09/11 on the USD/EUR Foreign Exchange Market

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Abstract
We study the relationship between foreign exchange trading activity and volatility on the USD/EUR foreign exchange market on the basis of a unique data set around the events of 09/11/2001. We find that volatility and bid-ask spreads are by far larger at that time, but the shock is not persistent. The positive correlation between volume and volatility does not break up, but intensifies strongly indicating the arrival of new information and increased price risk. We conclude that the USD/EUR foreign exchange market maintains its liquid structure and its efficient processing of exogenous shocks.

JEL-Classification: F31, G14, G15
Keywords: foreign exchange, market microstructure, liquidity, sudden events

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09/11 on the USD/EUR Foreign Exchange Market

1 Introduction

On September 11 2001 the United States experienced its most devastating terrorist attack when terrorists crashed hijacked airliners into the World Trade Center and the Pentagon. The tragic events affected not only people all over the world, but also the financial markets worldwide. Because of the attacks and damage to the New York City financial district, US financial markets were closed until September 17 (see Carter and Simkins, 2002). When the markets opened again stock prices were exposed to substantial turbulences. Airline and tourist industry stock prices fell rapidly. Stock markets in Europe were more vulnerable to US stock market shocks even months after the tragedy (see Carter and Simkins, 2002; Hon, Strauss and Yong, 2004).

However, foreign exchange markets were not closed down, not even in the midst of the attacks. It is well known that these markets do react highly sensitively to events attributed to political factors whereas war and coup (attempts) are the most significant ones (see Lobo, 2002). Thus, the question arises what happened on the USD/EUR foreign exchange market at that time. Did 09/11 have any influence on the exchange rate or other determinants of foreign exchange trading, such as the volatility, trading volumes and bid-ask spreads? Did the market suffer a liquidity squeeze or not? The general notion is that foreign exchange markets quickly absorbed the shock due to the immediate response of central bank authorities by providing liquidity (Lacker, 2004), and due to their decentralized structure itself (Bishop, 2002). However, empirical evidence in support of this view has not yet been provided.

This paper gives an answer to the question as we are looking at the relationship between trading volume and volatility. This relationship provides insights into the structure of foreign exchange markets. The issue is important because of its implications for the analysis of market liquidity. The empirical microstructure literature has typically found a positive correlation between volumes and volatility in financial markets (Karpoff, 1987). But especially in times of stress this relation can change dramatically, indicating high or low market liquidity respectively (Sarr and Lybek, 2002; Galati, 2003).

In particular, we study the relationship between foreign exchange trading activities and realized exchange rate volatility on the USD/EUR foreign exchange market on the basis of a unique joint data set, consisting of actual transaction data of a small bank in Germany and market-wide quoted data. We focus on the volume-volatility-relation because it depends not only on the market-size and its degree of liquidity, but also on the rate of information flow to the market (Karpoff, 1987). Knowledge of this relationship can be used to measure changes of the price process due to a sudden event. To our knowledge there is no other study existent which examines 09/11 on the basis of both market-wide data and tick-by-tick trading data, and thus, analyzing real trading behavior and quoting activity at the same time.

We find that volatility and quoted spreads are by far larger during 09/11 than before. The shock is not persistent though and the impact on volatility and spreads vanishes after approximately one day. As expected, we find a positive correlation between trading activity and volatility. This relationship does not break up during the events, as a Chow Breakpoint Test confirms. Quite the contrary, the relation intensifies strongly during the events of 09/11, indicating the arrival of new information, uncertainty and increased price risk. The foreign exchange market maintains its liquid structure and its efficient processing of exogenous shocks. We conclude that the USD/EUR foreign exchange market is a very liquid market due to the huge number of market participants. Furthermore, its decentralized structure can be considered as a guarantor of market efficiency with regards to exogenous shocks.

The remainder proceeds as follows. In Section 2 we introduce the common theoretical background. Section 3 first introduces the joint data set we use. We then present the results of our estimations, both on a daily basis and a 10-minute interval basis, after. Section 4 concludes.

