter	Estimate	P-value	Estimate	P-value	Estimate	P-value	Estimate	P-value	Estimate	P-value	Estimate	P-value
Number of Quote Revisions	-0.0121170000	[.000]*	-0.0001495030	[.000]*	-0.0000637820	[.000]*	-0.0000402244	[.803]	-0.0000511016	[.000]*	-0.0000509301	[.000]*
Interest Rate	-0.1391790000	[.055]*	0.0042540800	[.000]*	-0.0105400000	[.000]*	0.0070796100	[.640]	-0.0020955400	[.000]*	-0.0105250000	[.000]*
Volatility	281.4230000000	[.000]*	5.6188800000	[.016]*	0.4998380000	[.665]	1.0232100000	[.273]	1.3799200000	[.033]*	0.6343410000	[.247]
Seasonality (UK)												
Preceding Holiday:												
UK only	0.0015644400	[.019]*	0.0000080611	[.224]	-0.0000214188	[.020]*	0.0000060556	[.225]	0.0000027860	[.193]	0.0000003298	[.911]
Common	0.0021671600	[.139]	0.0000608519	[.000]*	0.0000506863	[.000]*	0.0000148517	[.187]	0.0000199750	[.000]*	0.0000040373	[.325]
Post Holiday:												
UK only	0.0012344500	[.019]*	0.0000085168	[.166]	0.0000205546	[.000]*	-0.0000265447	[.881]	-0.0000021586	[.240]	0.0000018216	[.374]
Common	-0.0009597570	[.465]	0.0000186881	[.426]	-0.0001190560	[.000]*	0.0000308515	[.877]	0.0000132487	[.003]*	-0.0000507643	[.000]*
Last Day of Month	-0.0000008696	[.998]	0.0000040564	[.592]	0.0000044010	[.221]	-0.0000006191	[.889]	-0.0000009139	[.464]	0.0000022112	[.118]
Monday	-0.0006466040	[.000]*	-0.0000099094	[.000]*	-0.0000013502	[.355]	-0.0000009710	[.964]	-0.0000017441	[.000]*	-0.0000024066	[.000]*
Friday	-0.0034165400	[.000]*	-0.0000041652	[.599]	0.0000090095	[.486]	0.0000047710	[.710]	-0.0000041883	[.031]*	-0.0000094565	[.069]**
Macroeconomic Ann. (UK)												
GDP preliminary: GDPP(Before)	-0.0002590150	[.708]	-0.0000053383	[.444]	0.0000076798	[.277]	0.0000012967	[.880]	-0.0000017438	[.456]	0.0000014617	[.582]
GDP preliminary: GDPP(After)	0.0003417280	[.602]	0.0000125858	[.031]*	0.0000040221	[.636]	0.0000032046	[.665]	0.0000037778	[.080]**	0.0000011077	[.741]
Consumer Price Index: CPI (Before)	-0.0004182800	[.288]	0.0000025760	[.560]	-0.0000011456	[.780]	-0.0000005863	[.923]	0.0000039798	[.003]*	-0.0000006170	[.704]
Consumer Price Index: CPI (After)	-0.0001984430	[.613]	-0.0000082324	[.080]**	-0.0000008786	[.827]	0.0000006804	[.949]	0.0000000895	[.947]	-0.0000024757	[.116]
Federal Fund Rate: IR (Before)	0.0002363250	[.540]	-0.0000005614	[.922]	-0.0000035610	[.378]	-0.0000013663	[.753]	0.0000004811	[.727]	-0.0000006367	[.695]
Federal Fund Rate: IR (After)	0.0002488500	[.525]	0.0000037109	[.694]	-0.0000128091	[.001]*	0.0000008211	[.934]	-0.0000003180	[.815]	-0.0000055646	[.000]*
Trade Balance:TB (Before)	-0.0005236120	[.175]	0.0000089388	[.385]	0.0000015888	[.723]	-0.0000021097	[.752]	0.0000013460	[.325]	0.0000001761	[.920]
Trade Balance:TB (After)	-0.0014351500	[.000]*	0.0000041803	[.445]	-0.0000008421	[.838]	-0.0000041386	[.651]	0.0000003017	[.824]	-0.0000019508	[.236]
Multiplicative Dummies												
Friday X Quote Revisions	0.0016754600	[.000]*	0.0000033337	[.389]	-0.0000036134	[.530]	-0.0000020999	[1.00]	0.0000029128	[.004]*	0.0000043484	[.057]**
Prec. Holiday X Quote Revisions	0.0000867493	[.691]	0.0000026816	[.189]	0.0000154299	[.000]*	0.0000014914	[.783]	0.0000020717	[.008]*	0.0000008360	[.253]
Friday X Volatility	25.0748000000	[.896]	3.8303000000	[.271]	1.8437400000	[.404]	0.0157310000	[.994]	1.0310900000	[.445]	0.4696950000	[.611]
Prec. Holiday X Volatility	-308.9420000000	[.658]	92.4769000000	[.009]*	-41.0056000000	[.056]**	4.7000900000	[.826]	36.3450000000	[.000]*	-5.0205500000	[.601]
Lagged Spread	0.1004530000	[.000]*	0.1212940000	[.000]*	0.0692770000	[.000]*	0.0902450000	[.000]*	0.1359410000	[.000]*	0.1023520000	[.000]*
Data Feeder Dummies												
DDF2	-0.0083177200	[.000]*	-0.0001423510	[.000]*	0.0000077007	[.004]*	-0.0000435318	[.000]*	-0.0000271441	[.000]*	0.0000126214	[.000]*
DDF3	0.0034910700	[.000]*	0.0000463501	[.000]*	0.0000019406	[.553]	0.0000171902	[.313]	0.0000096078	[.000]*	-0.0000058175	[.000]*
DDF4	0.0015035900	[.229]	0.0000429234	[.001]*	0.0000383877	[.159]	0.0000033696	[.930]	0.0000154592	[.000]*	0.0000222837	[.095]**
DDF5	0.0034938700	[.000]*	0.0000908081	[.000]*	-0.0000015946	[.756]	0.0000155213	[.636]	0.0000246008	[.000]*	-0.0000058121	[.020]*
DDF6	-0.0171500000	[.000]*	-0.0001297330	[.000]*	-0.0000681901	[.000]*	-0.0000725033	[.405]	-0.0000319497	[.000]*	-0.0000521140	[.000]*
α_0	0.0000000999	[.000]*	0.0000000000	[.000]*	0.0000000000	[.000]*	0.0000000001	[.039]			0.0000000000	[.007]*
α_1	0.0149440000	[.000]*	0.0142240000	[.000]*	0.0138610000	[.000]*	0.1271840000	[.300]			0.0127310000	[.000]*
β_1	0.9850250000	[.000]*	0.9850080000	[.000]*	0.9854080000	[.000]*	0.8712770000	[.000]*			0.9873070000	[.000]*
Intercept	0.0752030000		0.0008376840		0.0004992900		0.0002818310		0.0002456260		0.0002734400	
Adjusted R-squared	0.197296		0.200385		0.051312		0.216212		0.201953		0.147888	
a: OLS estimates *: 5 percent level of significance, **: 10 percent level of significance												

