Intra-day Seasonality in Activities of the Foreign Exchange Markets: Evidence from the Electronic Broking System*

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Abstract:
This paper examines intra-day patterns of the high-frequency exchange rate behavior, using the "firm" bid-ask quotes and transactions recorded in the electronic broking system of the spot foreign exchanges. First, activities of quotes and transaction volumes are high in the beginning hours of the three major currency markets—Tokyo, London, and New York, and low during the Tokyo and London lunch hours and late afternoon in New York. The U-shape of intra-day activities is confirmed only in Tokyo and London participants. Second, activities do not increase toward the end of business hours in the New York market, even on Fridays (ahead of weekend hours of non-trading). Third, an average bid-ask spread is narrow (wide), when quote and deal frequencies are high (low, respectively), except the beginning hour of Tokyo (GMT 0), when the bid-ask spread is wide despite high levels of activity.
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1. Introduction

The foreign exchange market remains sleepless. Someone is trading somewhere all the time—24 hours a day, (almost) 7 days a week. Analyzing the behavior of the exchange rate has become a popular sport of international finance researchers, while global financial institutions are investing millions of dollars to build a real-time computer trading scheme. High-frequency, reliable data are the key in finding robust results for researchers or profitable schemes for businesses.

The objective of this paper is a modest one, namely to examine intra-day patterns of market activities—frequency of quote revisions, transaction volumes, and bid-ask spread—of the yen/dollar and the euro/dollar spot exchange rates using a newly available data of the electronic broking system for the spot foreign exchanges. The intra-day seasonality is in itself interesting but it serves as a basis for further theoretical and empirical analysis. In an earlier paper of ours, Ito and Hashimoto (2004), we have analyzed intraday patterns without an additional data set of trade volume shares, which will be described later. This paper is an improved version of our earlier paper with an additional data set, with the same objective.

The spot foreign exchange markets have evolved in recent years, and, by now, the overwhelming majority of the spot foreign exchanges are transacted through the global electronic broking systems—the EBS and Reuters D3000. The data, provided by the EBS, consist of global electronic broking bid-ask quotes and transaction volumes for three years starting January 01, 1999 at the frequency of every one second.[1] The EBS data have advantage over the frequently-used, indicative quotes of a foreign exchange market tick-by-tick data set, such as FXFX of Reuters, in at least in two important aspects. First, the quotes in the EBS data set are "firm", in that banks that post quotes are committed to trade at those quoted prices, when they are "hit".[2] In contrast, the indicative quotes of FXFX screen are those input by dealers for information only, without any commitment for trade. The reliability of indicative quotes as a market reality is much less than firm quotes. Second, transactions data that are available in the electronic broking system is simply not available in the FXFX screen. Although exact trading volumes are not disclosed, transactions counts (counts of seconds that had

[1] The data set was provided for fee by the EBS Co., for the use at the University of Tokyo, Research Center for the Advanced Science and Technology. The authors are grateful to EBS for such an arrangement.

[2] See Goodhart and O'Hara (1997: p.78) for general discussions on the difference between the indicative and firm quotes.

at least one transaction) and trade volume shares (a share of trading volumes in one second).

Major findings with respect to intraday seasonality of market activities and bid-ask spread include the following: (1) Activities are high in the beginning hours of the three major currency markets—Tokyo, London, and New York; (2) Activities are high toward the end of business hours in Tokyo and London, but not in New York, even during the closing hours of New York on Fridays ahead of weekend recess. In fact, activities become quite low by mid-afternoon in New York. Therefore the U-shape pattern is not confirmed—this is a new observation; (3) Activities are quite low during the lunch hours of Tokyo, and, to lesser extent in London; (4) An average bid-ask spread is narrow (wide), when quote and deal frequencies are high (low, respectively), except the beginning minutes in the first hour of the Tokyo (GMT 0) market, when the bid-ask spread is wide despite a high level of activities.

The contribution of this paper to the literature is three-fold. First, the paper presents a careful description of intra-day seasonality, using the electronic broking data consisting of "firm" quotes and deals as well as trade volume shares, taking into account time zone and daylight saving time of major markets, national holidays, day of the week effect, and other factors. Second, it is found that there exists U-shape pattern in market activities and trade shares in both Tokyo and London markets, but no daily U-shape pattern in New York market. Third, a negative correlation between the number of deals and the width of bid-ask spread is generally observed during the active time of the day, but in the first business minutes of Tokyo, bid ask spread and activities have high correlation, compared to the following hour.

The rest of this paper is organized as follows: Section 2 describes the data. Section 3 is a main part of this paper, establishing intra-day seasonality of activities. In section 4, various tests are conducted to establish the patterns revealed in the data. Section 5 concludes the paper.

2. The EBS data

2.1. EBS electronic broking system

The almost all spot exchange rate transactions of major currencies are now done by electronic broking systems, EBS and Reuters D-3000. The state of the global foreign

exchange market is available from a market survey by central banks conducted under coordination of the Bank for International Settlements (BIS), once every three years. In different categorization, the trades between dealers who report to the BIS surveys have declined substantially.[3]

> "*This can in part be explained by the growing role of electronic brokers in the spot interbank market. The use of electronic brokers implies that foreign exchange dealers generally need to trade less actively among themselves.*" (BIS (2002; p.7).)

This trend means that "hot potatoes" (Lyons (1997)) are less important now, and a cool supercomputer is increasingly important. In other words, dealers' tactics to transform order flows from the corporate sector into the interbank market may be less important than before, and the dealers' behavior in posting firm bids and asks through the electronic broking system is more important then before.[4]

The EBS is a provider of trading technology, and the quotes and transactions are shown continuously, 24 hours a day. The EBS screen shows the "firm bid" and "firm offer", the bid and offer that are committed to trade if someone on the other side is willing to trade at that price. (For the general reference on the microstructure of the foreign exchange market, see Goodhart and O'Hara (1997), Lyons (1995) and Lyons (2001). For earlier work that used the electronic broking system, see Goodhart, Ito and Payne (1996) and Goodhart and Payne (1996) have used the data obtained from Reuter D2000-2 that is predecessor of D3000.)

The EBS has a strong market share (in absolute terms and in comparison to Reuter D-3000) in the yen/dollar rate and the Euro/dollar rate and covers more than 90% of the yen/dollar and euro/dollar trade.[5] Therefore, it is safe to assume that almost all electronically brokered yen/dollar spot deals are represented in the data set.

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[3] However, from the preliminary report of the most recently conducted survey of April 2004, there are indications that spot trades of major currencies have increased between 2001 and 2004. See, a summary of such a trend on the EBS home page: http://www.ebs.com/products/spot.asp.

[4] Our interviews (in November 2003) with banks with substantial foreign exchange trading in London reveals that they have reduced in the last few years the degree of discretion of dealers and shifted proprietary trading to the specialized section. Computer models have replaced dealers' instincts.

[5] Reuters have significant market shares in exchanged related to sterling, Canadian dollar, and Australian dollars.

The EBS system facilitates, as part of the dealing rules, each institution to control bilateral credit lines. Namely, each EBS-linked institution sets credit lines (including zero) against all other potential counter-parties. Therefore, an institution faces a restriction of bid, offer, or deal from other institutions. When bid and offer rates are posted for the system, they are not necessarily available to all participants of the EBS system. The EBS-registered trader's screen shows the best bid and best offer of the market and best bid and best offer for that particular institution. In normal times, the best bid of the market is lower than the best offer of the market. Otherwise, some institution that has positive credit lines with both institutions on the bid and ask sides will be able to make profits by arbitrage.

As part of facilitating an orderly market, EBS requires any newly linked institution to secure a sufficient number of other banks that are willing to open credit lines with the new comer. A smaller or regional bank may have fewer trading relationships, thus not as many credit relationships. Then the best bid and ask for that institution may be different from the best bid and ask of the market. A smaller or regional bank may post more aggressive prices (higher bids or lower asks) because they will have relatively fewer credit relationships, implying that they will see fewer dealable prices generally.

2.2. The EBS Data Set

The EBS has made available two sets of data, the price data set and the trade volume share data set. Both data sets include information on the yen/dollar and the euro/dollar currency pairs from January 1, 1999 to December 31, 2001. The first data set is the first to become available for the researchers on the firm quotes in high frequency, and the second data set is the first to become available on the actual trading volumes in high-frequency.[6] The first data set contains information of, among others, best bid, best ask, deal prices done on the bid side (lowest given) and deal prices done on the ask side (highest paid).[7] The second high-frequency data set includes relative trade

[6] Data are of the 1-second time slice. The system records, at every second, bid, offer, deals that are posted and carried out in the world-wide EBS system. Bid and offer rates are recorded at the end of time slice. For example, bid and offer rate at xx hour, yy minute, zz second. Fluctuations of the bid and offer rates within the second (in the time slice) are not recorded and cannot be inferred. It is theoretically possible that bid and offer rates move up and down within the second, but not shown in the data set. Deal rates are recorded on the basis of Highest Paid and Lowest Given in the 1-second time slice.

[7] The deal (on either side) recorded at zz second includes those that took place between zz-1 second to zz second. When there are multiple trades within one second, "lowest given price" and "highest paid price" will be shown. A highest paid deal means the highest price hit (done) on the ask side within one second and the lowest given deal means the lowest price hit (done) on the bid side within

volume shares that are the share of trade volumes (one-second slice) relative to the total trading volumes in that day.[8] Moreover, the EBS price history shows whether the deal is done on the bid side (the bid was taken) or the ask side. It does not contain information on the volume of transactions associated with bid, offer, or deal. However, the data set of trading volume share gives at least the trade volume in terms of the share in the total volume of the day. The EBS global system consists of three regional computer sites, based in Tokyo, London, and New York, and it matches orders either within the site or across different sites. Each region covers Europe, North America and Asia, respectively. The three regions are often abbreviated as LN, NY and TY regions in this paper. The intra-regional deal of LN consists of deals whose maker and taker are both from London region. And inter-regional deal of LN&NY consists of deals whose maker and taker are from two different regions of London and New York. The trade volume share data set also has the

The basic characteristics of the data used in this study are shown in Table 1. “The number of price changes” means the number of quote changes on either side of the bid-ask quotes or both at the same time.[9] Then, the difference between “the number of price changes” and the sum of “the number of price changes on the bid side” and “that on the ask side” is the number of quote changes on both sides simultaneously.

Table 1-1

The best ask price (in the yen/dollar unit) is almost always higher than the best bid price. But there are a small number of reversals (that is, the best bid being higher than the ask price)[10].

Deal traffic patterns are described in terms of intra-regional deals as well as inter-regional deals among the three markets. The relative deal volume of six pairs of three markets is shown as percentage of the total daily volume by region. Originally the

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one second.

[8] The data set is a proprietary information of EBS. The usage is restricted to those who are affiliated at the University of Tokyo.

[9] Price changes could be generated by new entries of quotes, withdrawal of former quotes or disappearance of the quote due to “hits”.

[10] In some situations, different third parties see the bid or ask. The price seen by a third party may represent a very aggressive bid or ask, but not an arbitrage price. A single third party may see both prices. In such situations, they may see an arbitrage opportunity, but there is no guarantee that they can execute deals at both prices. It is a matter of timing and such prices are likely to be short lived.

percentage is shown in the one-minute timeslice basis. The hourly data are constructed as time-aggregation of percentages of all minutes in the hour, and the daily data are constructed as time-aggregation of 24 hours.

Table 1-2

Table 1-2 shows the three-year average of relative daily volume percentages of the yen-dollar and the euro-dollar deals. The first three rows show percentages of intra-market deals of London, New York, and Tokyo. The next three rows show the three possible inter-regional pairs of three regions. Then, we calculate the shares of deals that can be attributable to a particular region by adding the intra-regional deal share and the sum of halves of inter-regional deals. For example, the Tokyo share is the sum of the intra-regional share, Tokyo-Tokyo, half of the Tokyo-NY, and the half of the Tokyo-London deal shares. In other words, one LN-TY transaction is divided into 0.5 Tokyo region deal and 0.5 London region deal.

There are two salient features that emerge from this table. First, there is a home-market advantage, namely the yen is traded more by Tokyo financial institutions (Tokyo-Tokyo deals, Tokyo-London deals, in particular) and the euro is traded more by London financial institutions (London-London deals, London-New York deals, in particular). In total, 42% of yen trades are attributable to the Tokyo financial institutions (30 % for London), and 54% of euro trades are attributable to the London financial institutions (14% for Tokyo). The New York institutions participate in the deals less than the Tokyo institutions for the yen and less than London institutions for the euro transactions. Second, the overlapping business hours encourage inter-regional transactions. For both the yen and the euro, the London-New York deal share is the highest, and the Tokyo-New York deal share is the lowest. This reflects that business hours overlap more than three active business hours, while Tokyo and New York does not share any business hour.

3. A First Look at the Intra-day Patterns

3.1. Definition of Activity during the day

The hourly changes in the market activities and bid-ask spread for a standardized time aggregation (one hour) are examined. As for market activities, we will take the number of price changes and the number of deals (the sum of bid-side deals and ask-side deals)

in each hour of the day, averaged over a particular period (mostly over a year) with a differentiation of the standard and daylight saving time.[11] The hourly average bid-ask spread, that is the average of the bid-ask spared for 3600 observations (seconds) per hour. Then the hourly bid-ask spread is averaged over the period (e.g., for one year).

We also use the *relative volume share of an hour*, which is defined as hourly aggregated relative volumes in that day. The hourly trading volumes measured in the aggregate deals in the contract numbers, with each contract being one million US dollars, is divided by the total trading volume of the day. The trading volume share is calculated for six possible pairs of participants from three regions (Tokyo-Tokyo; Tokyo-London; Tokyo-NY; London-London; London-NY; NY-NY).

The difference between the deal count and the trading volume share is two fold. The deal count is the number of seconds in which there are more than one deals. Therefore a second that experienced the deal may contain more than one deal and one deal may mean one million US dollars or several millions of US dollars. The trading volumes are the total amount of deals, but expressed in the share within the day.

The intraday patterns have been explored in many papers before.[12] For example, Admati and Pleiderer (1988) provided a theory to explain why the concentration of trading and high volatility could happen in a day endogenously using the model where there are two types of traders, liquidity traders and informed traders. Andersen and Bollerslev (1997, 1998) and Baillie and Bollerslev (1990) show the patterns of intraday volatility and then proceeded to examine the dynamics of volatility clustering and other properties. However, except for Goodhart, Ito, and Payne (1996) and Goodhart and Payne (1996), all papers use indicative prices. Moreover, the period for analysis is typically for several months. This paper establishes the facts with firm quotes and deals, that are far better in describing the market than indicative prices. The sample period extends to three years, with a second as a frequency.

A higher level of activities means a larger number of price changes, and a larger number

[11] Note that the number of price changes and the number of deals in the data set may not be exactly match the total number of price changes and deals in the EBS system, because the data set is in terms of the one-second slice. If there are more price changes and deals within one second, the recorded numbers are less than the true numbers. The original data set is by second. Therefore, the maximum number of deals or price changes in one hour is 3,600.

[12] Many papers are contained in a conference volume on the High Frequency Data in Finance, edited by Baillie and Dacorogna (1997).

of deals. This is due to the fact that the number of price changes by dealers tends to increase when more (heterogeneous) participants are in the market; when more news become available; when the most competitive participant (who post best bid and ask) is reacting to news and market develops quickly; and when the bids and asks are hit more often (so that the best bids or asks are knocked out). The number of deals tends to increase when more participants with different expectations are present in the market (so that someone sells while someone buys at the same price); and when more news that can be interpreted differently, become available.

The bid-ask spread tends to become narrower when more participants are in the market (that is, market is deep) and when expectations are relatively homogeneous.

3.2. Standard Time and Daylight Saving Time

Activities are represented by the number of seconds where price changes are recorded and the number of seconds where deals are recorded. The average bid-ask spread of the hour also represents the market depth. These indicators of market activities are calculated for each GMT Hour (Hour 0 to 23), and then averaged over a certain period.

Since daylight saving time is adopted in London (from the last Sunday of March to the last Sunday of October) and New York (from the first Sunday of April to the last Sunday of October), the GMT hours corresponding to the local business hours of London and New York shift by one hour during their respective summer season. Table 2 summarizes the GMT hours and corresponding Local time of the three major markets.

Table 2

In the following, aggregation for the year is divided into the two periods:[13]

Daylight Saving (Summer) Time: First Sunday of April-last Sunday of October,
Standard (Winter) Time: January-last Sunday of March, the next working day of the last Sunday of October-December.

Note that we eliminate the one-week period in the spring when Europe is under the

[13] Daylight saving time in 1999 was from April 4 to October 31 in the United States; from March 28 to October 31 in the United Kingdom; in 2000, from April 2 to October 29 in the United States, and from March 26 to October 29 in the United Kingdom; and in 2001, from April 1 to October 28 in the United States and from March 25 to October 28 in the United Kingdom.