2 Trading volume and volatility in the literature

There is vast amount of literature examining the relationship between volume and volatility in financial markets with regard to measuring liquidity. Whilst Karpoff (1987) provides a detailed overview of earlier work, Hasbrouck and Seppi (2001), and Sarr and Lybek (2002) summarize and evaluate different liquidity measures for different financial markets up to date. Lyons (2001), Sarno and Taylor (2001) review such work on foreign exchange markets. The overall finding is a positive correlation between different measures of trading volume and price volatility, which holds for different data frequencies (see for example Harris, 1986; Bollerslev and Melvin, 1994; Jorion, 1996; Park, Switzer and Bedrossian, 1999; Chordia, Roll and Subrahmanyam, 2001; Bjønnes, Rime and Solheim, 2002; Galati, 2003).

In economic theory there are different explanations for the co-movement of trading volume and volatility of which we favor the so-called "mixture of distributions hypothesis" (MDH) which was first proposed by Clark (1973). The MDH states that volume and volatility are both driven by the same, unobservable factor: the arrival of public information. However, this factor has two opposite effects (see Tauchen and Pitts, 1983). First, as the number of traders grows prices become less volatile. Second, an increase in volume reflects greater disagreement among a given number of traders about new information and hence leads to higher volatility. In a liquid market the second link should outweigh the first, as the number of traders is already big enough to provide immediacy, i.e. a high speed of order execution, and depth, i.e. order abundance. Thus, volume and volatility are positively correlated. However, at times when market liquidity is low, this second link breaks down. Small volumes are then connected to high volatility, because now single orders have a relatively large impact on the price.

The above mentioned relationship has been confirmed by numerous empirical studies for many financial markets, using all kinds of volatility and trading volume measures. However, most of the trading in foreign exchange markets is conducted over the counter. Therefore, comprehensive high-frequency data on actual trading volumes are generally not available to researchers. Thus, alternative measures for trading volume have to be pulled up.

Studies using easier to obtain data on future contracts also find a positive correlation between volume and volatility (see Jorion, 1996; Wang and Yau, 2000). However, because trading volume in foreign exchange future markets is comparatively small, such studies may not reflect the behavior of total foreign exchange market activity. Other studies rely on indicative quotes by Reuters or other providers instead (see Goodhart and Figliuoli, 1991; Bollerslev and Domowitz, 1993; Goodhart, Ito and Payne, 1996; Melvin and Yin, 2000). They usually find a positive relation between quoting activity – used as a proxy for trading activity – and volatility. Nevertheless, quotes do not represent actual trades. So the revealed relationship might be misrepresented. Studies by Wei (1994) and Hartmann (1999) focus on YEN/USD transaction data provided by the Bank of Japan. Unfortunately, they represent not more than 5% of the global market.

A big step forward was made by looking at high-frequency data on actual transactions in the spirit of the new microstructure approach to exchange rates (Lyons, 2001). Data sets as used in Lyons (1995), Yao (1998), Bjønnes and Rime (2004) and Mende, Menkhoff and Osler (2004) cover all transactions of individual foreign exchange dealers and provide useful insights in the displayed behavior of market participants. Unfortunately, they typically map only a very limited segment of the market and mostly cover a short time period.

Two exceptions are noteworthy. Galati (2003) collects broader data for several emerging market countries. He records actual trading volume, fairly covering the total trading activity in those foreign exchange markets. He receives mixed results for different countries, though he is generally able to confirm the MDH. He finds indications that the degree of liquidity can be measured by the relation between volume and volatility. This degree differs for periods "under stress", i.e. the positive relation between trading volume and volatility breaks down during turbulent times in some emerging markets. Bjønnes, Rime and Solheim (2002) study the SEK/DEM foreign exchange market. Their data set covers a remarkable 95% of the market revealing a positive correlation of volume and volatility. These results suggest a high level of liquidity in foreign exchange markets of developed countries.