Panel R : ASIA Time Zone, Period 3 Sample: Intraday

	Quoted Spread						Relative Spread					
	JP/US		GB/US		EU/US		JP/US		GB/US		EU/US	
Parameter	Estimate	P-value	Estimate	P-value	Estimate	P-value	Estimate	P-value	Estimate	P-value	Estimate	P-value
Number of Quote Revisions	-0.0000269085	[.000]*	-0.0000789359	[.000]*	-0.0000848865	[.000]*	-0.0000269085	[.000]*	-0.0000200217	[.000]*	-0.0000383652	[.000]*
Interest Rate	-0.0057028400	[.000]*	-0.0217920000	[.000]*	-0.0323900000	[.000]*	-0.0057028400	[.000]*	-0.0092176800	[.000]*	-0.0196310000	[.000]*
Volatility	0.4483400000	[.084]**	1.9707300000	[.027]*	0.5254540000	[.333]	0.4483400000	[.084]*	0.5315690000	[.019]*	0.2291020000	[.302]
Seasonality (ASIA)												
Preceding Holiday:												
ASIA only	-0.0000012591	[.529]	-0.0000106167	[.040]*	-0.0000084023	[.096]**	-0.0000012591	[.529]	-0.0000024391	[.078]**	-0.0000022228	[.247]
Common	0.0000236524	[.000]*	0.0000422616	[.000]*	-0.0000770397	[.000]*	0.0000236524	[.000]*	0.0000211351	[.001]*	-0.0000238984	[.000]*
Post Holiday:												
ASIA only	0.0000010392	[.456]	-0.0000021348	[.574]	0.0000067150	[.069]**	0.0000010392	[.456]	-0.0000003574	[.696]	0.0000002702	[.849]
Common	0.0000424333	[.000]*	0.0000551144	[.018]*	0.0000334084	[.017]*	0.0000424333	[.000]*	0.0000124736	[.115]	0.0000193265	[.004]*
Last Day of Month	0.0000038778	[.013]*	-0.0000022438	[.566]	-0.0000098490	[.013]*	0.0000038778	[.013]	-0.0000006171	[.568]	-0.0000037040	[.018]*
Monday	0.0000066113	[.000]*	0.0000014823	[.310]	0.0000103683	[.000]*	0.0000066113	[.000]*	0.0000003262	[.422]	0.0000036825	[.000]*
Friday	0.0000142721	[.000]*	0.0000230391	[.000]*	0.0000143111	[.059]**	0.0000142721	[.000]*	0.0000057770	[.000]*	0.0000055383	[.094]**
Macroeconomic Ann. (ASIA)												
GDP preliminary: GDPP(Before)	0.0000053418	[.090]**	0.0000070060	[.482]	0.0000076350	[.346]	0.0000053418	[.090]**	0.0000024048	[.355]	0.0000018128	[.566]
GDP preliminary: GDPP(After)	0.0000077599	[.057]**	0.0000144342	[.180]	-0.0000108955	[.240]	0.0000077599	[.057]*	0.0000048845	[.076]**	-0.0000021190	[.566]
Consumer Price Index: CPI (Before)	-0.0000007256	[.647]	-0.0000006353	[.872]	-0.0000066712	[.130]	-0.0000007256	[.647]	-0.0000002114	[.837]	-0.0000022588	[.195]
Consumer Price Index: CPI (After)	0.0000040489	[.017]*	-0.0000049973	[.199]	0.0000011073	[.801]	0.0000040489	[.017]*	-0.0000018726	[.064]**	-0.0000011111	[.527]
Federal Fund Rate: IR (Before)	0.0000034437	[.016]*	-0.0000041234	[.224]	0.0000136248	[.000]*	0.0000034437	[.016]*	-0.0000012116	[.183]	0.0000048665	[.001]*
Federal Fund Rate: IR (After)	0.0000030077	[.036]*	0.0000047633	[.184]	-0.0000088904	[.021]*	0.0000030077	[.036]	0.0000022862	[.016]*	-0.0000012097	[.429]
Trade Balance:TB (Before)	-0.0000009555	[.570]	0.0000043240	[.360]	-0.0000093995	[.028]*	-0.0000009555	[.570]	0.0000013297	[.286]	-0.0000033666	[.047]*
Trade Balance:TB (After)	0.0000002481	[.882]	-0.0000017236	[.608]	-0.0000030146	[.472]	0.0000002481	[.882]	-0.0000002644	[.773]	-0.0000019536	[.233]
Multiplicative Dummies												
Friday X Quote Revisions	-0.0000077145	[.000]*	-0.0000148846	[.000]*	-0.0000069102	[.090]*	-0.0000077145	[.000]*	-0.0000037170	[.000]*	-0.0000026222	[.131]