Summer Time but the US is not. Also excluded from the sample are Saturdays, Sundays, and days in which one of the three markets is closed for national holidays.

3.3. Intraday Activity Patterns

Price changes and Deals

Figures 2-1 and 2-2 show the intraday (Hour 0-23) pattern of the activities and the bid-ask spread of the USD-JPY pair and Figures 2-3 and 2-4 show those of the Euro-USD pair.

Figures 2-1 and 2-2 reveal several interesting features. First, a high correlation between the "number of price changes" and the "number of deals" is found in the USD-JPY foreign exchange market. Second, as to the number of price changes and the number of deals, there are three peaks in a day. In summer, peaks of the activity of USD-JPY pair are seen at Hour 0, Hours 6-7 and Hours 12-14; and in winter, Hour 0, Hour 8, and Hours 13-15. Third, we find three troughs in a day. In summer: Hour 3; Hours 10-11; and Hour 21: and in winter, Hour 3, Hour 11, and Hour 22. Fourth, the bid-ask spread is narrower during the first half of the day, then it becomes wider after Hours 16-17 and peaks at Hours 21-22.

In general, the bid-ask spread tends to be negatively correlated with the number of deals (or price changes): The three troughs of the number of deals (or price changes) mostly correspond to three peaks of the bid-ask spread. One deviation is the Hour 0, when the bid-ask spread is higher than other business hours in Tokyo (except lunch hour at Hour 3) but the number of deals (or price changes) is at the one of the peaks; that is, unlike other times, a positive correlation.

Figure 2-1-Figure 2-2

The decrease in activities during the Tokyo lunch hour is remarkable. There used to be regulations that prohibited the interbank foreign exchange trading during the lunch hour in Tokyo. But the regulation was lifted in December 1994, and the tradition seems to continue—history seems to matter.[14]

[14] Historically, the interbank foreign exchange transactions had a lunch break (regulatory shutdown) during the lunch hours. When the regulation was removed, the activities during the lunch hour increased at the expense of those before and after, the net effect was higher. See Ito, Lyons and Melvin (1998) and Covrig and Melvin (2005). Then, in the afternoon and market-ending hours of Tokyo market, activity again increases in terms of relative transaction volume: it peaks around

Figures 2-3 and 2-4 show hourly-aggregated Euro-USD activities, that corresponds to the earlier figures for the USD-JPY pair. Similar observations emerge. First, a high correlation between the "number of price changes" and the "number of deals" is found. Second, as for the number of price changes and deals, three peaks on the hours similar to those of the USD-JPY pair, in a day are found, with one distinctive feature. The height of the first peak, Hour 0, is much lower for the Euro-USD pair than the USD-JPY. It is remarkable that during the peak hours in the London morning and the overlapping hours of London afternoon and New York morning, the number of deals (the sum of those on the bid and ask sides) exceeds that of price changes. This is evidence that the market is thick enough that many deals did not result in the price change. Third, we find three troughs in a day: at Tokyo lunch hour, London lunch hour, and at Hour 21-22. Fourth, the bid-ask spread is narrow during the London business hours. It becomes wider after Hours 16-17 and peaks at Hours 21-22.

Figure 2-3 2-4

In sum, comparing the USD-JPY and Euro-USD tradings, intraday activities show very similar patterns, with the following notable exceptions. First, there seems to be a "home-market advantage," in the sense that activities of the Tokyo market relative to the London market is higher for the USD-JPY and lower for the Euro-USD. In fact, the heights of the three peaks for the yen are roughly equal, but, for the euro, the height of the peak during the Tokyo opening hour is distinctively low. The Tokyo market (or to be precise, the Asian market in general) is not significant in the euro trading. Second, the the Euro-USD market is particularly deep in London morning and even deeper in the London afternoon hours that overlap with the New York morning. This is shown in the number of deals exceeding the number of price change during London business hours. Such a characteristics is not generally observed in the USD-JPY trading (only once at Hour 8 in the 1999-2001 summer).

Trade volume

In the above analysis based on counts of deals and quote changes, we cannot attribute the activities to specific locations (or, to be precise, market participants in the region). Therefore, in the price data set, a surge in activities in the Tokyo mid-afternoon hours cannot be attributed to activities of the Tokyo participants or the London participants.

Hour5-6.

Similarly, an activity surge in the overlapping hours of London afternoon and New York morning cannot be attributed to London participants or New York participants. Fortunately, the data set of the trading volume shares has the label of participants (regional names) for the trading shares. By calculating the shares of the specific regions, we can infer whether Tokyo participants or London participants are more responsible for the activity surge in the Tokyo afternoon-London morning hours, and similarly whether London participants or New York participants are more responsible for the activity surge in the London afternoon-New York morning hours. We define trading shares of participants of location X is defined as the sum of X-X; 0.5 of X-Y; and 0.5 of X-Z trading shares. For example, the trading share of Tokyo participants is defined as the sum of one Tokyo-Tokyo; 0.5 of Tokyo-London; and 0.5 of Tokyo-New York trading shares.

The relative trading volume shares of deals that can be attributable to participants of a particular region for the JPY-USD pair are shown in Figures 3-1 and 3-2. The regional volume share is the sum of the intra-regional deal share and the halves of the inter-regional deals that have at least one side of deals attributed to that region, as explained above. The volumes of yen trades done by Tokyo financial institutions and London financial institutions clearly show the U-shape patterns, respectively, whereas yen trade by New York financial institutions shows a single peak pattern. The peak of volume shares by the Tokyo participant (Hour 0) is higher than that by the London participants (Hours 7-8) or that by the New York participants (Hours 14-15). Tokyo participants remain in the market, although with low shares, during the London and New York business hours. The Tokyo participants start to trade the yen in the 7am Tokyo time (Hour 22), although a sudden surge at 9am is quite remarkable. The trading volume share of 8am (Hour 23) is higher than that during the London business hours. The New York peak volume share is higher than that of the London volume share (Hour 12-13). The London and New York participants are quite dormant in the yen trading during the Tokyo business hours.[15]

Figure 3-1- 3-2

[15] In our earlier study, Ito and Hashimoto (2004), we used the data set that did not distinguish the regional origins of the deals, so we guessed the regional attribution by the change in trading patterns. In the earlier work, the trading was counted as the number of deals (or to be precise, the number of seconds in which there were at least one deals). In this paper, it is the share of trading volumes, relative to that day.

Figures 3-3 and 3-4 show the relative trading volume shares for the EURO-USD pair. It is immediately clear that the share of euro trades by the Tokyo participants is quite small. Although there is a U-shape pattern in the euro trading by the Tokyo participants, the shape and height of the U-shape is quite different from that for the yen-dollar trading. The Tokyo participants' share of Euro trading compared to that of the yen-dollar trading is low, and unlike the yen-dollar trading, the euro-dollar trading show that the trading share in the late afternoon hours (Hour 7 in the summer, Hour 6 in the winter) is higher than that of the beginning of the market (Hour 0). This shows that the Tokyo participants can find among themselves the trading counterparties for the yen trade, but for the euro trade, they have to wait for London participants to find counterparties. In other words, for the yen-dollar trades, the Tokyo market has new information becoming available and heterogeneous reactions to the news generate trading, but for the euro trades, the Tokyo market relatively lacks news or has homogeneous participants.

Figure 3-3, 3-4

The trading shares of the London participants are particularly high for the euro market during the two peaks (Hours 8 and 13-15 in winter; Hours 7 and 12-13 in summer). The trading shares of the New York participants show only a single peak (Hour 15 in winter and Hour 14 in summer). For the yen-dollar trading, the peak of the London participants' share is lower than the New York participants' share in the overlapping hours (Hours 13-15), while for the euro-dollar trading, the London participants' peak is higher than the New York participants' peak. Even for the euro trading, the London and New York participants are almost non-existent in the Tokyo business hours.

In sum, the trading volume share data show the following five salient features. First, a U-shape intra-day activity pattern is confirmed for the Tokyo and London market participants, but not for the New York market participants. The lack of a U-shape activity for New York market participants is a new finding in the microstructure literature.[16] Second, the activity share for the yen trading is the highest by the Tokyo participants at the opening hours of the Tokyo market, while for the euro trading, the highest is by London participants during the overlapping hours of London afternoon and

[16] For the empirical test and survey of the U-Shape pattern in financial markets, see, for example, Harris (1986), Foster and Viswanathan, (1993), Ito, Lyons and Melvin (1998), Andersen and Bollerslev (1998).

New York morning. Third, the relative trading share of the Tokyo market participants for the euro trading even their peak hour is significantly lower than the London or New York participants. Fourth, the London and New York participants are quite dormant in their trading during the Tokyo market hours, while the Tokyo participants maintain some trading activities during the London business hours, both for the yen and euro trading. Fifth, comparing the number of seconds that include at least one deal (Figures 2-1 through 2-4) and the volume shares (aggregate of three regional participants, or a vertical sum of three points for each hour in Figures 3-1 to 3-4) have quite similar patterns. Three peaks during the day for the yen-dollar trading, and two high peaks and one low peak for the euro-dollar trading.

4. Relationship between the number of price changes, deals, and spread

The number of market participants varies from one day to next, and from one hour to next within the day. There are conventional wisdoms regarding the depth of the market, market activities, and the bid-ask spread. When many market participants are participating in the market, the market is commonly called deep. When many participants with very different background and forecasts are present in the market, deals tend to occur. When there are many participants in the market, spreads tends to be narrower and trades do not change the best quotes. These common senses can be quantitatively tested and shown using our data.

It is theoretically expected that the bid-ask spread is negatively correlated with either the number of price (firm quote) changes or the number of deals. When many participants are present in the market, then the price changes will be frequent, and at the same time, spreads will become narrower. For the hours where the number of deals is high, it may also be expected that spreads are narrower. Thus, the following relationships can be examined.

$$Spread_{(t)} = constant + a_1 * number\ of\ price\ changes_{(t)} + \varepsilon_{(t)},$$
$$Spread_{(t)} = constant + b_1 * number\ of\ deals_{(t)} + \varepsilon_{(t)}.$$

However, there may be an exception to this relationship. When the Tokyo market opens after a long break, such as a weekend, the bid-ask spread may be wider because market participants are unsure about the market conditions and other participants' positions, while the numbers of deals and quote revisions may be higher, as some participants

have to carry out some accumulated orders from customers quickly.

4.1 Tokyo opening hours

First of all, let us test a hypothesis that the opening hour of the Tokyo market has special characteristics, because it follows a few hours of extremely low activity. The bid-ask spread and the number of price changes has a stable relationship throughout the day, except for the first business hour of the Tokyo market. Then the model examined is as follows:

$$Spread_{(t)} = constant + (a_1 + H0dum)*number\ of\ price\ changes_{(t)} + \varepsilon_{(t)},$$
$$Spread_{(t)} = constant + (b_1 + H0dum)*number\ of\ deals_{(t)} + \varepsilon_{(t)}.$$

Presumably, the larger the number of entries (quotes, deals), the smaller the spread, and therefore a_1 (b_1) is expected to be negative. *H0dum* is an hour 0 dummy, taking the value 1 when the quote is recorded in the period of Hour 0 (Tokyo 9am) and 0 otherwise. The expected sign of coefficient is positive. The explanatory variable, the relative volume, is also included in each of regression in order to control for the effect of transaction volume on the spread. Estimation results are shown in Table 4-1 (USD-JPY pair) and in Table 4-2 (EURO-USD pair). A separate regression is conducted for each of the three years, and using the number of price changes (Panel A) or the number of deals (Panel B).

Table 4-1 Table 4-2

As for the USD-JPY trade, shown in the table 4-1, the statistically significant and negative coefficients of a_1 and b_1, as expected, are found. That is, when market is deep (when the number of price (quotes) changes is large and deals done are large), the bid-ask spread tends to narrower. The *H0dum* is estimated significantly positive only for a regression model with number of deals on spread in 1999 and whole sample for USD-JPY pair. Others are either negative or insignificantly positive.

The result for the Euro-USD trade is almost the same. In Table 4-2, a predicted negative relationship between number of price change and spread in 2000 and in 2001 and between deals and spread for every sample period is found, although there exists an insignificant relationship between the number of price change and the bid-ask spread for the whole sample and 1999 sample. The coefficients of *H0dum* are not estimated

significantly positive.

Therefore, the hypothesis of a special first hour effect, a positive correlation between the spread and activities—namely, the Tokyo opening effect, is not supported in the regressions.

4.2 Monday opening effects

Even though the effect of opening hours on activity is not significant, it is still worth checking the Monday morning effect because Tokyo market opens for the first time of the week after a long weekend break. If orders accumulated during the weekend (about 35 hours) is much larger than those accumulated during the overnight gap (2-3 hours) between New York close and Tokyo open, then the first hour of Tokyo on Monday (Hour 0 in adjusted GMT) may be quite different, most likely much higher activity, from that hour on any other day of the week.

Here, we test the effect of Monday morning on the market using the Monday Hour 0 dummy in the following regression model:

$$Spread_{(t)} = const + (a_1 + MonH0dum)*number\ of\ price\ changes_{(t)} + \varepsilon_{(t)},$$
$$Spread_{(t)} = const + (b_1 + MonH0dum)*number\ of\ deals_{(t)} + \varepsilon_{(t)}.$$

MonH0dum takes 1 when the price changes (deals) is put in at Monday Hour 0 and 0 otherwise. The expected sign of coefficient a_1 (b_1) is negative, and that of *MonH0dum* is positive. Again, in order to control for the effect of transaction volume on the spread, the relative volume is also included as an explanatory variable in each of regression

Regression results for USD-JPY pair are shown in Table 4-3. The coefficients of a_1 and b_1 are estimated significantly negative, as expected. However, the hypothesis of Monday morning effect on the number of price changes does not seem supported in Panel A, does not support. The regression result of the spread on number of deals, in Panel B, is slightly different. The Monday Hour 0 dummy is estimated to be positive in the full sample and in 2000 (at 5% significance level) and in 1999 (at 10%). The finding of Monday morning effect on deal activities suggests that the market participants carry out some accumulated orders over the weekend in the first hour of the week, the Monday Tokyo morning at Hour 0, despite the relatively wide bid-ask spread. Table 4-4 for the Euro-USD trade shows negative coefficients of a_1 and b_1, except for a_1 for estimation in 1999 as well as the full sample period. The Monday opening effect is

not estimated significantly positive at all.

Table 4-3 Table 4-4

Overall, the results suggests the existence of Monday opening effect only for USD-JPY deals in both 1999 and 2000, but we found no Monday morning effect in explaining the spread by the foreign exchange activities in other estimation periods.

5. London and New York opening effects

Finally, three hypotheses will be examined, using the time aggregation of one hour. As shown in Sections 3 and 4, we find several features on intra-day patterns such as that the London opening and New York market effects are seen from the shift between the winter time and daytime saving time and that no Monday morning effects is found in the FX market from the day-of-the-week examination. Tokyo opening effect (Hour 0) is (seemingly) insignificant, which is partly because of the pattern of activity specific to Hour 0. In the following, three hypotheses on the intraday pattern of activity will be statistically tested using various dummy variables. The hypotheses to be examined are:

(H1) The bid-ask spread is narrower (wider) when the activity is higher (lower, respectively);
(H2) During the opening hours of the major markets (Tokyo, London/Europe, New York), activities are higher;
(H3) Toward the close of the major markets, activity is higher.