Prec. Holiday X Quote Revisions	0.0000012082	[.121]	0.0000066899	[.003]*	0.0000008267	[.648]	0.0000012082	[.121]	0.0000013730	[.017]*	-0.0000006370	[.345]
Friday X Volatility	0.2736300000	[.638]	-0.1808480000	[.901]	-0.4551880000	[.669]	0.2736300000	[.638]	0.0482390000	[.903]	-0.1135440000	[.784]
Prec. Holiday X Volatility	0.9858680000	[.504]	5.3937200000	[.279]	0.4319680000	[.862]	0.9858680000	[.504]	1.1398400000	[.353]	-0.1340250000	[.888]
Lagged Spread	0.1631530000	[.000]*	0.2413020000	[.000]*	0.1168470000	[.000]*	0.1631530000	[.000]*	0.2972270000	[.000]*	0.1678790000	[.000]*
Data Feeder Dummies												
DDF2	-0.0000317363	[.000]*	-0.0000970163	[.000]*	-0.0000209613	[.000]*	-0.0000317363	[.000]*	-0.0000178892	[.000]*	0.0000043387	[.003]*
DDF3	0.0000265725	[.000]*	0.0000063521	[.256]	0.0000039150	[.252]	0.0000265725	[.000]*	-0.0000011969	[.467]	-0.0000054593	[.001]*
DDF4	0.0000027410	[.549]	0.0000064504	[.625]	0.0000103452	[.378]	0.0000027410	[.549]	0.0000004357	[.911]	0.0000071985	[.189]
DDF5	-0.0000093076	[.001]*	0.0000820829	[.000]*	0.0000265973	[.000]*	-0.0000093076	[.001]*	0.0000192672	[.000]*	0.0000016128	[.596]
DDF6	-0.0000735726	[.000]*	-0.0001086890	[.000]*	-0.0000370182	[.000]*	-0.0000735726	[.000]*	-0.0000421730	[.000]*	-0.0000432960	[.000]*
α_0	0.0000000000	[.000]*	0.0000000002	[.000]*	0.0000000001	[.002]*	0.0000000000	[.000]*	0.0000000000	[.000]*	0.0000000000	[.003]*
α_1	0.0438860000	[.000]*	0.0713260000	[.000]*	0.0218780000	[.000]*	0.0438860000	[.000]*	0.0649570000	[.000]*	0.0181960000	[.000]*
β_1	0.9546130000	[.000]*	0.9275890000	[.000]*	0.9771250000	[.000]*	0.9546130000	[.000]*	0.9358380000	[.000]*	0.9818040000	[.000]*
Intercept	0.0002504390		0.0006333470		0.0005493150		0.0002504390		0.0001669500		0.0002418800	
Adjusted R-squared	0.195176		0.195112		0.098447		0.26155		0.243092		0.195176	

*: 5 percent level of significance, **: 10 percent level of significance

Appendix 7

Panels S – U: Cross Autocorrelations

(US, UK and Asia Time Zone)

Panels S, T and U present first order cross autocorrelation results between four variables; number of quote revisions, spread (quoted and relative), exchange rate volatility and interest rate differential using the full sample. The VAR has been ordered according to which variable leads another.

Panel S: Cross Autocorrelation Matrix, US Time Zone

JP/US Quoted Spread

	Spread Quoted (0)	Quote Revisions (0)	Volatility (0)	I.R Differential (0)
Spread (-1)	0,89	-0,74	0,17	-0,02
Quote Revisions (-1)	-0,71	0,85	-0,11	-0,07
Volatility (-1)	0,20	-0,11	0,32	-0,02
I.R Differential (-1)	-0,02	-0,07	-0,04	0,87
Spread (-2)	0,88	-0,71	0,19	-0,02
Quote Revisions (-2)	-0,71	0,80	-0,13	-0,07
Volatility (-2)	0,20	-0,12	0,26	-0,03
I.R Differential (-2)	-0,02	-0,07	-0,03	0,78
Spread (-3)	0,87	-0,71	0,18	-0,01
Quote Revisions (-3)	-0,71	0,79	-0,14	-0,09
Volatility (-3)	0,19	-0,11	0,23	-0,02
I.R Differential (-3)	-0,02	-0,09	-0,04	0,75
Spread (-4)	0,87	-0,71	0,19	-0,01
Quote Revisions (-4)	-0,73	0,81	-0,15	-0,10
Volatility (-4)	0,18	-0,11	0,23	-0,02
I.R Differential (-4)	-0,02	-0,09	-0,04	0,71
Spread (-5)	0,87	-0,72	0,19	-0,01
Quote Revisions (-5)	-0,71	0,85	-0,13	-0,10
Volatility (-5)	0,20	-0,11	0,24	-0,03
I.R Differential (-5)	-0,01	-0,10	-0,04	0,68

GB/US Quoted Spread

	Spread Quoted (0)	Quote Revisions (0)	Volatility (0)	I.R Differential (0)
Spread (-1)	0,88	-0,78	-0,02	0,09
Quote Revisions (-1)	-0,76	0,82	0,07	-0,05
Volatility (-1)	-0,01	0,09	0,21	0,00
I.R Differential (-1)	0,09	-0,04	0,00	0,87
Spread (-2)	0,85	-0,74	-0,02	0,08
Quote Revisions (-2)	-0,75	0,76	0,05	-0,05
Volatility (-2)	-0,02	0,08	0,17	-0,01
I.R Differential (-2)	0,09	-0,04	0,00	0,78
Spread (-3)	0,84	-0,75	-0,03	0,09
Quote Revisions (-3)	-0,74	0,75	0,05	-0,07
Volatility (-3)	-0,02	0,09	0,19	-0,01
I.R Differential (-3)	0,10	-0,07	0,00	0,75
Spread (-4)	0,84	-0,74	-0,01	0,10
Quote Revisions (-4)	-0,75	0,77	0,05	-0,09
Volatility (-4)	-0,02	0,09	0,13	-0,01
I.R Differential (-4)	0,10	-0,07	0,00	0,71
Spread (-5)	0,85	-0,75	-0,01	0,10
Quote Revisions (-5)	-0,75	0,82	0,07	-0,09
Volatility (-5)	-0,01	0,10	0,18	-0,02
I.R Differential (-5)	0,11	-0,08	-0,02	0,68

EU/US Quoted Spread

	Spread Quoted (0)	Quote Revisions (0)	Volatility (0)	I.R Differential (0)
Spread (-1)	0,62	-0,46	-0,16	-0,52
Quote Revisions (-1)	-0,37	0,61	0,21	0,28
Volatility (-1)	-0,09	0,23	0,08	0,04
I.R Differential (-1)	-0,52	0,28	0,02	0,87
Spread (-2)	0,47	-0,35	-0,14	-0,52
Quote Revisions (-2)	-0,30	0,53	0,16	0,27
Volatility (-2)	-0,12	0,22	0,16	0,01
I.R Differential (-2)	-0,52	0,27	0,01	0,78
Spread (-3)	0,48	-0,32	-0,12	-0,51
Quote Revisions (-3)	-0,31	0,51	0,20	0,25
Volatility (-3)	-0,15	0,25	0,19	0,01
I.R Differential (-3)	-0,51	0,28	0,02	0,75
Spread (-4)	0,55	-0,33	-0,12	-0,50
Quote Revisions (-4)	-0,38	0,51	0,17	0,24
Volatility (-4)	-0,15	0,26	0,08	0,00
I.R Differential (-4)	-0,50	0,27	0,02	0,71
Spread (-5)	0,62	-0,38	-0,06	-0,49
Quote Revisions (-5)	-0,40	0,62	0,19	0,24
Volatility (-5)	-0,07	0,25	0,19	0,00
I.R Differential (-5)	-0,51	0,28	0,00	0,68

JP/US Relative Spread

	Spread Relative (0)	Quote Revisions (0)	Volatility (0)	I.R Differential (0)
Spread (-1)	0,92	-0,71	0,09	0,06
Quote Revisions (-1)	-0,68	0,85	-0,11	-0,07
Volatility (-1)	0,12	-0,11	0,32	-0,02
I.R Differential (-1)	0,06	-0,07	-0,04	0,87
Spread (-2)	0,90	-0,69	0,10	0,06
Quote Revisions (-2)	-0,68	0,80	-0,13	-0,07
Volatility (-2)	0,12	-0,12	0,26	-0,03
I.R Differential (-2)	0,07	-0,07	-0,03	0,78
Spread (-3)	0,90	-0,68	0,09	0,07
Quote Revisions (-3)	-0,68	0,79	-0,14	-0,09
Volatility (-3)	0,11	-0,11	0,23	-0,02
I.R Differential (-3)	0,06	-0,09	-0,04	0,75
Spread (-4)	0,89	-0,68	0,10	0,07
Quote Revisions (-4)	-0,69	0,81	-0,15	-0,10
Volatility (-4)	0,10	-0,11	0,23	-0,02
I.R Differential (-4)	0,06	-0,09	-0,04	0,71
Spread (-5)	0,90	-0,69	0,10	0,06
Quote Revisions (-5)	-0,69	0,85	-0,13	-0,10
Volatility (-5)	0,12	-0,11	0,24	-0,03
I.R Differential (-5)	0,08	-0,10	-0,04	0,68