The combination of hypotheses (H2) and (H3) amount to the U-shape activities.[17] We test above hypotheses using one of the following specifications:

$$y_{(t)} = \beta * D_1 + \gamma * D_2 + \varepsilon_{(t)},$$

where y is one of the three variables, number of price changes, the number of deals, or the bid-ask spread; and D_1 and D_2 are dummy vectors. The relative volume is included as an explanatory variable to represent the depth of the market. D_1 consists of dummy variables representing Hour 0 to Hour 23 to control the hour of the day effects. D_2 are

[17] The U-shape pattern was originally documented for the stock market. In the exchange market, see Hsieh and Kleidon (1996), Ito, Lyons, and Melvin (1998).

dummy vectors that examine opening and lunch hours over and above the GMT hour effect, as will be explained below. Opening hours of London and New York can be identified separately from the GMT hour dummies because the opening hour shifts by one hour between summer and winter (with or without daylight saving time). Since the Tokyo market does not observe the daylight saving time, the opening effect or its lunch hour is not identifiable separately from the Hour 0 effect. Here, D_2 can be written as follows:

$$D_2 = \left|\begin{array}{cccc:cccc} 0 & & 0 & 1 & 0 & 0 & & 0 \\ & \ddots & & 1 & 0 & & \ddots & \\ 0 & & 0 & 1 & 0 & 0 & & 0 \\ \hdashline 0 & & 0 & 0 & 1 & 0 & & 0 \\ & \ddots & & 0 & 1 & & \ddots & \\ 0 & & 0 & 0 & 1 & 0 & & 0 \end{array}\right|.$$

The D_2 variables include the following open and lunch hour dummy variables. In the observation of figures in the earlier sections, lunch breaks in London seems to begin at GMT Hour10 in summer and GMT Hour 11 in winter, the London lunch dummy takes the following expression:

$$\text{LDN lunch} = \begin{cases} 1 \text{ at Hour 10 in summer} \\ 1 \text{ at Hour 11 in winter} \\ 0 \text{ otherwise.} \end{cases}$$

Since $dy / dD_2 = \gamma$ is independent from other explanatory variables, it simply depicts the effect of London lunch (London opening, NY opening) over and above the GMT Hour effect.[18]

In running regressions, opening hours of two major markets are considered along with the London lunch time. Therefore, the London opening dummy takes the form:

[18] The test is conducted including three other sets of dummies: London opening(version 2) = 1 at Hour 6 in summer, 1 at Hour 7 in winter, and 0 otherwise; NY open (version 2)= 1 at Hour 14 in summer, 1 at Hour 15 in winter, and 0 otherwise; NY open (version 3)= 1 at Hour 13 in summer, 1 at Hour 14 in winter, and 0 otherwise. The results is not reported save space, but it is found that each of the London opening, London lunch, and NY opening has a significant effect on both price changes and spread, and that the opening (lunch) hours significantly shifts with the daylight saving time.

$$\text{LDN open 1} = \begin{cases} 1 \text{ at Hour 7 in summer} \\ 1 \text{ at Hour 8 in winter} \\ 0 \text{ otherwise.} \end{cases}$$

Since a large jump of quote entries between hour 5 and hour 6 in summer (which corresponds to the London 5 and 6 hour in the morning) and between hour 6 and hour 7 in winter is in some cases found in Figures 2-1 to 2-4, we consider the case where the London market opens at Hour 6 in summer and Hour 7 in winter.

$$\text{LDN open 2} = \begin{cases} 1 \text{ at Hour 6 in summer} \\ 1 \text{ at Hour 7 in winter} \\ 0 \text{ otherwise,} \end{cases}$$

It is not exactly clear from the Figures which hour is the New York opening hour, and therefore we consider three types of the New York opening dummies as follows:

$$\text{NY open 1} = \begin{cases} 1 \text{ at Hour 14 in summer} \\ 1 \text{ at Hour 15 in winter} \\ 0 \text{ otherwise,} \end{cases}$$

$$\text{NY open 2} = \begin{cases} 1 \text{ at Hour 13 in summer} \\ 1 \text{ at Hour 14 in winter} \\ 0 \text{ otherwise,} \end{cases}$$

$$\text{NY open 3} = \begin{cases} 1 \text{ at Hour 12 in summer} \\ 1 \text{ at Hour 13 in winter} \\ 0 \text{ otherwise,} \end{cases}$$

Regression results

Regression results for the USD-JPY pair are shown in Table 5-1. The result of Number of Price Changes on Dummy is provided in Panel A. The results generally show that the Hour dummy variables are significant in most of the time. The London open dummies, London lunch dummy, and New York open dummies are all significant and positive. The results indicate that the London opening effect and New York opening effect, controlling for the GMT Hour effect and the trading volume effect, are clearly identified, as the London open dummies as well as New York open dummies are positive and

statistically significant. The number of price changes are estimated approximately 25-30% larger during opening hours than other business hours. The London lunch dummy is estimated significantly negative as expected.

Panel B summarizes regression results of the number of deals on dummy variables for the USD-JPY pair. The GMT hour effects are significant, and the opening hours of London and New York as well as London Lunch hours are significant. The number of deals becomes 35-43% larger during the opening hours.

Panel C shows the regression result of the spread on the dummy variables for the USD-JPY pair. Estimation results show that the GMT hour dummy variables as well as London Lunch effect are significant in all of the regressions, whereas London and New York opening effects are insignificant in 2000 and 2001. The spread is estimated more than 3% narrower during the opening hours. In particular, it drops by more than 6% during New York opening hours. The opening hour effects are significantly negative in 1999, indicating the spread becomes narrower at the beginning of London and New York markets. However, coefficients of opening are found insignificant in 2000 and in 2001. This suggests that it is difficult to infer from the movement of the spread when the London and New York market opens in 2000 and 2001. The width of spread is not significantly different from other hours even during the opening hours of London and New York. Contrary to the opening hour effects, London lunch hour is estimated significantly positive in all regressions. The result means the evidence of wider spread during lunch break.

Table 5-1

Regression results of the Euro-USD pair are shown in Table 5-2. The result of regression of the Number of Price Changes on the Dummy variables is provided in Panel A. The results show that the Hour dummy variables, as well as the London open dummies, London lunch dummy and New York open dummies are significant in most of the time (one exception being for the estimation in 2000). From the regression, the opening hour of the London market is identified exactly at Hour 6 in summer and at Hour 7 in winter, and the New York market opens at Hour 14 in summer and at Hour 15 in winter in 2000.

Panel B in Table 5-2 provides the results of the Number of Deals on the Dummy

variables for Euro-USD pair. All of the coefficients, except for the London Lunch dummy in 2000 and of whole sample period, are significant. That is, that the number of deals during the London lunch hours was not significantly different from other business hours, when the Hour effect is controlled for.

Panel C summarizes the result of Bid-ask Spread on the Dummy variables for Euro-USD pair. Although the Hour dummies are all significant, London and New York opening dummies and London lunch dummies are insignificant in most cases. Overall, the results are similar to that of the USD-JPY pair in that the width of spread is not significantly different from other business hours even during the opening hours of London and New York.

Table 5-2

Both the lack of the upswing of the U-shape in the afternoon for the trading activities and the insignificant market open effects in New York in terms of bid-ask spread may be due to the recent widespread practice of continuous trading and better control of inventory. The U-shape, in particular the increase in the afternoon, is often regarded as willingness to trade in order to control inventory ahead of a long break (between the days or over the weekend). However, the widespread use of the trading systems like the EBS system and the computer programs made it much easier for dealers and proprietary traders to find market rates and counterparties even in other regions of the world regardless of the local hours and to manage inventories continuously. This may have contributed to the disappearance of the pick up of the activities toward the end of the business hours in New York, and little changes of the bid-ask spread during the business hours from Tokyo, London, and New York.[19] However, the Tokyo market open effect on the bid-ask spread as well as activities appear to be significant because the trading during the preceding two hours before the Tokyo market opens is extremely thin.

7. Conclusion

In this paper, the intra-daily patterns were investigated from the rich data sets of EBS quotes, deals and relative trading shares. Some of the findings are well-known such as the high activities at the opening of the market, high correlations between quote entries and deals, and higher activities being associated with narrow spreads. However, some

[19] We thank Rich Lyons for his suggestion of this interpretation.

of the findings are somewhat surprising. The following observations are new in the literature.

First, there is no U-shape intraday activity pattern in the yen/dollar or euro/dollar market in New York market. The activities are high during the opening hours but not ending hours. Careful observations on the peak of activities, exploiting the difference between Tokyo and New York in adoption of summer (daylight saving) and winter time to conclude where the activities originate during the overlapping business hours. There is no surge in activities toward the end of the New York afternoon hours. Even on Fridays, there is no pick up in activities in the NY afternoon hours.

Second, intra-day patterns of activities and bid-ask spreads are quite stable over the time (yearly comparison). Namely, the peak of activities is observed in the opening hours (9am in Tokyo; 8am in Europe/7am London, and 8-10am New York), and the troughs are late afternoon hours of New York, with significant drops during the lunch hours in Tokyo and, to the lesser extent, in European lunch hours.

Third, the bid-ask spread is generally negatively correlated with the indicator of activities: Higher activities are associated with narrow spreads and low activities are associated with wide spreads. However, the first hour, or to be more specific the first half hour of the Tokyo market (GMT Hour 0) has a slightly wider spread than other hours of comparable activities.

Fourth, from observations of the figures, we found that a home-market bias in the foreign exchange market is significant. The yen is traded more by Tokyo financial institutions (Tokyo-Tokyo deals, Tokyo-London deals, in particular) and the euro is traded more by London financial institutions (London-London deals, London-New York deals, in particular). In total, about half of yen trades are attributable to the Tokyo financial institutions and more than half of euro trades are attributable to the London financial institutions.

Fifth, it is interesting to know that the overlapping business hours encourage inter-regional transactions and overall surges in activities. For both the yen and the euro, the London-New York deal share is the highest, and the Tokyo-New York deal share is the lowest. This may reflect the fact that participants from other regions may have different reactions to the same news, and resulting in the deal.

Sixth, a rigorous analysis of the opening hour effects of London and New York, and lunch hour effects of London, taking advantage of the one-hour shift between the regular and daylight saving times, we find that there are significant opening hour surge and lunch hour decline in activities (the number of deals and the number of price changes). However, there seems to be insignificant effects on the bid-ask spread from the London or New York openings or London lunch hour. These features are common between the yen and the euro trading.

Although we have found several interesting facts in the newly available data, there are many tasks left for future research. First, changes in the exchange rate and an activity indicator may be correlated. If the deal is done on one side only, then the exchange rate may move toward that direction. The price impact of deals will be investigated in the future. Second, macroeconomic announcements are often planned during the hour that are before the market opening (say, 8:45 am). However, other markets are open in the case of foreign exchange markets. Additional activities on the day of announcements may be detected not in the market (say, NY) where it is announced but in other markets (say, London).

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Table 1-1: Data summary; Jan 1, 1999 – December 28, 2001

(Excluding Saturdays, Sundays, and national holidays in at least one of the three major markets)

（A） Quote and Deal data for the USD-JPY pair

Quote			
	Number of price changes		8,429,303
	spread	mean	0.020846
		variance	0.000261
		skew	1.727
		kurtosis	7.492
Deal			
	Number of deals		
		bid-side	3,113,109
		ask-side	3,287,321

（B）Quote and Deal data for Euro-USD pair

Quote			
	Number of Price changes		8,009,431
	spread	mean	0.00015
		variance	1.03247D-08
		skew	4.080
		kurtosis	42.613
Deal			
	Number of deals		
		bid-side only	4,435,318
		ask-side only	4,551,988

Table 1-2: Relative deal amount by region in the EBS Market.

(A)Relative volume for the USD-JPY pair

Hourly relative volume by region	
Intra-market trading	
London	16.75
New York	15.00
Tokyo	32.64
Inter-market trading	
LN-NY	14.86
LN-TY	13.47
NY-TY	6.00
Relative trading share by market	
London	30.91
New York	25.43
Tokyo	42.38

Note: percentage of the total daily volume for the USD-JPY pair

(B)Relative volume for the Euro-USD pair

Hourly relative volume by region	
Intra-market trading	
London	36.96
New York	18.54
Tokyo	7.78
Inter-market trading	
LN-NY	24.28
LN-TY	9.01
NY-TY	2.99
Relative trading share by market	
London	53.60
New York	32.18
Tokyo	13.79

Note: percentage of the total daily volume for the EUR-USD pair

Table 2: Intraday timeline: GMT Clock and corresponding Local time of the three major markets

Normal (Winter)

GMT	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Tokyo	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	+0	+1	+2	+3	+4	+5	+6	+7	+8
London	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
NY	-19	-20	-21	-22	-23	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18

Daylight saving time (Summer)

GMT	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Tokyo	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	+0	+1	+2	+3	+4	+5	+6	+7	+8
London	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	+0
NY	-20	-21	-22	-23	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19

March-April 1 week (Daylight saving time in London and Winter time in New York)

GMT	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Tokyo	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	+0	+1	+2	+3	+4	+5	+6	+7	+8
London	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	+0
NY	-19	-20	-21	-22	-23	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18

Table 4-1: Hour 0 Effect for USD-JPY trade

Panel A: Correlation between Number of Price change and Spread

	Constant		s.e.	# of price change		s.e.	H0 Dummy		s.e.	relative volume		s.e.	NOB
whole	0.0223	***	1.21E-04	-3.17E-06	***	2.36E-07	-5.11E-07		4.02E-07	-1.73E-05		2.66E-05	16454
1999	0.0238	***	2.43E-04	-1.81E-06	***	4.78E-07	5.13E-07		6.75E-07	-3.91E-04	***	4.30E-05	5322
2000	0.0211	***	1.77E-04	-3.96E-06	***	3.84E-07	-7.67E-07		6.71E-07	1.41E-04	**	7.25E-05	5590
2001	0.0227	***	2.03E-04	-3.81E-06	***	3.64E-07	-1.35E-06	**	7.30E-07	9.69E-05	**	5.56E-05	5542

Note: ***, ** and * indicate significance at the 1,5, and 10%, respectively.

Panel B: Correlation between Number of Deals and Spread

	Constant		s.e.	# of deals		s.e.	H0 Dummy		s.e.	relative volume		s.e.	NOB
whole	0.0226	***	8.81E-05	-5.65E-06	***	2.09E-07	6.28E-07	*	4.59E-07	1.98E-04	***	2.73E-05	16454
1999	0.0238	***	1.71E-04	-3.20E-06	***	3.89E-07	1.27E-06	**	7.18E-07	-2.33E-04	***	4.69E-05	5322
2000	0.0215	***	1.31E-04	-6.98E-06	***	3.42E-07	3.00E-07		8.19E-07	3.14E-04	***	6.88E-05	5590
2001	0.0232	***	1.57E-04	-7.05E-06	***	3.50E-07	-3.79E-07		8.91E-07	1.50E-04	***	5.38E-05	5542

Note: ***, ** and * indicate significance at the 1,5, and 10%, respectively.

Table 4-2 Hour 0 Effect for Euro-USD trade

Panel A: Correlation between Number of Price change and Spread

	Constant		s.e.	# of price change		s.e.	H0 Dummy		s.e.	relative volume		s.e.	NOB
whole	1.72E-04	***	1.71E-06	-9.91E-09	**	5.70E-09	-3.47E-08	***	1.12E-08	-4.08E-06	***	3.31E-07	16449
1999	1.88E-04	***	3.05E-06	-5.71E-08	***	1.07E-08	-3.33E-08	**	1.85E-08	-2.50E-06	***	5.93E-07	5321
2000	1.68E-04	***	3.24E-06	1.23E-08		1.04E-08	-6.63E-08	***	2.12E-08	-5.10E-06	***	6.39E-07	5587
2001	1.62E-04	***	2.68E-06	1.78E-09		8.97E-09	2.49E-09		1.86E-08	-4.18E-06	***	5.08E-07	5541

Note: ***, ** and * indicate significance at the 1,5, and 10%, respectively.

Panel B: Correlation between Number of Deals and Spread

	Constant		s.e.	# of deals		s.e.	H0 Dummy		s.e.	relative volume		s.e.	NOB
whole	1.74E-04	***	1.18E-06	-5.20E-08	***	4.87E-09	-6.09E-08	***	1.76E-08	4.78E-07		5.04E-07	16449
1999	1.82E-04	***	2.04E-06	-8.27E-08	***	9.34E-09	-6.66E-08	**	2.87E-08	2.21E-06	***	8.90E-07	5321
2000	1.76E-04	***	2.20E-06	-4.79E-08	***	9.34E-09	-1.09E-07	***	3.38E-08	5.38E-07		1.02E-06	5587
2001	1.67E-04	***	1.88E-06	-4.35E-08	***	7.62E-09	-5.45E-09		2.87E-08	1.09E-07		7.89E-07	5541

Note: ***, ** and * indicate significance at the 1,5, and 10%, respectively.

Table 4-3: Monday Opening effect for USD-JPY trade

Panel A: Correlation between the Number of Price changes and spread.

	Constant		s.e.	# of price change		s.e.	MonH0 Dummy		s.e.	relative volume		s.e.	NOB
whole	0.0223	***	1.20E-04	-3.24E-06	***	2.32E-07	7.81E-07		9.15E-07	-1.58E-05		2.66E-05	16454
1999	0.0238	***	2.42E-04	-1.78E-06	***	4.70E-07	1.55E-06		1.46E-06	-3.93E-04	***	4.30E-05	5322
2000	0.0212	***	1.76E-04	-4.10E-06	***	3.76E-07	1.67E-06		1.52E-06	1.61E-04	**	7.15E-05	5590
2001	0.0227	***	2.03E-04	-3.91E-06	***	3.60E-07	-6.11E-07		1.79E-06	1.06E-04	**	5.54E-05	5542

Note: ***, ** and * indicate significance at the 1,5, and 10%, respectively.