GB/US Relative Spread

	Spread Relative (0)	Quote Revisions (0)	Volatility (0)	I.R Differential (0)
Spread (-1)	0,89	-0,77	-0,06	0,00
Quote Revisions (-1)	-0,76	0,82	0,07	-0,05
Volatility (-1)	-0,05	0,09	0,21	0,00
I.R Differential (-1)	0,00	-0,04	0,00	0,87
Spread (-2)	0,87	-0,74	-0,06	-0,01
Quote Revisions (-2)	-0,74	0,76	0,05	-0,05
Volatility (-2)	-0,05	0,08	0,17	-0,01
I.R Differential (-2)	0,00	-0,04	0,00	0,78
Spread (-3)	0,86	-0,74	-0,07	0,00
Quote Revisions (-3)	-0,74	0,75	0,05	-0,07
Volatility (-3)	-0,05	0,09	0,19	-0,01
I.R Differential (-3)	0,01	-0,07	0,00	0,75
Spread (-4)	0,85	-0,74	-0,05	0,01
Quote Revisions (-4)	-0,75	0,77	0,05	-0,09
Volatility (-4)	-0,05	0,09	0,13	-0,01
I.R Differential (-4)	0,01	-0,07	0,00	0,71
Spread (-5)	0,86	-0,75	-0,05	0,01
Quote Revisions (-5)	-0,75	0,82	0,07	-0,09
Volatility (-5)	-0,05	0,10	0,18	-0,02
I.R Differential (-5)	0,02	-0,08	-0,02	0,68

EU/US Relative Spread

	Spread Relative (0)	Quote Revisions (0)	Volatility (0)	I.R Differential (0)
Spread (-1)	0,86	-0,55	-0,21	-0,62
Quote Revisions (-1)	-0,49	0,61	0,21	0,28
Volatility (-1)	-0,18	0,23	0,08	0,04
I.R Differential (-1)	-0,62	0,28	0,02	0,87
Spread (-2)	0,81	-0,48	-0,21	-0,62
Quote Revisions (-2)	-0,45	0,53	0,16	0,27
Volatility (-2)	-0,19	0,22	0,16	0,01
I.R Differential (-2)	-0,62	0,27	0,01	0,78
Spread (-3)	0,81	-0,47	-0,20	-0,61
Quote Revisions (-3)	-0,46	0,51	0,20	0,25
Volatility (-3)	-0,21	0,25	0,19	0,01
I.R Differential (-3)	-0,61	0,28	0,02	0,75
Spread (-4)	0,83	-0,47	-0,19	-0,60
Quote Revisions (-4)	-0,50	0,51	0,17	0,24
Volatility (-4)	-0,21	0,26	0,08	0,00
I.R Differential (-4)	-0,61	0,27	0,02	0,71
Spread (-5)	0,85	-0,51	-0,17	-0,60
Quote Revisions (-5)	-0,51	0,62	0,19	0,24
Volatility (-5)	-0,16	0,25	0,19	0,00
I.R Differential (-5)	-0,61	0,28	0,00	0,68

Panel T: Cross Autocorrelation Matrix, UK Time Zone

JP/US Quoted Spread

	Spread Quoted (0)	Quote Revisions (0)	Volatility (0)	I.R Differential (0)
Spread (-1)	0,93	-0,73	0,19	0,05
Quote Revisions (-1)	-0,73	0,78	-0,05	-0,06
Volatility (-1)	0,19	-0,03	0,36	-0,02
I.R Differential (-1)	0,05	-0,06	-0,03	0,87
Spread (-2)	0,91	-0,73	0,19	0,05
Quote Revisions (-2)	-0,73	0,73	-0,06	-0,07
Volatility (-2)	0,19	-0,05	0,28	-0,02
I.R Differential (-2)	0,05	-0,05	-0,02	0,78
Spread (-3)	0,91	-0,73	0,18	0,06
Quote Revisions (-3)	-0,72	0,73	-0,06	-0,09
Volatility (-3)	0,19	-0,03	0,26	-0,02
I.R Differential (-3)	0,05	-0,07	-0,03	0,75
Spread (-4)	0,90	-0,74	0,18	0,06
Quote Revisions (-4)	-0,72	0,75	-0,07	-0,10
Volatility (-4)	0,19	-0,03	0,26	-0,02
I.R Differential (-4)	0,05	-0,07	-0,04	0,71
Spread (-5)	0,90	-0,74	0,18	0,05
Quote Revisions (-5)	-0,72	0,79	-0,05	-0,10
Volatility (-5)	0,18	-0,04	0,25	-0,03
I.R Differential (-5)	0,06	-0,08	-0,03	0,68

GB/US Quoted Spread

	Spread Quoted (0)	Quote Revisions (0)	Volatility (0)	I.R Differential (0)
Spread (-1)	0,93	-0,66	-0,09	0,11
Quote Revisions (-1)	-0,66	0,75	0,17	-0,04
Volatility (-1)	-0,08	0,19	0,27	0,01
I.R Differential (-1)	0,10	-0,03	0,01	0,87
Spread (-2)	0,91	-0,65	-0,09	0,10
Quote Revisions (-2)	-0,65	0,68	0,16	-0,05
Volatility (-2)	-0,09	0,17	0,24	-0,01
I.R Differential (-2)	0,11	-0,03	0,02	0,78
Spread (-3)	0,90	-0,65	-0,09	0,10
Quote Revisions (-3)	-0,64	0,67	0,15	-0,06
Volatility (-3)	-0,10	0,20	0,22	0,00
I.R Differential (-3)	0,11	-0,04	0,01	0,75
Spread (-4)	0,90	-0,65	-0,09	0,11
Quote Revisions (-4)	-0,64	0,70	0,15	-0,09
Volatility (-4)	-0,09	0,19	0,20	-0,01
I.R Differential (-4)	0,11	-0,05	0,01	0,71
Spread (-5)	0,89	-0,67	-0,09	0,10
Quote Revisions (-5)	-0,63	0,75	0,18	-0,08
Volatility (-5)	-0,09	0,20	0,26	-0,02
I.R Differential (-5)	0,12	-0,06	0,01	0,68