Panel B: Correlation between Number of Deals and spread

	Constant		s.e.	# ofdeals		s.e.	MonH0 Dummy		s.e.	relative volume		s.e	NOB
whole	0.0226	***	8.81E-05	-5.63E-06	***	2.06E-07	2.07E-06	**	1.03E-06	1.97E-04	***	2.73E-05	16454
1999	0.0238	***	1.71E-04	-3.13E-06	***	3.86E-07	2.35E-06	*	1.56E-06	-2.34E-04	***	4.69E-05	5322
2000	0.0215	***	1.31E-04	-7.02E-06	***	3.36E-07	3.71E-06	**	1.77E-06	3.20E-04	***	6.81E-05	5590
2001	0.0232	***	1.57E-04	-7.08E-06	***	3.46E-07	3.21E-07		2.23E-06	1.52E-04	***	5.36E-05	5542

Note: ***, ** and * indicate significance at the 1,5, and 10%, respectively.

Table 4-4: Monday Opening effect for Euro-USD trade

Panel A: Correlation between the Number of Price changes and spread.

	Constant		s.e.	# of price change		s.e.	MonH0 Dummy		s.e.	relative volume		s.e.	NOB
whole	1.72E-04	***	1.71E-06	-1.12E-08	**	5.69E-09	-3.91E-08	*	2.53E-08	-3.97E-06	***	3.29E-07	16449
1999	1.88E-04	***	3.05E-06	-5.94E-08	***	1.06E-08	-1.42E-08		4.07E-08	-2.34E-06	***	5.86E-07	5321
2000	1.67E-04	***	3.23E-06	1.06E-08		1.04E-08	-7.34E-08	*	4.82E-08	-4.91E-06	***	6.36E-07	5587
2001	1.62E-04	***	2.68E-06	2.08E-09		8.94E-09	-3.08E-08		4.26E-08	-4.21E-06	***	5.04E-07	5541

Note: ***, ** and * indicate significance at the 1,5, and 10%, respectively.

Panel B: Correlation between Number of Deals and spread

	Constant		s.e.	# ofdeals		s.e.	MonH0 Dummy		s.e.	relative volume		s.e	NOB
whole	1.74E-04	***	1.16E-06	-5.21E-08	***	4.87E-09	-7.33E-08	**	4.07E-08	5.41E-07		5.04E-07	16449
1999	1.81E-04	***	2.02E-06	-8.31E-08	***	9.34E-09	-4.57E-08		6.64E-08	2.31E-06	***	8.90E-07	5321
2000	1.75E-04	***	2.16E-06	-4.78E-08	***	9.35E-09	-1.26E-07	*	7.97E-08	6.31E-07		1.02E-06	5587
2001	1.67E-04	***	1.85E-06	-4.36E-08	***	7.62E-09	-5.83E-08		6.58E-08	1.20E-07		7.89E-07	5541

Note: ***, ** and * indicate significance at the 1,5, and 10%, respectively.

Table 5-1

Panel A: Number of Price Change on Dummy

Dependent variable: Number of price change

	Whole period		1999		2000		2001	
	Coefficient	s.e.	Coefficient	s.e.	Coefficient	s.e.	Coefficient	s.e.
H0DUM	685.24 ***	7.26	819.09 ***	14.00	604.75 ***	10.41	637.80 ***	11.95
H1DUM	591.16 ***	7.26	674.91 ***	14.00	517.17 ***	10.41	585.31 ***	11.95
H2DUM	459.98 ***	7.26	537.75 ***	14.00	393.07 ***	10.41	452.74 ***	11.95
H3DUM	267.15 ***	7.26	298.13 ***	14.00	222.21 ***	10.41	282.70 ***	11.95
H4DUM	408.08 ***	7.26	464.07 ***	14.00	339.39 ***	10.41	423.56 ***	11.95
H5DUM	511.57 ***	7.26	611.32 ***	14.00	431.72 ***	10.41	496.26 ***	11.95
H6DUM	517.02 ***	10.20	592.78 ***	19.63	471.53 ***	14.54	489.05 ***	16.87
H7DUM	523.99 ***	11.18	553.27 ***	21.47	495.58 ***	15.96	523.43 ***	18.52
H8DUM	639.22 ***	7.78	704.42 ***	14.96	565.36 ***	11.15	651.03 ***	12.80
H9DUM	603.51 ***	7.26	644.49 ***	14.00	534.41 ***	10.41	633.84 ***	11.95
H10DUM	540.12 ***	7.26	560.15 ***	14.00	493.88 ***	10.41	567.52 ***	11.95
H11DUM	555.85 ***	7.72	565.57 ***	14.86	511.76 ***	11.07	591.04 ***	12.71
H12DUM	554.80 ***	10.24	560.30 ***	19.70	512.19 ***	14.60	593.26 ***	16.94
H13DUM	616.55 ***	11.59	609.28 ***	22.24	546.81 ***	16.55	695.80 ***	19.23
H14DUM	657.30 ***	11.35	634.40 ***	21.78	598.63 ***	16.21	740.39 ***	18.81
H15DUM	675.67 ***	7.79	689.73 ***	14.98	617.70 ***	11.17	721.31 ***	12.82
H16DUM	580.76 ***	9.91	624.85 ***	19.10	534.93 ***	14.14	584.49 ***	16.38
H17DUM	386.91 ***	7.26	435.79 ***	14.00	351.39 ***	10.41	375.75 ***	11.95
H18DUM	357.31 ***	7.26	412.41 ***	14.00	309.46 ***	10.41	352.63 ***	11.95
H19DUM	300.61 ***	7.26	327.38 ***	14.00	280.09 ***	10.41	295.58 ***	11.95
H20DUM	235.06 ***	7.26	248.74 ***	14.00	219.17 ***	10.41	237.94 ***	11.95
H21DUM	170.11 ***	7.26	185.80 ***	14.00	160.47 ***	10.41	164.77 ***	11.95
H22DUM	164.43 ***	7.29	198.55 ***	14.10	143.61 ***	10.43	152.95 ***	11.98
H23DUM	273.17 ***	7.29	321.09 ***	14.10	249.06 ***	10.43	251.87 ***	11.98
LNOPEN	173.85 ***	11.91	223.19 ***	22.96	124.06 ***	17.02	178.05 ***	19.65
LNOPEN2	175.34 ***	11.91	205.98 ***	22.96	129.56 ***	17.02	193.42 ***	19.65
NYOPEN	170.64 ***	12.01	238.40 ***	23.14	146.61 ***	17.16	128.22 ***	19.82
NYOPEN2	182.36 ***	12.74	247.34 ***	24.51	171.80 ***	18.20	128.57 ***	21.07
NYOPEN3	210.08 ***	12.01	239.25 ***	23.14	203.55 ***	17.16	187.57 ***	19.82
LNLUNCH	-72.63 ***	11.23	-76.74 ***	21.68	-93.88 ***	16.04	-47.43 ***	18.49
NOB	16454		5322		5590		5542	

Note: ***, ** and * indicate significance at the 1,5, and 10%, respectively.

Table 5-1

Panel B: Number of Deals on Dummy

Dependent variable: Number of Deals

	Whole period		1999		2000		2001	
	Coefficient	s.e.	Coefficient	s.e.	Coefficient	s.e.	Coefficient	s.e.
H0DUM	551.78 ***	9.02	707.87 ***	20.03	460.28 ***	11.47	494.08 ***	12.67
H1DUM	498.12 ***	9.02	601.80 ***	20.03	419.16 ***	11.47	478.12 ***	12.67
H2DUM	355.67 ***	9.02	442.74 ***	20.03	289.16 ***	11.47	339.07 ***	12.67
H3DUM	171.64 ***	9.02	198.52 ***	20.03	137.44 ***	11.47	180.29 ***	12.67
H4DUM	292.71 ***	9.02	352.30 ***	20.03	227.10 ***	11.47	301.61 ***	12.67
H5DUM	407.09 ***	9.02	531.09 ***	20.03	317.56 ***	11.47	378.23 ***	12.67
H6DUM	413.84 ***	12.66	484.92 ***	28.08	376.49 ***	16.03	381.71 ***	17.89
H7DUM	439.00 ***	13.88	447.49 ***	30.72	433.94 ***	17.60	434.24 ***	19.63
H8DUM	593.63 ***	9.66	709.71 ***	21.41	507.50 ***	12.30	569.00 ***	13.57
H9DUM	513.41 ***	9.02	602.05 ***	20.03	436.81 ***	11.47	505.48 ***	12.67
H10DUM	393.78 ***	9.02	441.69 ***	20.03	346.51 ***	11.47	395.42 ***	12.67
H11DUM	394.88 ***	9.59	433.73 ***	21.26	357.21 ***	12.21	395.35 ***	13.47
H12DUM	384.85 ***	12.71	372.28 ***	28.19	364.35 ***	16.09	418.12 ***	17.96
H13DUM	452.31 ***	14.40	418.32 ***	31.81	407.25 ***	18.24	532.01 ***	20.39
H14DUM	507.06 ***	14.09	482.69 ***	31.16	462.66 ***	17.87	576.73 ***	19.95
H15DUM	514.86 ***	9.67	573.07 ***	21.43	453.43 ***	12.31	521.53 ***	13.59
H16DUM	416.97 ***	12.31	506.62 ***	27.32	366.64 ***	15.58	381.02 ***	17.37
H17DUM	212.14 ***	9.02	265.46 ***	20.03	187.70 ***	11.47	185.55 ***	12.67
H18DUM	175.50 ***	9.02	219.01 ***	20.03	148.07 ***	11.47	161.35 ***	12.67
H19DUM	137.45 ***	9.02	162.06 ***	20.03	125.73 ***	11.47	125.61 ***	12.67
H20DUM	102.27 ***	9.02	114.01 ***	20.03	92.04 ***	11.47	101.29 ***	12.67
H21DUM	69.23 ***	9.02	80.22 ***	20.03	63.13 ***	11.47	64.82 ***	12.67
H22DUM	68.62 ***	9.05	87.92 ***	20.17	57.16 ***	11.50	61.81 ***	12.70
H23DUM	146.44 ***	9.05	180.68 ***	20.17	129.21 ***	11.50	131.21 ***	12.70
LNOPEN	243.81 ***	14.79	392.85 ***	32.86	154.17 ***	18.76	194.10 ***	20.83
LNOPEN2	225.78 ***	14.79	330.81 ***	32.86	148.57 ***	18.76	205.12 ***	20.83
NYOPEN	205.45 ***	14.91	343.16 ***	33.10	167.49 ***	18.91	111.30 ***	21.01
NYOPEN2	236.80 ***	15.82	407.08 ***	35.07	202.84 ***	20.07	106.94 ***	22.33
NYOPEN3	257.34 ***	14.91	381.94 ***	33.10	236.49 ***	18.91	158.84 ***	21.01
LNLUNCH	-94.04 ***	13.94	-118.24 ***	31.02	-105.15 ***	17.68	-59.11 ***	19.60
NOB	16454		5322		5590		5542	

Table 5-1

Panel C: Spread on Dummy

Dependent variable: Spread

	Whole period		1999		2000		2001	
	Coefficient	s.e.	Coefficient	s.e.	Coefficient	s.e.	Coefficient	s.e.
H0DUM	0.0191 ***	0.0002	0.0206 ***	0.0005	0.0178 ***	0.0003	0.0188 ***	0.0004
H1DUM	0.0168 ***	0.0002	0.0178 ***	0.0005	0.0159 ***	0.0003	0.0169 ***	0.0004
H2DUM	0.0169 ***	0.0002	0.0177 ***	0.0005	0.0161 ***	0.0003	0.0171 ***	0.0004
H3DUM	0.0185 ***	0.0002	0.0200 ***	0.0005	0.0172 ***	0.0003	0.0184 ***	0.0004
H4DUM	0.0182 ***	0.0002	0.0192 ***	0.0005	0.0172 ***	0.0003	0.0181 ***	0.0004
H5DUM	0.0170 ***	0.0002	0.0178 ***	0.0005	0.0162 ***	0.0003	0.0170 ***	0.0004
H6DUM	0.0169 ***	0.0003	0.0183 ***	0.0007	0.0160 ***	0.0005	0.0166 ***	0.0006
H7DUM	0.0167 ***	0.0004	0.0183 ***	0.0007	0.0157 ***	0.0005	0.0163 ***	0.0006
H8DUM	0.0168 ***	0.0003	0.0176 ***	0.0005	0.0159 ***	0.0004	0.0168 ***	0.0004
H9DUM	0.0180 ***	0.0002	0.0187 ***	0.0005	0.0171 ***	0.0003	0.0182 ***	0.0004
H10DUM	0.0202 ***	0.0002	0.0212 ***	0.0005	0.0195 ***	0.0003	0.0201 ***	0.0004
H11DUM	0.0207 ***	0.0003	0.0216 ***	0.0005	0.0198 ***	0.0004	0.0208 ***	0.0004
H12DUM	0.0207 ***	0.0003	0.0225 ***	0.0007	0.0195 ***	0.0005	0.0203 ***	0.0006
H13DUM	0.0199 ***	0.0004	0.0214 ***	0.0008	0.0185 ***	0.0005	0.0198 ***	0.0007
H14DUM	0.0193 ***	0.0004	0.0202 ***	0.0007	0.0182 ***	0.0005	0.0194 ***	0.0006
H15DUM	0.0203 ***	0.0003	0.0211 ***	0.0005	0.0192 ***	0.0004	0.0206 ***	0.0004
H16DUM	0.0215 ***	0.0003	0.0227 ***	0.0007	0.0201 ***	0.0005	0.0219 ***	0.0006
H17DUM	0.0253 ***	0.0002	0.0266 ***	0.0005	0.0234 ***	0.0003	0.0259 ***	0.0004
H18DUM	0.0262 ***	0.0002	0.0282 ***	0.0005	0.0240 ***	0.0003	0.0265 ***	0.0004
H19DUM	0.0266 ***	0.0002	0.0278 ***	0.0005	0.0251 ***	0.0003	0.0270 ***	0.0004
H20DUM	0.0287 ***	0.0002	0.0306 ***	0.0005	0.0269 ***	0.0003	0.0286 ***	0.0004
H21DUM	0.0283 ***	0.0002	0.0309 ***	0.0005	0.0261 ***	0.0003	0.0281 ***	0.0004
H22DUM	0.0245 ***	0.0002	0.0264 ***	0.0005	0.0228 ***	0.0003	0.0243 ***	0.0004
H23DUM	0.0206 ***	0.0002	0.0227 ***	0.0005	0.0192 ***	0.0003	0.0201 ***	0.0004
LNOPEN	-0.0005	0.0004	-0.0015 **	0.0008	-0.0002	0.0006	0.0002	0.0007
LNOPEN2	-0.0005 *	0.0004	-0.0014 **	0.0008	-0.0003	0.0006	0.0002	0.0007
NYOPEN	-0.0006 *	0.0004	-0.0010	0.0008	-0.0006	0.0006	-0.0002	0.0007
NYOPEN2	-0.0013 ***	0.0004	-0.0024 ***	0.0008	-0.0010 **	0.0006	-0.0007	0.0007
NYOPEN3	-0.0014 ***	0.0004	-0.0026 ***	0.0008	-0.0011 **	0.0006	-0.0005	0.0007
LNLUNCH	0.0024 ***	0.0004	0.0025 ***	0.0007	0.0020 ***	0.0005	0.0026 ***	0.0006
NOB	16454		5322		5590		5542	

Note: ***, ** and * indicate significance at the 1,5, and 10%, respectively.