EU/US Quoted Spread

	Spread Quoted (0)	Quote Revisions (0)	Volatility (0)	I.R Differential (0)
Spread (-1)	0,68	-0,30	-0,14	-0,48
Quote Revisions (-1)	-0,23	0,53	0,22	0,09
Volatility (-1)	-0,12	0,26	0,15	0,01
I.R Differential (-1)	-0,48	0,10	0,00	0,87
Spread (-2)	0,55	-0,22	-0,13	-0,47
Quote Revisions (-2)	-0,18	0,47	0,21	0,08
Volatility (-2)	-0,12	0,27	0,19	0,00
I.R Differential (-2)	-0,47	0,09	0,01	0,78
Spread (-3)	0,55	-0,21	-0,12	-0,46
Quote Revisions (-3)	-0,18	0,46	0,23	0,07
Volatility (-3)	-0,13	0,28	0,22	0,01
I.R Differential (-3)	-0,47	0,13	0,02	0,75
Spread (-4)	0,55	-0,24	-0,15	-0,46
Quote Revisions (-4)	-0,19	0,47	0,21	0,06
Volatility (-4)	-0,11	0,29	0,17	0,00
I.R Differential (-4)	-0,45	0,12	0,02	0,71
Spread (-5)	0,54	-0,25	-0,11	-0,45
Quote Revisions (-5)	-0,17	0,53	0,23	0,07
Volatility (-5)	-0,08	0,29	0,25	-0,01
I.R Differential (-5)	-0,46	0,12	0,01	0,68

JP/US Relative Spread

	Spread Relative (0)	Quote Revisions (0)	Volatility (0)	I.R Differential (0)
Spread (-1)	0,94	-0,74	0,11	0,10
Quote Revisions (-1)	-0,74	0,78	-0,05	-0,06
Volatility (-1)	0,12	-0,03	0,36	-0,02
I.R Differential (-1)	0,11	-0,06	-0,03	0,87
Spread (-2)	0,93	-0,73	0,11	0,11
Quote Revisions (-2)	-0,73	0,73	-0,06	-0,07
Volatility (-2)	0,12	-0,05	0,28	-0,02
I.R Differential (-2)	0,11	-0,05	-0,02	0,78
Spread (-3)	0,92	-0,74	0,10	0,11
Quote Revisions (-3)	-0,73	0,73	-0,06	-0,09
Volatility (-3)	0,12	-0,03	0,26	-0,02
I.R Differential (-3)	0,11	-0,07	-0,03	0,75
Spread (-4)	0,92	-0,74	0,10	0,11
Quote Revisions (-4)	-0,73	0,75	-0,07	-0,10
Volatility (-4)	0,12	-0,03	0,26	-0,02
I.R Differential (-4)	0,11	-0,07	-0,04	0,71
Spread (-5)	0,91	-0,75	0,09	0,11
Quote Revisions (-5)	-0,73	0,79	-0,05	-0,10
Volatility (-5)	0,12	-0,04	0,25	-0,03
I.R Differential (-5)	0,12	-0,08	-0,03	0,68

GB/US Relative Spread

	Spread Relative (0)	Quote Revisions (0)	Volatility (0)	I.R Differential (0)
Spread (-1)	0,92	-0,69	-0,14	0,04
Quote Revisions (-1)	-0,69	0,75	0,17	-0,04
Volatility (-1)	-0,13	0,19	0,27	0,01
I.R Differential (-1)	0,04	-0,03	0,01	0,87
Spread (-2)	0,90	-0,68	-0,14	0,03
Quote Revisions (-2)	-0,68	0,68	0,16	-0,05
Volatility (-2)	-0,14	0,17	0,24	-0,01
I.R Differential (-2)	0,04	-0,03	0,02	0,78
Spread (-3)	0,90	-0,69	-0,14	0,03
Quote Revisions (-3)	-0,68	0,67	0,15	-0,06
Volatility (-3)	-0,14	0,20	0,22	0,00
I.R Differential (-3)	0,05	-0,04	0,01	0,75
Spread (-4)	0,89	-0,69	-0,14	0,04
Quote Revisions (-4)	-0,67	0,70	0,15	-0,09
Volatility (-4)	-0,14	0,19	0,20	-0,01
I.R Differential (-4)	0,04	-0,05	0,01	0,71
Spread (-5)	0,89	-0,70	-0,14	0,03
Quote Revisions (-5)	-0,67	0,75	0,18	-0,08
Volatility (-5)	-0,13	0,20	0,26	-0,02
I.R Differential (-5)	0,05	-0,06	0,01	0,68