Table 5-2

Panel A: Number of Price Change on Dummy

Dependent variable: Number of price change

	Whole period		1999		2000		2001	
	Coefficient	s.e.	Coefficient	s.e.	Coefficient	s.e.	Coefficient	s.e.
H0DUM	328.49 ***	5.73	349.59 ***	9.64	321.63 ***	9.78	315.14 ***	9.80
H1DUM	274.78 ***	5.73	280.59 ***	9.64	272.43 ***	9.78	271.56 ***	9.80
H2DUM	229.38 ***	5.73	228.30 ***	9.64	228.00 ***	9.78	231.81 ***	9.80
H3DUM	135.86 ***	5.73	129.55 ***	9.64	137.48 ***	9.78	140.28 ***	9.80
H4DUM	194.89 ***	5.73	203.41 ***	9.64	191.60 ***	9.78	190.00 ***	9.80
H5DUM	307.22 ***	5.73	310.17 ***	9.64	317.21 ***	9.78	294.30 ***	9.80
H6DUM	396.09 ***	8.05	387.38 ***	13.52	436.92 ***	13.66	362.73 ***	13.84
H7DUM	499.50 ***	8.82	467.73 ***	14.79	562.45 ***	15.00	466.03 ***	15.19
H8DUM	558.83 ***	6.14	533.03 ***	10.31	597.29 ***	10.48	544.86 ***	10.50
H9DUM	531.33 ***	5.73	503.66 ***	9.64	558.31 ***	9.78	530.69 ***	9.80
H10DUM	497.42 ***	5.73	454.48 ***	9.64	543.40 ***	9.78	492.31 ***	9.80
H11DUM	540.97 ***	6.09	506.64 ***	10.24	591.06 ***	10.40	523.28 ***	10.42
H12DUM	551.35 ***	8.08	536.64 ***	13.57	613.25 ***	13.71	501.93 ***	13.90
H13DUM	633.55 ***	9.15	644.74 ***	15.32	697.66 ***	15.55	556.29 ***	15.77
H14DUM	692.16 ***	8.96	693.65 ***	15.00	754.23 ***	15.23	626.59 ***	15.43
H15DUM	772.66 ***	6.14	737.85 ***	10.31	850.18 ***	10.49	727.58 ***	10.51
H16DUM	691.02 ***	7.82	684.90 ***	13.15	769.63 ***	13.28	616.72 ***	13.44
H17DUM	492.66 ***	5.73	494.38 ***	9.64	542.76 ***	9.78	440.48 ***	9.80
H18DUM	444.42 ***	5.73	442.66 ***	9.64	483.95 ***	9.78	406.25 ***	9.80
H19DUM	383.73 ***	5.73	375.54 ***	9.64	421.07 ***	9.78	353.94 ***	9.80
H20DUM	292.96 ***	5.73	265.09 ***	9.64	329.98 ***	9.78	282.39 ***	9.80
H21DUM	201.76 ***	5.75	170.61 ***	9.67	223.25 ***	9.80	210.03 ***	9.82
H22DUM	153.35 ***	5.76	141.24 ***	9.71	158.64 ***	9.82	159.58 ***	9.82
H23DUM	181.65 ***	5.76	186.72 ***	9.71	182.27 ***	9.82	176.21 ***	9.82
LNOPEN	132.45 ***	9.40	118.05 ***	15.82	88.91 ***	15.99	190.25 ***	16.12
LNOPEN2	192.02 ***	9.40	172.76 ***	15.82	148.63 ***	15.99	254.28 ***	16.12
NYOPEN	159.64 ***	9.48	124.68 ***	15.94	144.48 ***	16.12	209.52 ***	16.25
NYOPEN2	144.00 ***	10.06	93.41 ***	16.88	134.06 ***	17.10	204.33 ***	17.28
NYOPEN3	162.54 ***	9.48	133.90 ***	15.94	149.54 ***	16.12	204.49 ***	16.25
LNLUNCH	-86.65 ***	8.86	-104.27 ***	14.93	-121.94 ***	15.07	-33.42 **	15.16
NOB	16449		5321		5587		5541	

Note: ***, ** and * indicate significance at the 1,5, and 10%, respectively.

Table 5-2

Panel B: Number of Deals on Dummy

Dependent variable: Number of Deals

	Whole period		1999		2000		2001	
	Coefficient	s.e.	Coefficient	s.e.	Coefficient	s.e.	Coefficient	s.e.
H0DUM	200.25 ***	8.68	209.45 ***	14.49	194.18 ***	14.91	197.52 ***	14.74
H1DUM	171.42 ***	8.68	168.47 ***	14.49	170.99 ***	14.91	174.70 ***	14.74
H2DUM	139.77 ***	8.68	133.23 ***	14.49	138.16 ***	14.91	147.67 ***	14.74
H3DUM	70.10 ***	8.68	60.97 ***	14.49	72.19 ***	14.91	76.76 ***	14.74
H4DUM	109.35 ***	8.68	111.19 ***	14.49	105.10 ***	14.91	111.87 ***	14.74
H5DUM	209.03 ***	8.68	210.04 ***	14.49	215.64 ***	14.91	201.39 ***	14.74
H6DUM	356.56 ***	12.18	360.48 ***	20.31	397.28 ***	20.83	311.17 ***	20.81
H7DUM	599.06 ***	13.36	550.02 ***	22.22	694.64 ***	22.87	549.51 ***	22.84
H8DUM	845.18 ***	9.29	768.30 ***	15.48	910.15 ***	15.98	853.69 ***	15.79
H9DUM	797.02 ***	8.68	716.09 ***	14.49	849.00 ***	14.91	822.36 ***	14.74
H10DUM	683.71 ***	8.68	576.50 ***	14.49	757.89 ***	14.91	711.91 ***	14.74
H11DUM	744.84 ***	9.23	667.43 ***	15.38	814.22 ***	15.87	749.28 ***	15.67
H12DUM	760.87 ***	12.23	721.00 ***	20.39	837.37 ***	20.91	721.96 ***	20.90
H13DUM	924.08 ***	13.85	896.86 ***	23.01	997.28 ***	23.71	876.54 ***	23.72
H14DUM	1001.76 ***	13.56	936.21 ***	22.54	1072.07 ***	23.22	994.43 ***	23.20
H15DUM	1015.99 ***	9.30	907.29 ***	15.50	1124.47 ***	16.00	1011.11 ***	15.81
H16DUM	771.50 ***	11.84	738.33 ***	19.76	868.96 ***	20.25	704.39 ***	20.20
H17DUM	374.34 ***	8.68	355.81 ***	14.49	420.38 ***	14.91	345.72 ***	14.74
H18DUM	301.48 ***	8.68	284.64 ***	14.49	330.58 ***	14.91	288.32 ***	14.74
H19DUM	241.42 ***	8.68	221.56 ***	14.49	269.48 ***	14.91	232.21 ***	14.74
H20DUM	171.41 ***	8.68	144.95 ***	14.49	194.42 ***	14.91	173.62 ***	14.74
H21DUM	97.35 ***	8.70	77.95 ***	14.52	110.04 ***	14.94	103.20 ***	14.77
H22DUM	59.95 ***	8.72	52.74 ***	14.59	63.42 ***	14.97	63.33 ***	14.77
H23DUM	78.31 ***	8.72	80.67 ***	14.59	78.73 ***	14.97	75.63 ***	14.77
LNOPEN	362.30 ***	14.24	316.61 ***	23.76	300.50 ***	24.38	467.76 ***	24.23
LNOPEN2	310.31 ***	14.24	286.57 ***	23.76	245.09 ***	24.38	398.53 ***	24.23
NYOPEN	347.04 ***	14.35	294.98 ***	23.94	370.94 ***	24.58	371.55 ***	24.44
NYOPEN2	336.77 ***	15.23	278.06 ***	25.36	366.85 ***	26.08	362.24 ***	25.98
NYOPEN3	361.20 ***	14.35	304.40 ***	23.94	367.54 ***	24.58	408.96 ***	24.44
LNLUNCH	-212.91 ***	13.42	-244.44 ***	22.43	-265.59 ***	22.98	-129.55 ***	22.80
NOB	16449		5321		5587		5541	

Note: ***, ** and * indicate significance at the 1,5, and 10%, respectively.

Table 5-2

Panel C: Spread on Dummy

Dependent variable: Spread

	Whole period		1999		2000		2001	
	Coefficient	s.e.	Coefficient	s.e.	Coefficient	s.e.	Coefficient	s.e.
H0DUM	0.00015 ***	3.66E-06	0.00015 ***	6.42E-06	0.00014 ***	6.68E-06	0.00015 ***	5.86E-06
H1DUM	0.00015 ***	3.66E-06	0.00015 ***	6.42E-06	0.00015 ***	6.68E-06	0.00014 ***	5.86E-06
H2DUM	0.00015 ***	3.66E-06	0.00016 ***	6.42E-06	0.00015 ***	6.68E-06	0.00015 ***	5.86E-06
H3DUM	0.00017 ***	3.66E-06	0.00018 ***	6.42E-06	0.00016 ***	6.68E-06	0.00015 ***	5.86E-06
H4DUM	0.00015 ***	3.66E-06	0.00016 ***	6.42E-06	0.00014 ***	6.68E-06	0.00015 ***	5.86E-06
H5DUM	0.00014 ***	3.66E-06	0.00015 ***	6.42E-06	0.00014 ***	6.68E-06	0.00013 ***	5.86E-06
H6DUM	0.00013 ***	5.13E-06	0.00013 ***	9.00E-06	0.00012 ***	9.34E-06	0.00013 ***	8.27E-06
H7DUM	0.00013 ***	5.63E-06	0.00014 ***	9.85E-06	0.00012 ***	1.03E-05	0.00012 ***	9.08E-06
H8DUM	0.00012 ***	3.92E-06	0.00012 ***	6.86E-06	0.00011 ***	7.16E-06	0.00012 ***	6.28E-06
H9DUM	0.00012 ***	3.66E-06	0.00011 ***	6.42E-06	0.00012 ***	6.68E-06	0.00011 ***	5.86E-06
H10DUM	0.00012 ***	3.66E-06	0.00011 ***	6.42E-06	0.00014 ***	6.68E-06	0.00012 ***	5.86E-06
H11DUM	0.00012 ***	3.89E-06	0.00011 ***	6.81E-06	0.00012 ***	7.11E-06	0.00011 ***	6.23E-06
H12DUM	0.00012 ***	5.15E-06	0.00012 ***	9.04E-06	0.00011 ***	9.37E-06	0.00012 ***	8.30E-06
H13DUM	0.00012 ***	5.84E-06	0.00012 ***	1.02E-05	0.00012 ***	1.06E-05	0.00012 ***	9.43E-06
H14DUM	0.00012 ***	5.71E-06	0.00013 ***	9.99E-06	0.00012 ***	1.04E-05	0.00011 ***	9.22E-06
H15DUM	0.00013 ***	3.92E-06	0.00013 ***	6.87E-06	0.00013 ***	7.17E-06	0.00013 ***	6.28E-06
H16DUM	0.00014 ***	4.99E-06	0.00015 ***	8.76E-06	0.00015 ***	9.08E-06	0.00014 ***	8.03E-06
H17DUM	0.00016 ***	3.66E-06	0.00016 ***	6.42E-06	0.00017 ***	6.68E-06	0.00015 ***	5.86E-06
H18DUM	0.00016 ***	3.66E-06	0.00017 ***	6.42E-06	0.00016 ***	6.68E-06	0.00015 ***	5.86E-06
H19DUM	0.00017 ***	3.66E-06	0.00017 ***	6.42E-06	0.00017 ***	6.68E-06	0.00017 ***	5.86E-06
H20DUM	0.00020 ***	3.66E-06	0.00020 ***	6.42E-06	0.00021 ***	6.68E-06	0.00019 ***	5.86E-06
H21DUM	0.00023 ***	3.67E-06	0.00024 ***	6.44E-06	0.00025 ***	6.70E-06	0.00021 ***	5.87E-06
H22DUM	0.00023 ***	3.67E-06	0.00023 ***	6.46E-06	0.00024 ***	6.71E-06	0.00023 ***	5.87E-06
H23DUM	0.00019 ***	3.67E-06	0.00019 ***	6.46E-06	0.00019 ***	6.71E-06	0.00019 ***	5.87E-06
LNOPEN	-0.00001 *	6.00E-06	-0.00002 **	1.05E-05	0.000000	1.09E-05	-0.00001	9.63E-06
LNOPEN2	-0.00001 *	6.00E-06	-0.00002 **	1.05E-05	-0.000001	1.09E-05	-0.000003	9.63E-06
NYOPEN	-0.000004	6.05E-06	-0.00001	1.06E-05	-0.000005	1.10E-05	0.000004	9.71E-06
NYOPEN2	0.000002	6.42E-06	-0.000002	1.12E-05	0.000002	1.17E-05	0.00001	1.03E-05
NYOPEN3	-0.000005	6.05E-06	-0.000001	1.06E-05	-0.000003	1.10E-05	-0.00001	9.71E-06
LNLUNCH	0.00001	5.65E-06	0.00001	9.94E-06	0.00001	1.03E-05	0.000001	9.06E-06
NOB	16449		5321		5587		5541	

Note: ***, ** and * indicate significance at the 1,5, and 10%, respectively.

Figure 2-1: Intraday Activities (USD-JPY), Winter 1999-2001

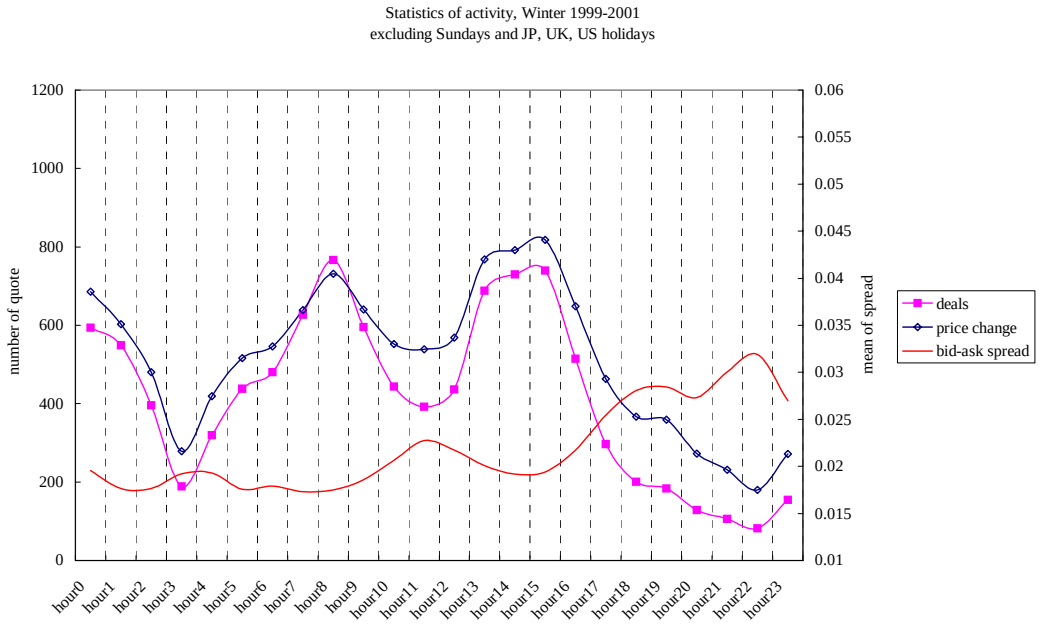


Figure 2-2: Intraday Activities (USD-JPY), Summer 1999-2001

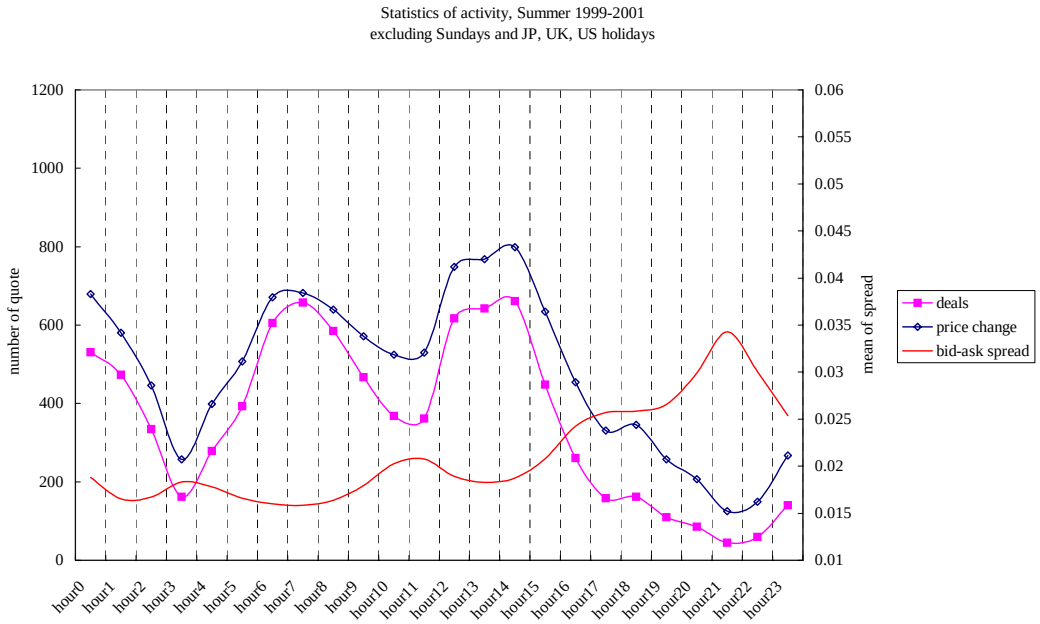


Figure 2-3: Intraday Activities (Euro-USD), Winter 1999-2001

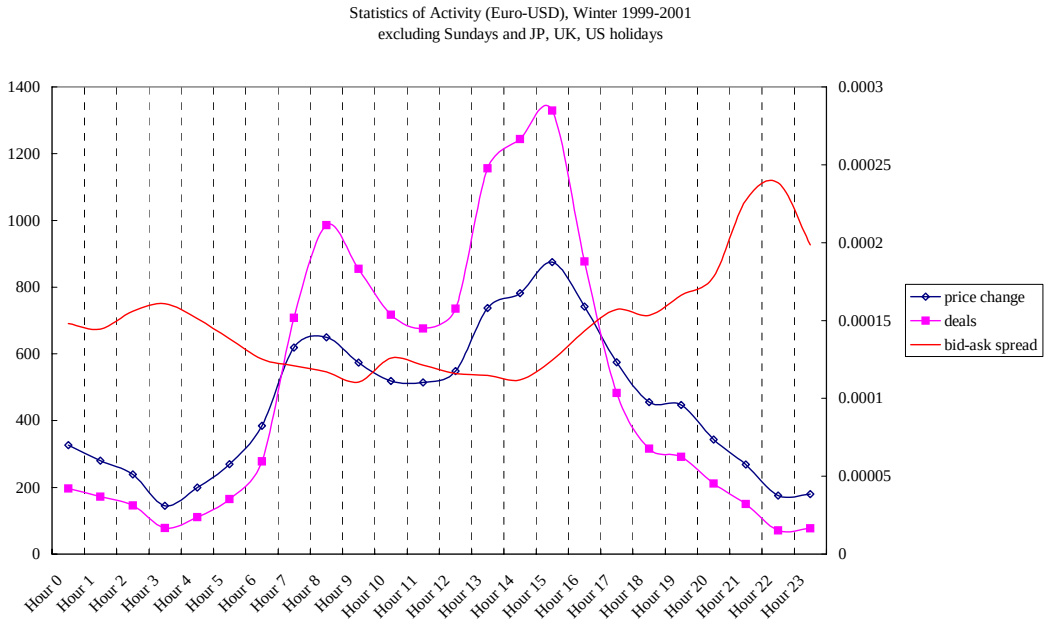


Figure 2-4: Intraday Activities (Euro-USD), Summer 1999-2001

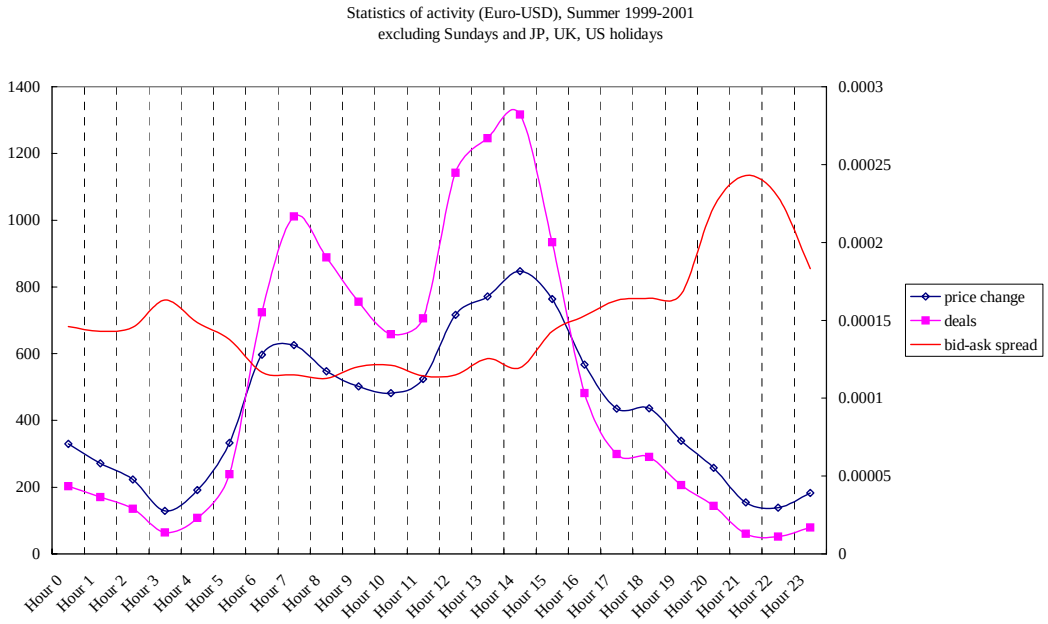


Figure 3-1: Relative volume (JPY-USD), Winter 1999-2001

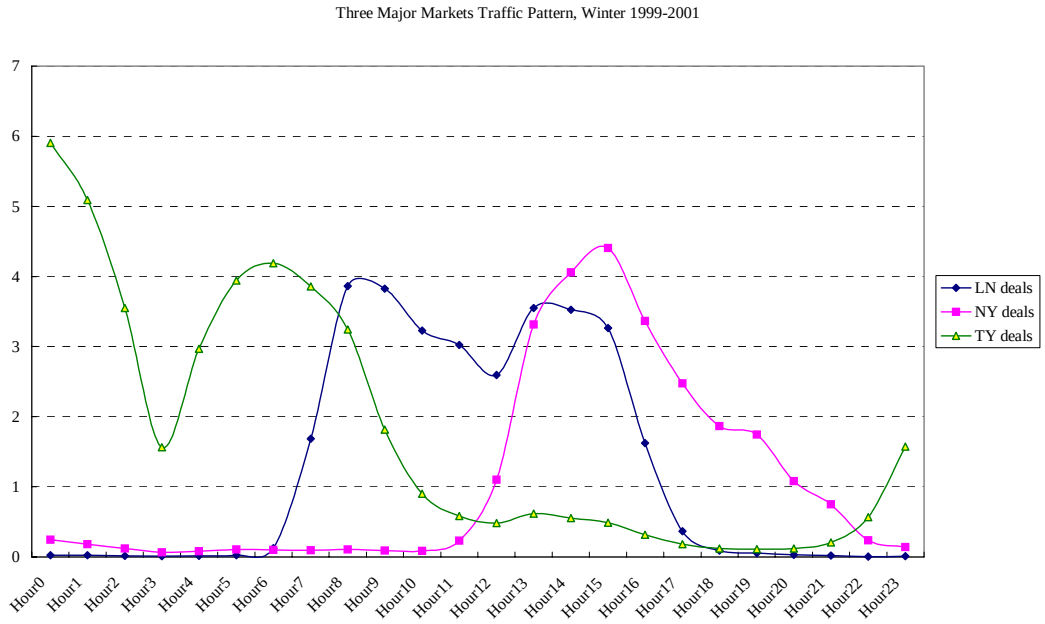


Figure 3-2: Relative volume (JPY-USD), Summer 1999-2001

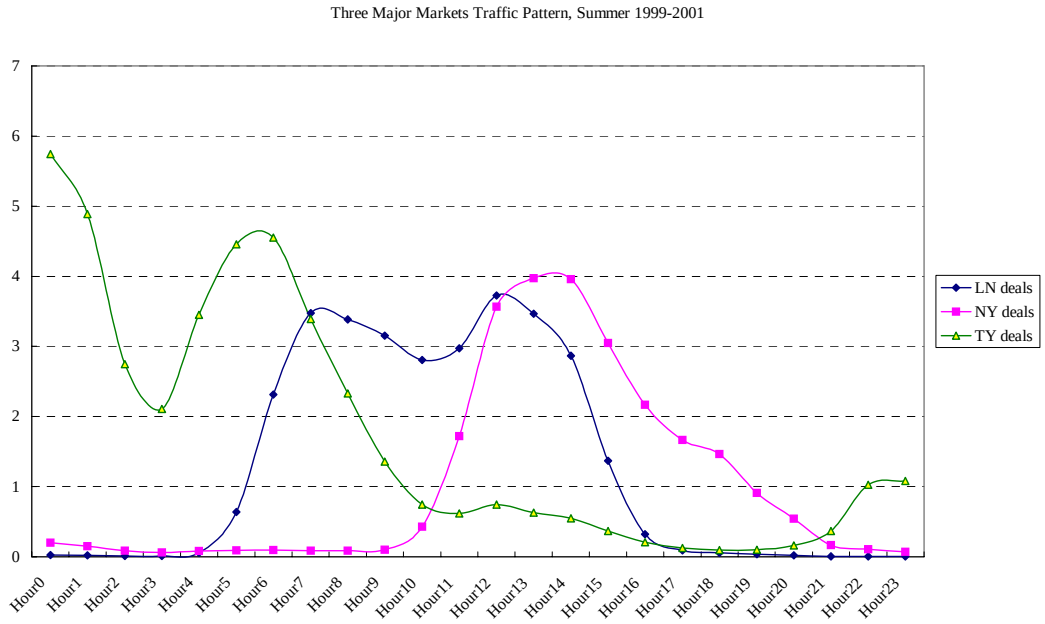


Figure 3-3: Relative volume (Euro-USD), winter 1999-2001

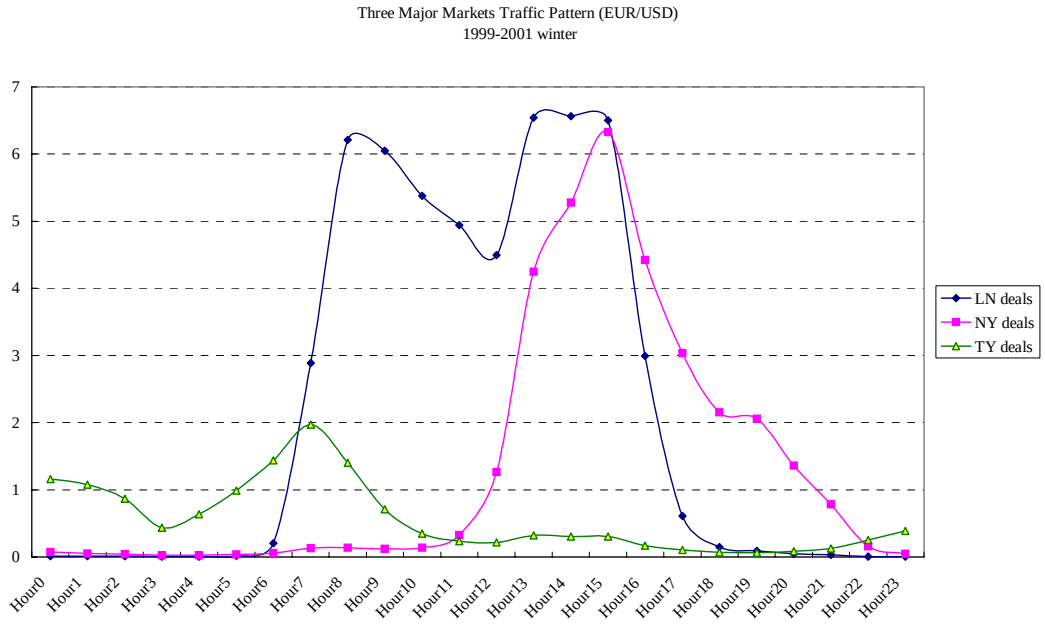
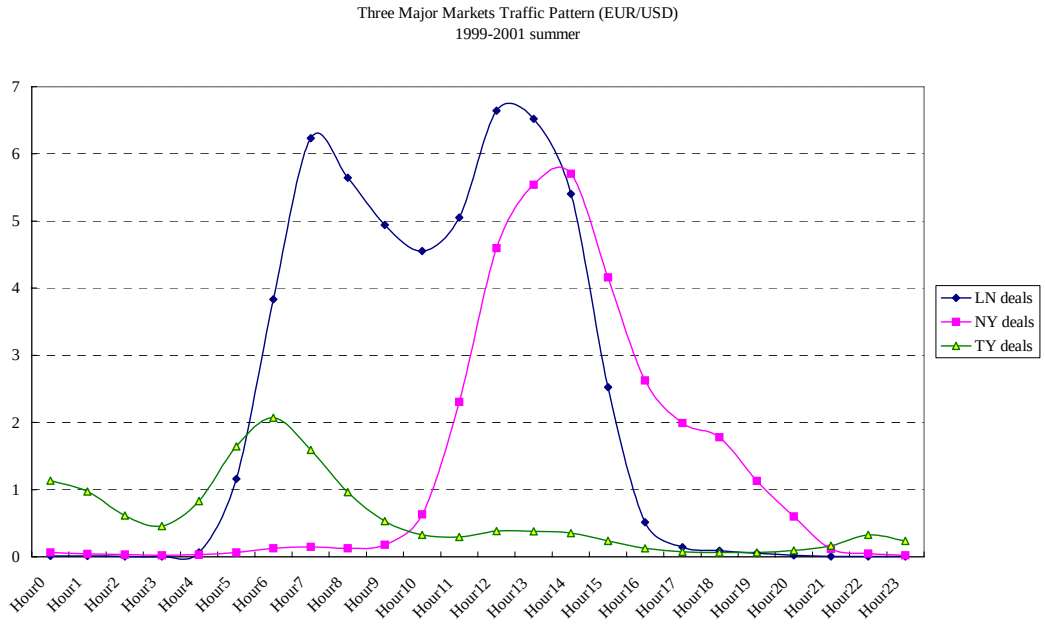