EU/US Relative Spread

	Spread Relative (0)	Quote Revisions (0)	Volatility (0)	I.R Differential (0)
Spread (-1)	0,87	-0,39	-0,22	-0,59
Quote Revisions (-1)	-0,33	0,53	0,22	0,09
Volatility (-1)	-0,20	0,26	0,15	0,01
I.R Differential (-1)	-0,59	0,10	0,00	0,87
Spread (-2)	0,83	-0,34	-0,21	-0,59
Quote Revisions (-2)	-0,30	0,47	0,21	0,08
Volatility (-2)	-0,20	0,27	0,19	0,00
I.R Differential (-2)	-0,59	0,09	0,01	0,78
Spread (-3)	0,83	-0,33	-0,21	-0,58
Quote Revisions (-3)	-0,30	0,46	0,23	0,07
Volatility (-3)	-0,20	0,28	0,22	0,01
I.R Differential (-3)	-0,58	0,13	0,02	0,75
Spread (-4)	0,82	-0,36	-0,22	-0,57
Quote Revisions (-4)	-0,30	0,47	0,21	0,06
Volatility (-4)	-0,20	0,29	0,17	0,00
I.R Differential (-4)	-0,58	0,12	0,02	0,71
Spread (-5)	0,82	-0,36	-0,20	-0,57
Quote Revisions (-5)	-0,29	0,53	0,23	0,07
Volatility (-5)	-0,18	0,29	0,25	-0,01
I.R Differential (-5)	-0,58	0,12	0,01	0,68

Panel U: Cross Autocorrelation Matrix, ASIA Time Zone

JP/US Quoted Spread

	Spread Quoted (0)	Quote Revisions (0)	Volatility (0)	I.R Differential (0)
Spread (-1)	0,89	-0,74	0,25	-0,02
Quote Revisions (-1)	-0,71	0,85	-0,15	-0,07
Volatility (-1)	0,24	-0,16	0,37	-0,02
I.R Differential (-1)	-0,02	-0,07	-0,01	0,87
Spread (-2)	0,88	-0,71	0,25	-0,02
Quote Revisions (-2)	-0,71	0,80	-0,15	-0,07
Volatility (-2)	0,24	-0,15	0,36	-0,01
I.R Differential (-2)	-0,02	-0,07	-0,03	0,78
Spread (-3)	0,87	-0,71	0,23	-0,01
Quote Revisions (-3)	-0,71	0,79	-0,17	-0,09
Volatility (-3)	0,24	-0,17	0,33	-0,01
I.R Differential (-3)	-0,02	-0,09	-0,03	0,75
Spread (-4)	0,87	-0,71	0,24	-0,01
Quote Revisions (-4)	-0,73	0,81	-0,18	-0,10
Volatility (-4)	0,25	-0,16	0,30	-0,03
I.R Differential (-4)	-0,02	-0,09	-0,02	0,71
Spread (-5)	0,87	-0,72	0,24	-0,01
Quote Revisions (-5)	-0,71	0,85	-0,17	-0,10
Volatility (-5)	0,25	-0,17	0,30	-0,04
I.R Differential (-5)	-0,01	-0,10	-0,02	0,68

GB/US Quoted Spread

	Spread Quoted (0)	Quote Revisions (0)	Volatility (0)	I.R Differential (0)
Spread (-1)	0,88	-0,78	-0,03	0,09
Quote Revisions (-1)	-0,76	0,82	0,10	-0,05
Volatility (-1)	-0,05	0,10	0,33	-0,01
I.R Differential (-1)	0,09	-0,04	-0,01	0,87
Spread (-2)	0,85	-0,74	-0,05	0,08
Quote Revisions (-2)	-0,75	0,76	0,09	-0,05
Volatility (-2)	-0,06	0,10	0,32	-0,02
I.R Differential (-2)	0,09	-0,04	0,00	0,78
Spread (-3)	0,84	-0,75	-0,04	0,09
Quote Revisions (-3)	-0,74	0,75	0,08	-0,07
Volatility (-3)	-0,05	0,10	0,27	-0,02
I.R Differential (-3)	0,10	-0,07	0,00	0,75
Spread (-4)	0,84	-0,74	-0,05	0,10
Quote Revisions (-4)	-0,75	0,77	0,09	-0,09
Volatility (-4)	-0,05	0,10	0,30	-0,03
I.R Differential (-4)	0,10	-0,07	-0,01	0,71
Spread (-5)	0,85	-0,75	-0,05	0,10
Quote Revisions (-5)	-0,75	0,82	0,08	-0,09
Volatility (-5)	-0,04	0,09	0,25	-0,04
I.R Differential (-5)	0,11	-0,08	-0,01	0,68

EU/US Quoted Spread

	Spread Quoted (0)	Quote Revisions (0)	Volatility (0)	I.R Differential (0)
Spread (-1)	0,62	-0,46	-0,06	-0,52
Quote Revisions (-1)	-0,37	0,61	0,14	0,28
Volatility (-1)	-0,09	0,23	0,20	0,01
I.R Differential (-1)	-0,52	0,28	0,03	0,87
Spread (-2)	0,47	-0,35	-0,04	-0,52
Quote Revisions (-2)	-0,30	0,53	0,17	0,27
Volatility (-2)	-0,09	0,22	0,25	0,01
I.R Differential (-2)	-0,52	0,27	0,02	0,78
Spread (-3)	0,48	-0,32	-0,07	-0,51
Quote Revisions (-3)	-0,31	0,51	0,15	0,25
Volatility (-3)	-0,06	0,21	0,21	0,00
I.R Differential (-3)	-0,51	0,28	0,01	0,75
Spread (-4)	0,55	-0,33	-0,10	-0,50
Quote Revisions (-4)	-0,38	0,51	0,16	0,24
Volatility (-4)	-0,09	0,20	0,24	0,01
I.R Differential (-4)	-0,50	0,27	0,01	0,71
Spread (-5)	0,62	-0,38	-0,11	-0,49
Quote Revisions (-5)	-0,40	0,62	0,20	0,24
Volatility (-5)	-0,10	0,22	0,17	0,00
I.R Differential (-5)	-0,51	0,28	0,00	0,68