Figure 3-4: Relative volume(Euro-USD), summer 1999-2001



Appendix figures

Figure A-2-1: Statistics of Price Changes and Deals (USD-JPY), Winter 1999

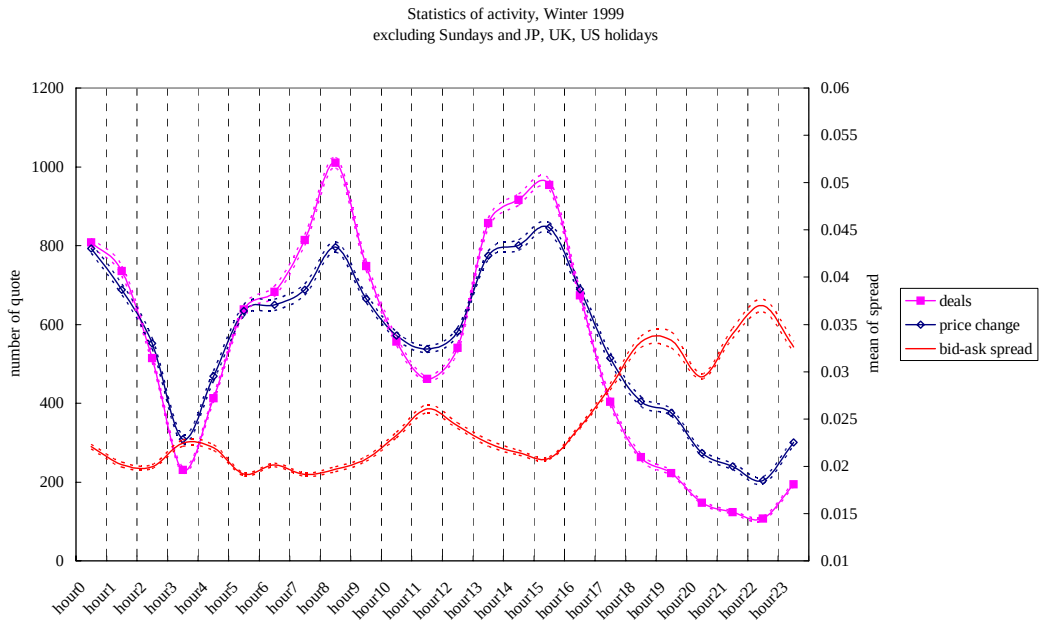


Figure A-2-2: Statistics of Price Changes and Deals (USD-JPY),Summer 1999

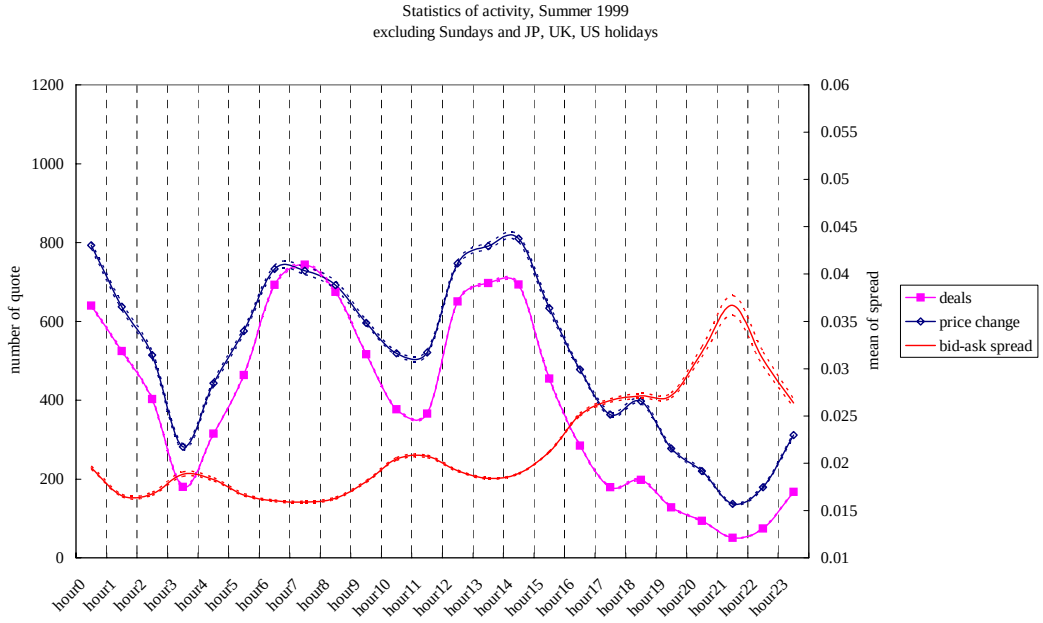


Figure A-2-3: Statistics of Price Changes and Deals (USD-JPY),Winter 2000

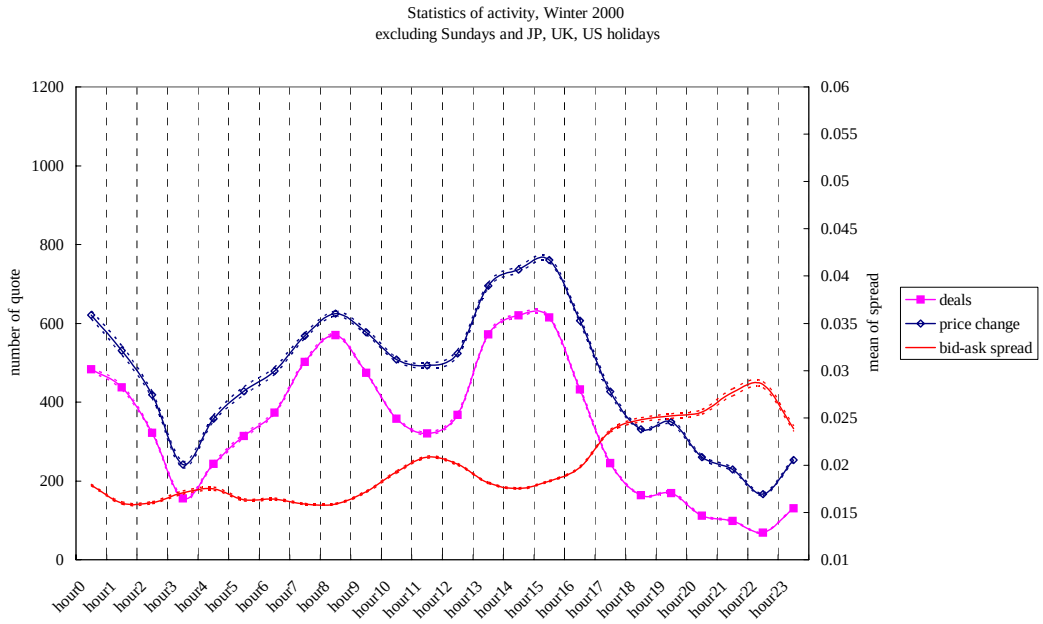


Figure A-2-4: Statistics of Price Changes and Deals (USD-JPY),Summer 2000

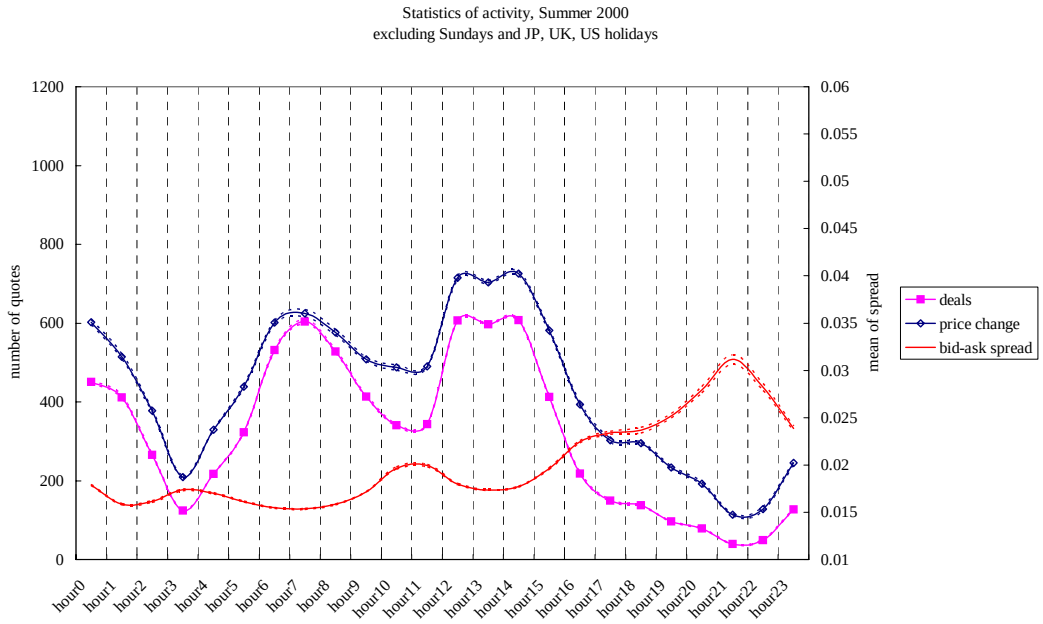


Figure A-2-5: Statistics of Price Changes and Deals (USD-JPY),Winter 2001

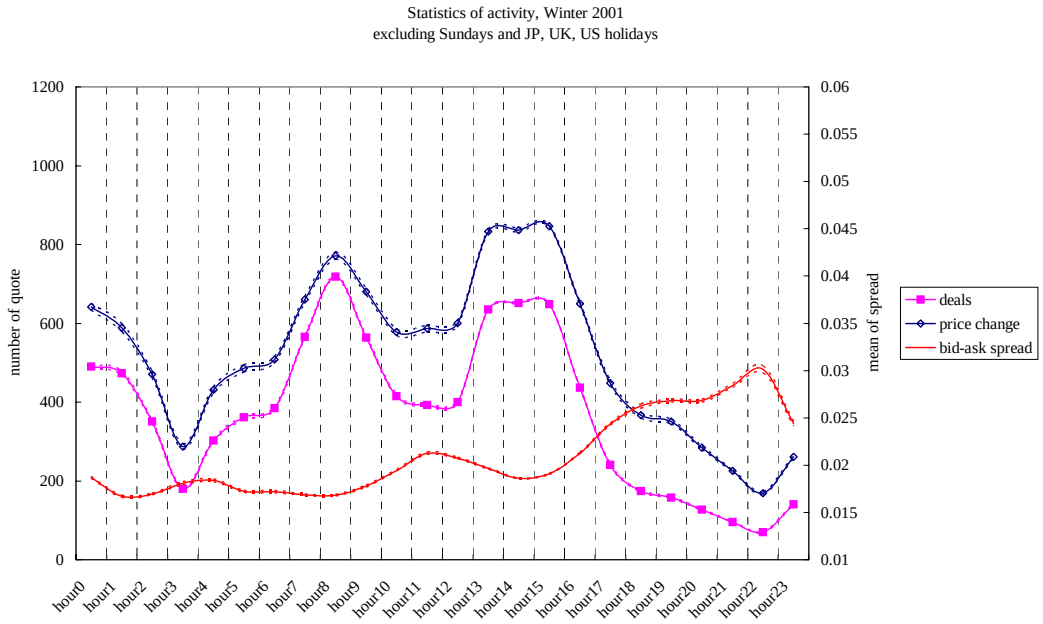


Figure A-2-6: Statistics of Price Changes and Deals (USD-JPY),Summer 2001

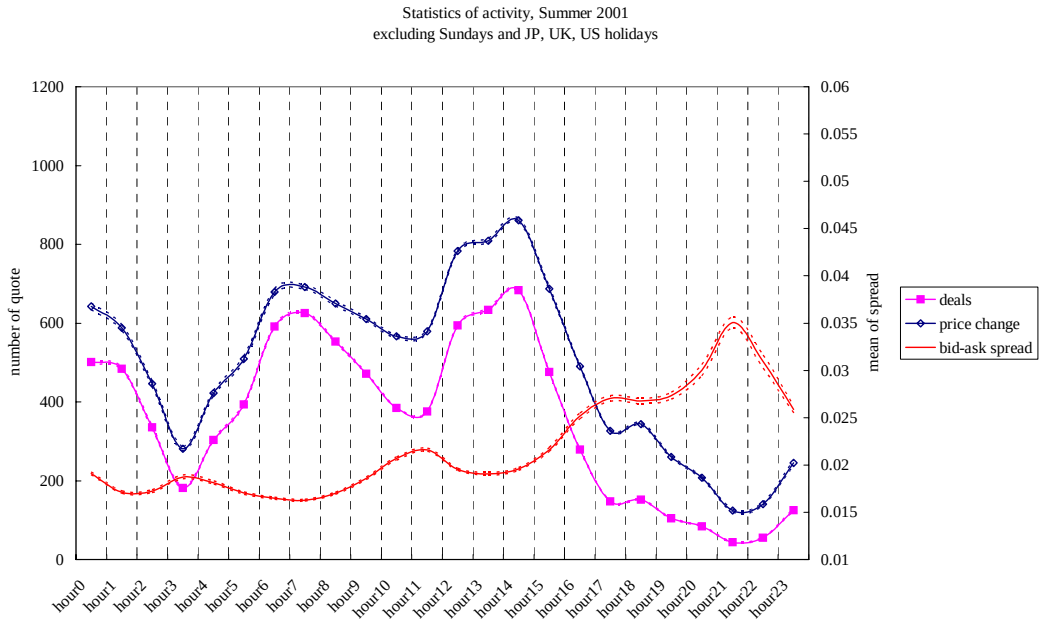


Figure A-3-1: Relative volume (JPY-USD), Winter 1999

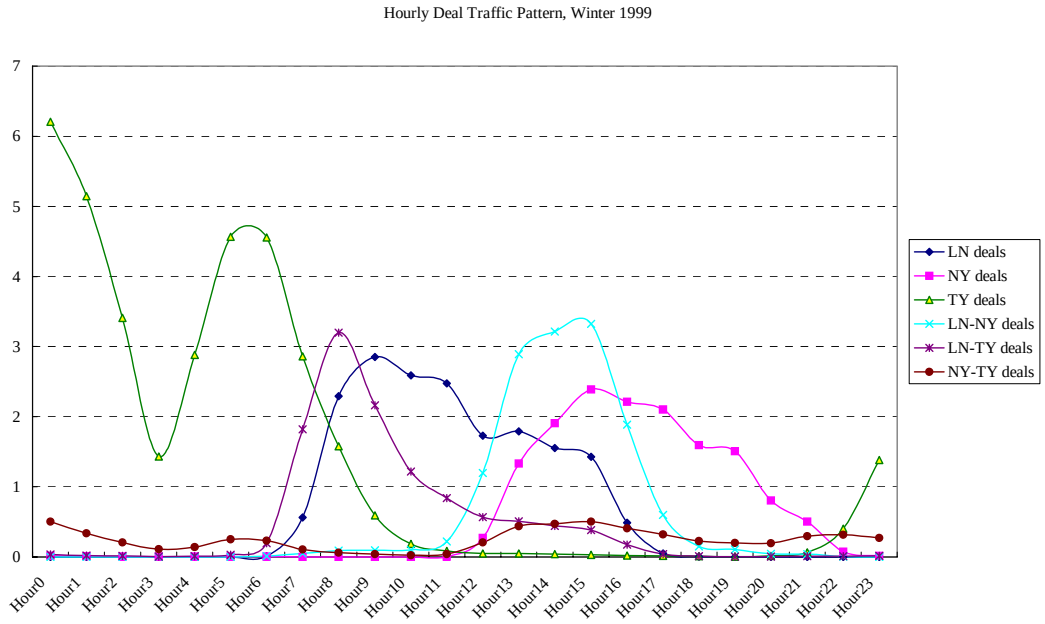


Figure A-3-2: Relative volume (JPY-USD), Summer 1999

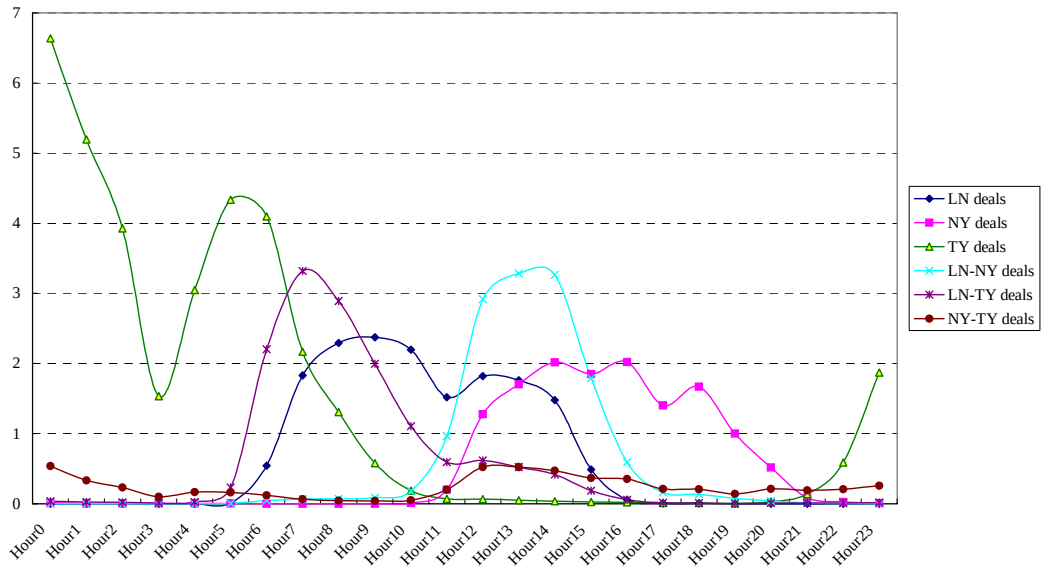


Figure A-3-3: Relative volume (JPY-USD), Winter 2000

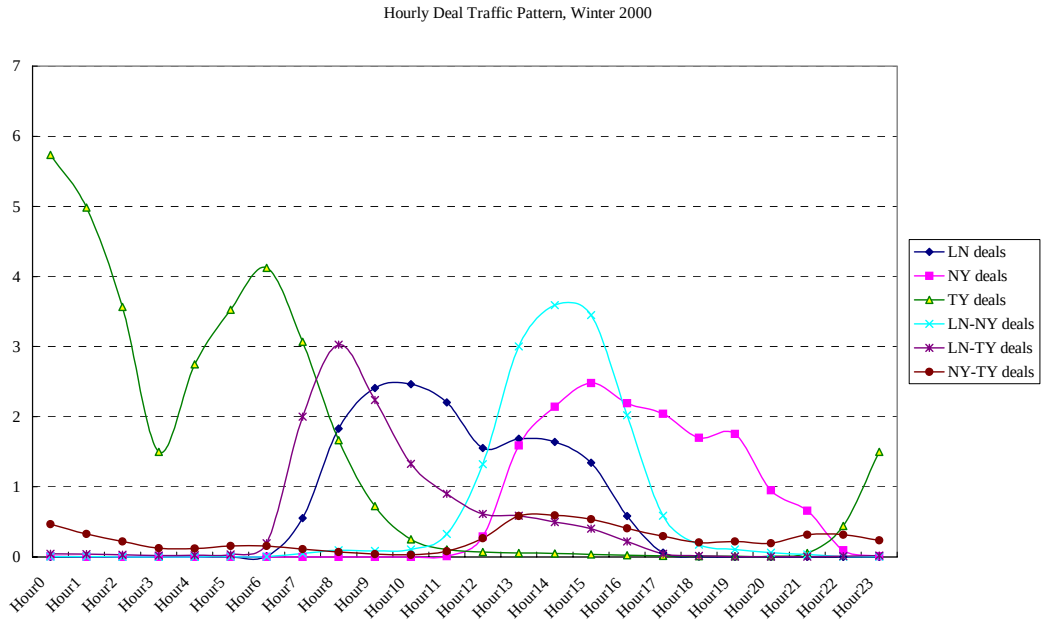


Figure A-3-4: Relative volume (JPY-USD), Summer 2000

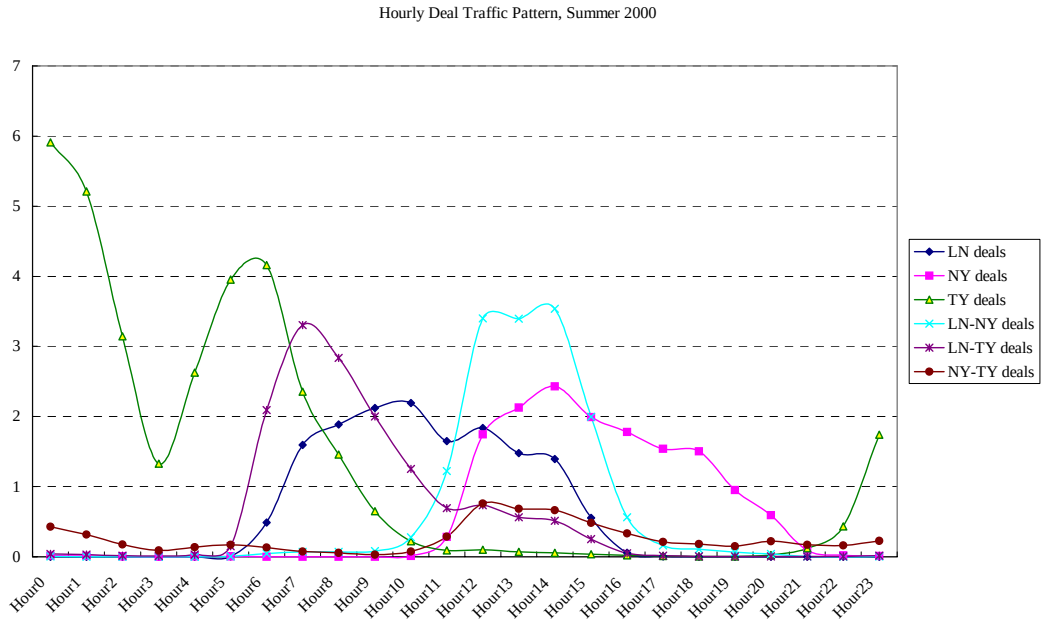


Figure A-3-5: Relative volume (JPY-USD), Winter 2001

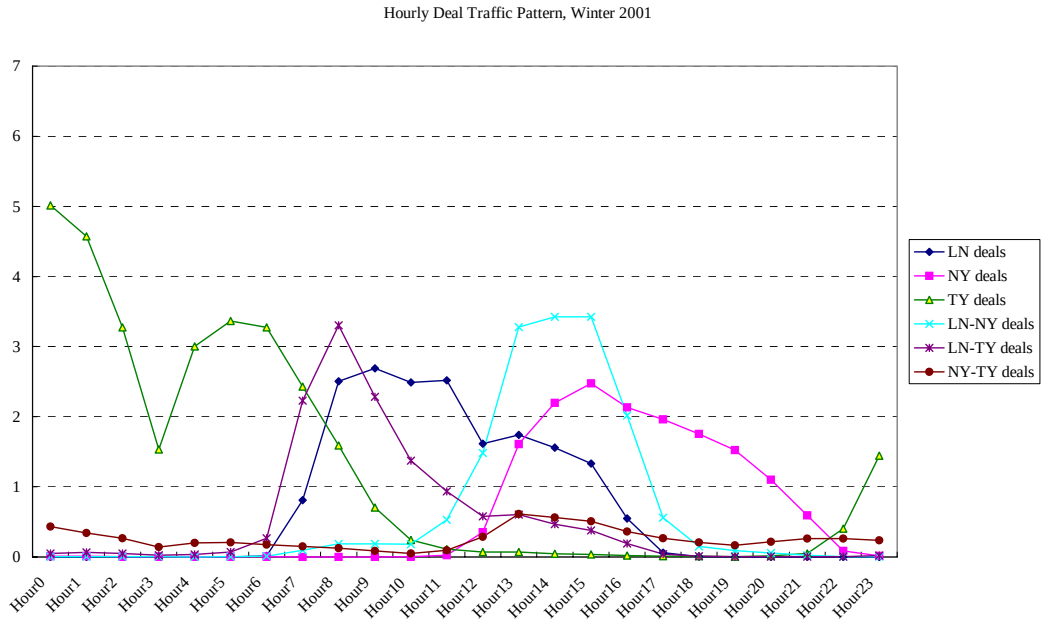


Figure A-3-6: Relative volume (JPY-USD), Summer 2001

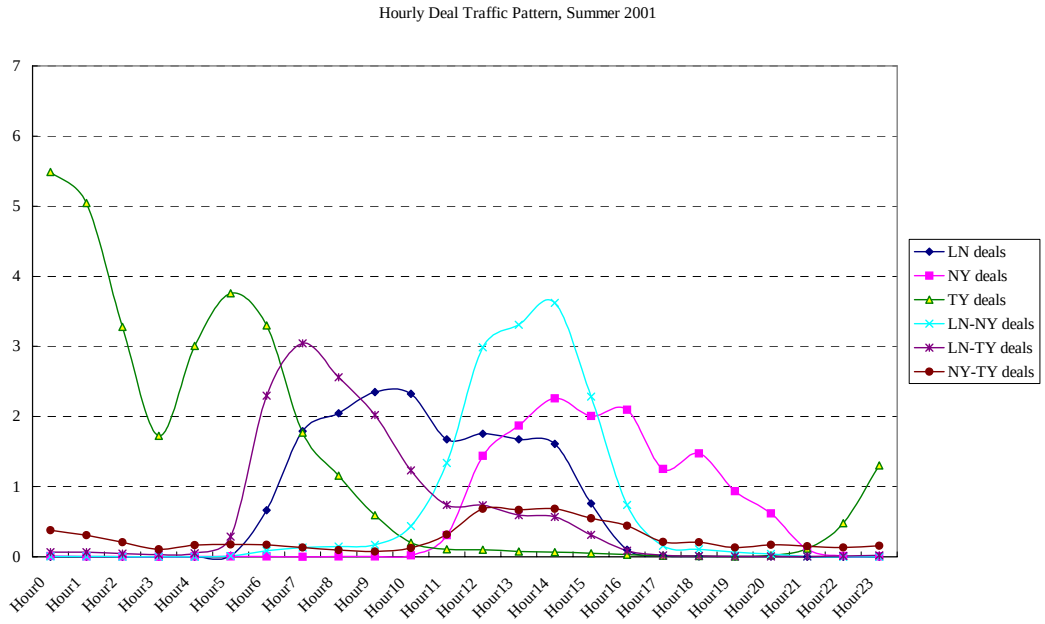


Figure A-4-1: Relative volume (EURO-USD), Winter 1999

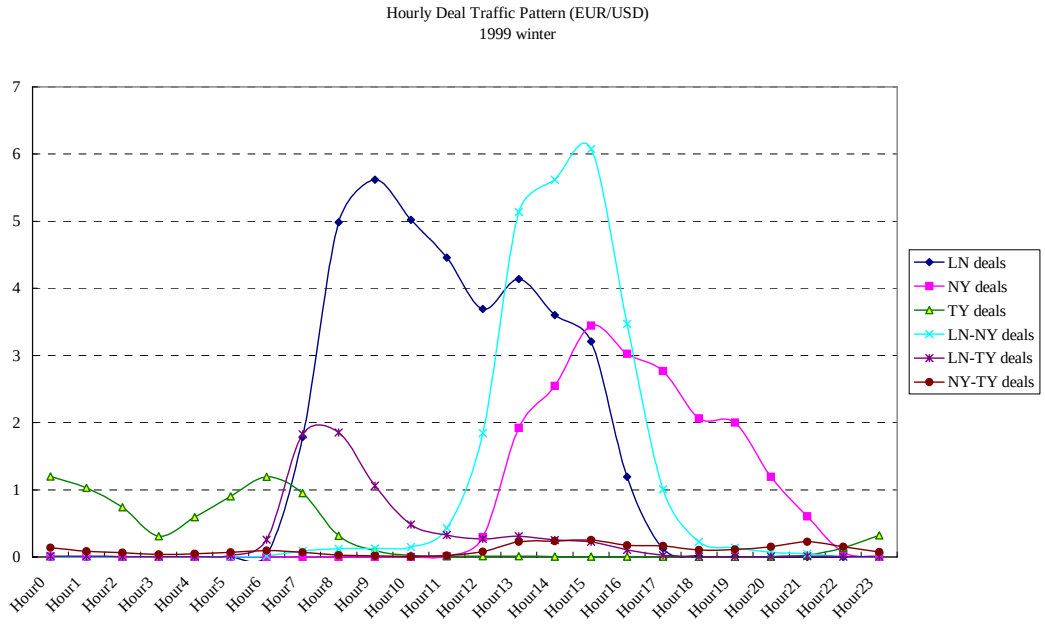


Figure A-4-2: Relative volume (EURO-USD),Summer 1999

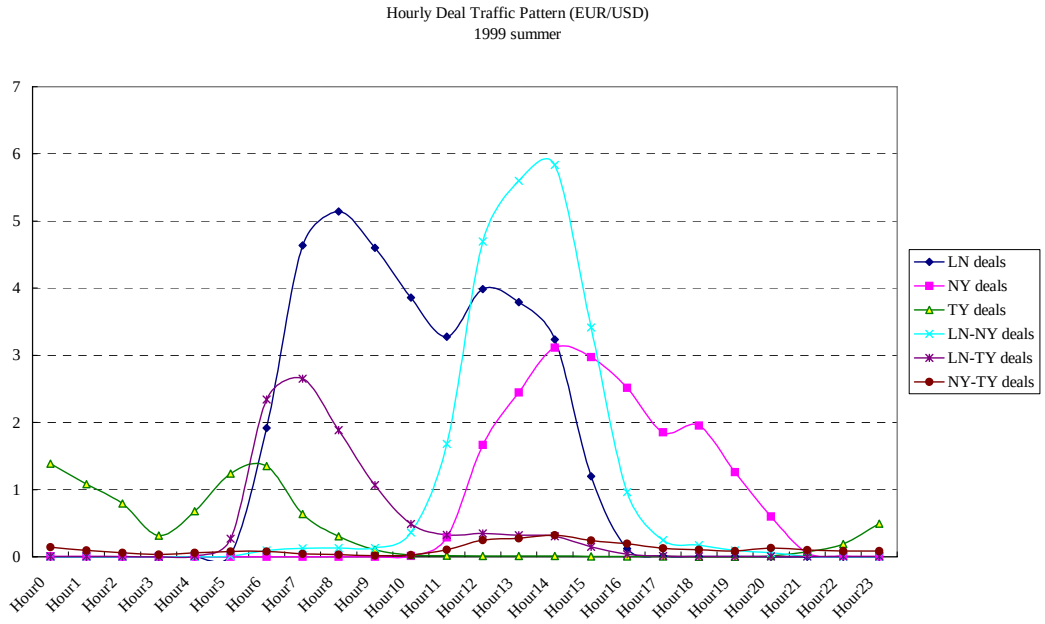


Figure A-4-3: Relative volume (EURO-USD),Winter 2000

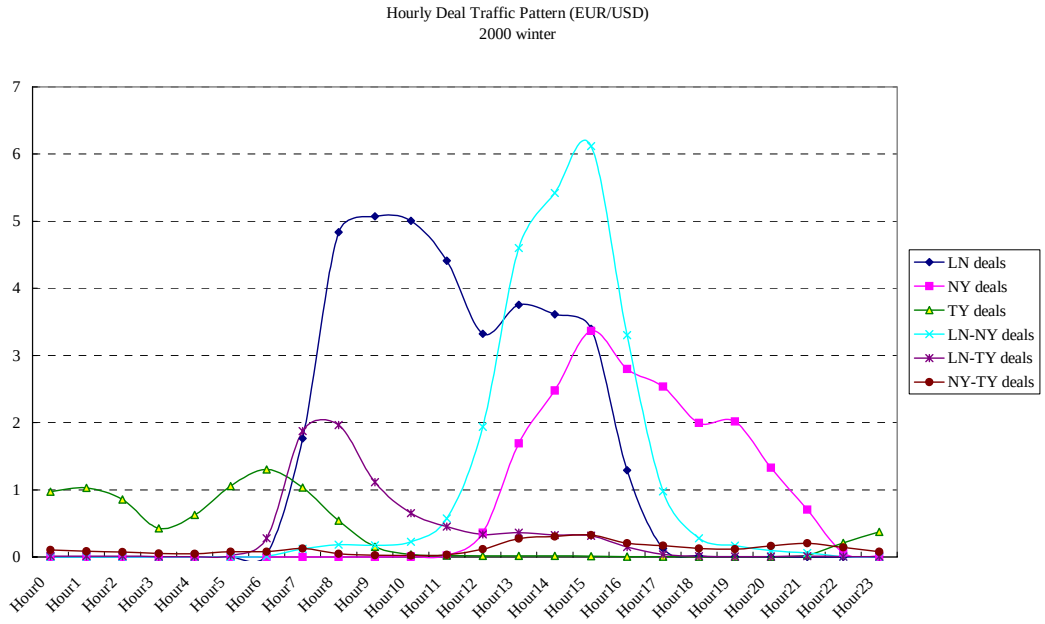


Figure A-4-4: Relative volume (EURO-USD),Summer 2000

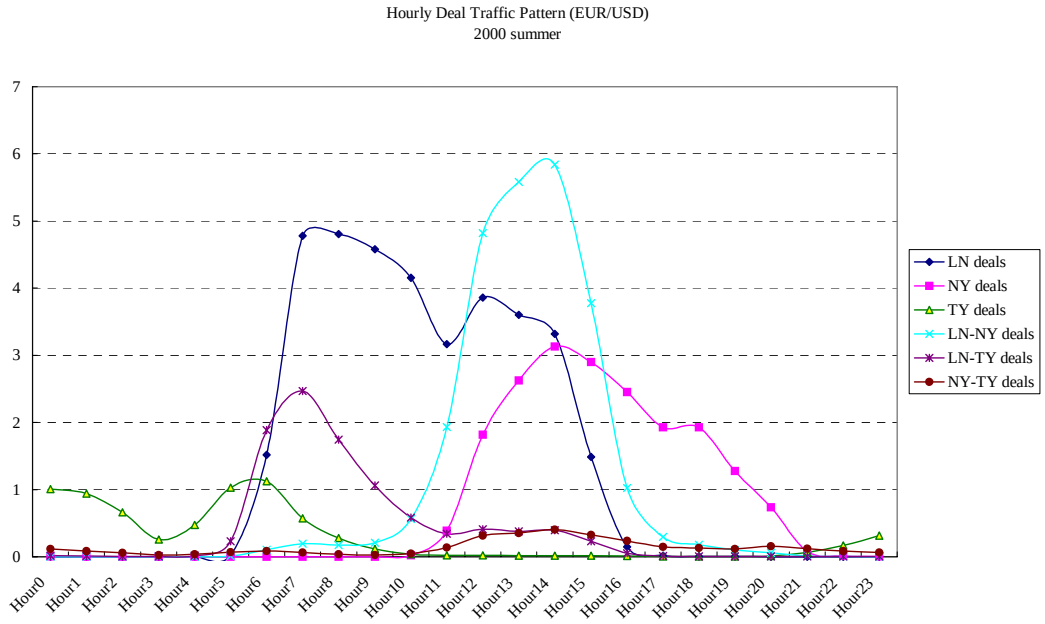


Figure A-4-5: Relative volume (EURO-USD),Winter 2001

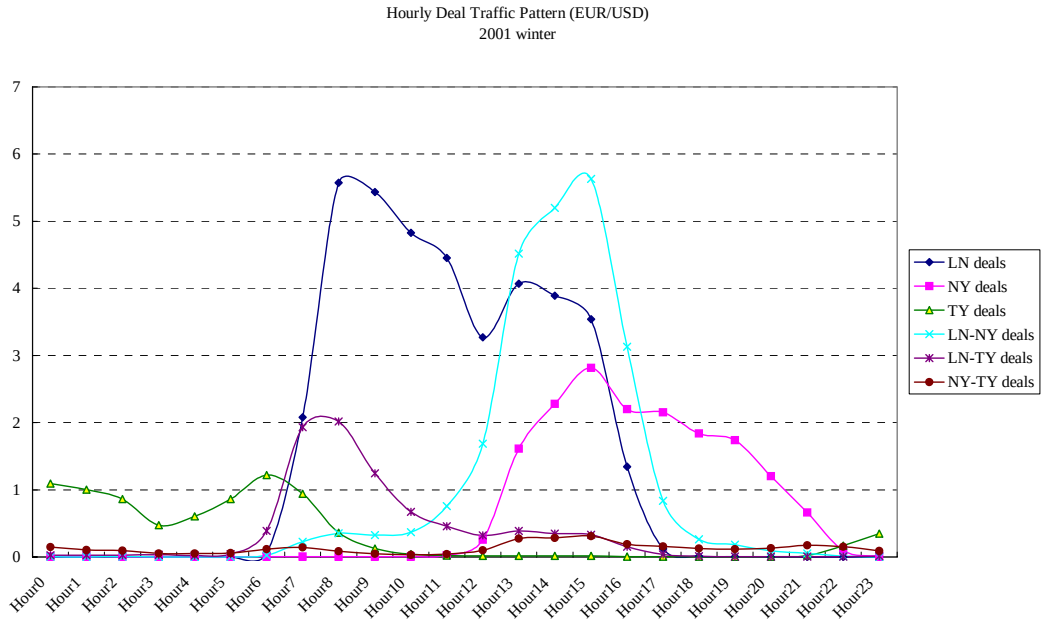


Figure A-4-6: Relative volume (EURO-USD),Summer 2001