JP/US Relative Spread

	Spread Relative (0)	Quote Revisions (0)	Volatility (0)	I.R Differential (0)
Spread (-1)	0,91	-0,65	0,15	-0,03
Quote Revisions (-1)	-0,66	0,85	-0,15	-0,07
Volatility (-1)	0,17	-0,16	0,37	-0,02
I.R Differential (-1)	-0,02	-0,07	-0,01	0,87
Spread (-2)	0,90	-0,64	0,14	-0,02
Quote Revisions (-2)	-0,64	0,80	-0,15	-0,07
Volatility (-2)	0,16	-0,15	0,36	-0,01
I.R Differential (-2)	-0,02	-0,07	-0,03	0,78
Spread (-3)	0,89	-0,64	0,13	-0,02
Quote Revisions (-3)	-0,64	0,79	-0,17	-0,09
Volatility (-3)	0,15	-0,17	0,33	-0,01
I.R Differential (-3)	-0,02	-0,09	-0,03	0,75
Spread (-4)	0,89	-0,65	0,12	-0,02
Quote Revisions (-4)	-0,64	0,81	-0,18	-0,10
Volatility (-4)	0,15	-0,16	0,30	-0,03
I.R Differential (-4)	-0,01	-0,09	-0,02	0,71
Spread (-5)	0,89	-0,65	0,12	-0,02
Quote Revisions (-5)	-0,65	0,85	-0,17	-0,10
Volatility (-5)	0,16	-0,17	0,30	-0,04
I.R Differential (-5)	-0,01	-0,10	-0,02	0,68

GB/US Relative Spread

	Spread Relative (0)	Quote Revisions (0)	Volatility (0)	I.R Differential (0)
Spread (-1)	0,85	-0,66	-0,10	-0,15
Quote Revisions (-1)	-0,66	0,82	0,10	-0,05
Volatility (-1)	-0,10	0,10	0,33	-0,01
I.R Differential (-1)	-0,15	-0,04	-0,01	0,87
Spread (-2)	0,83	-0,64	-0,11	-0,15
Quote Revisions (-2)	-0,65	0,76	0,09	-0,05
Volatility (-2)	-0,08	0,10	0,32	-0,02
I.R Differential (-2)	-0,15	-0,04	0,00	0,78
Spread (-3)	0,81	-0,64	-0,11	-0,14
Quote Revisions (-3)	-0,65	0,75	0,08	-0,07
Volatility (-3)	-0,10	0,10	0,27	-0,02
I.R Differential (-3)	-0,14	-0,07	0,00	0,75
Spread (-4)	0,81	-0,65	-0,11	-0,14
Quote Revisions (-4)	-0,64	0,77	0,09	-0,09
Volatility (-4)	-0,10	0,10	0,30	-0,03
I.R Differential (-4)	-0,12	-0,07	-0,01	0,71
Spread (-5)	0,81	-0,65	-0,10	-0,14
Quote Revisions (-5)	-0,64	0,82	0,08	-0,09
Volatility (-5)	-0,09	0,09	0,25	-0,04
I.R Differential (-5)	-0,12	-0,08	-0,01	0,68

EU/US Relative Spread

	Spread Relative (0)	Quote Revisions (0)	Volatility (0)	I.R Differential (0)
Spread (-1)	0,88	-0,51	-0,18	-0,65
Quote Revisions (-1)	-0,50	0,61	0,14	0,28
Volatility (-1)	-0,20	0,23	0,20	0,01
I.R Differential (-1)	-0,65	0,28	0,03	0,87
Spread (-2)	0,86	-0,49	-0,17	-0,64
Quote Revisions (-2)	-0,49	0,53	0,17	0,27
Volatility (-2)	-0,18	0,22	0,25	0,01
I.R Differential (-2)	-0,65	0,27	0,02	0,78
Spread (-3)	0,85	-0,48	-0,17	-0,64
Quote Revisions (-3)	-0,48	0,51	0,15	0,25
Volatility (-3)	-0,18	0,21	0,21	0,00
I.R Differential (-3)	-0,64	0,28	0,01	0,75
Spread (-4)	0,86	-0,49	-0,20	-0,63
Quote Revisions (-4)	-0,47	0,51	0,16	0,24
Volatility (-4)	-0,17	0,20	0,24	0,01
I.R Differential (-4)	-0,64	0,27	0,01	0,71
Spread (-5)	0,88	-0,49	-0,18	-0,63
Quote Revisions (-5)	-0,52	0,62	0,20	0,24
Volatility (-5)	-0,18	0,22	0,17	0,00
I.R Differential (-5)	-0,63	0,28	0,00	0,68