3 Empirical results

3.1 Data description

The data set in this study is compiled by two different data sets, i.e. quoted FX spot data and actual transaction data of a single dealing bank respectively. Whereas the high frequency data provided by Olsen Financial Technologies is publicly available (for a small fee), the bank's transaction data is of private property and only available to the author. By combining these two data sets we are able to connect actual trades to market-wide foreign exchange prices and hence measure real trading activity and market developments applied to one of the main foreign exchange markets at the same time.

The transaction data set consists of the complete USD/EUR trading record of a small bank in Germany. The record covers 87 trading days, beginning on Wednesday, 07/11/2001, and ending on Friday, 11/09/2001. The data overlap 09/11 roughly symmetrically. The record contains all trades conducted at the bank's foreign exchange department, including indirect trades executed by voice-brokers or electronic brokerage systems, direct trades completed by telephone or electronically, internal trades and customer trades. All trades were entered manually into the "deals blotter" by the backoffice without differentiating between the several trading channels of each transaction.[1] The variables we generate are the daily exchange rate and the daily number of trades.[2]

Whereas this part of the data set covers actual transactions of a single market participant, the other part of the data set consists of market-wide – yet quoted – foreign exchange data. Olsen's FX spot data records all best bid and ask USD/EUR quotes as well as the number of quotes every minute, 24 hours a day, from the beginning of July until the end of November 2001. We have adjusted this massive data set in order to match our own individual trading data. Therefore, we set the time period from July 11 to November 9 and only use the minute-by-minute quote data from 8:00 to 18:00 (MET) as our bank has not carried out any transaction before or after. We thus get 600 observations per day. We also obtain the quoted exchange rate, i.e. the midpoint of best bid and best ask quote, the narrowest quoted spread, i.e. the gap between best bid and best ask quote, and the number of quotes.

To measure the intraday and daily volatility of the exchange rate we decided to use the realized volatility, i.e. sum of squared exchange rate returns. Many papers have documented the excellent performance of the realized volatility as a volatility measure and it has become common use – especially in high-frequency data analyses (see for example Frankel and Wei, 1991; Jorion, 1996; Poon, Blair and Taylor, 2001; Andersen, Bollerslev and Diebold, 2003; Andersen, Bollerslev and Meddahi, 2003; Galati, 2003; Koopman, Jungbacken and Hol, 2004). In our case it also provides the best empirical results compared to other measures of volatility.

To establish a link between market-wide foreign exchange activity around 09/11 events and the actual trading activity of our particular market participant during that time, we merge both data sets on a daily basis and on a basis of a time-interval of ten minutes. The latter part of the merged data set only covers the days September 10, 11 and 12 2001. Daily trading volume is measured by the number of trades conducted at the small bank's foreign exchange department. Thus, this variable actually captures real trading activity. Intraday trading activity is approximated by the number of quotes because there are too few and unsteady trades at the small bank within the ten minute intervals. Table 1 presents descriptive statistics on the daily variables. Maximum values

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[1] For a detailed description of this part of the data set, please refer to Mende, Menkhoff and Osler (2004). Some cases are deleted from the data due to extreme price changes of more than 100 basis points or tiny volumes of less than 1,000 USD, as both characteristics may blur the relationships of interest.

[2] Each day we average out the overall bid and ask rate, i.e. amount of USD sold (bought) divided by amount of EUR bought (sold). We chose the midpoint as the daily exchange rate.

of spreads and volatility are always realized on 09/11 while the other variables do not reach a peak on that very day.

3.2 Impact and persistence of 09/11 on foreign exchange trading determinants

Figure 1 and 2 depict the USD/EUR exchange rate, the realized volatility, the bid-ask spread and the number of trades, number of quotes respectively during the observation period. Figure 1 shows daily foreign exchange variables. The vertical grey line represents 09/11/2001. Panel A shows the movements of quoted exchange rates, i.e. the midpoints of best bid and ask quotes every minute averaged out each day, and the movement of calculated foreign exchange prices, i.e. midpoints of daily volume-weighted prices of the foreign exchange trading at the small bank. Obviously calculated prices and quoted exchange rates are virtually identical. Thus, the bank's foreign exchange trading is in tune with worldwide market developments. One can see that there were no substantial changes in the exchange rate. Figures 1B and C show the realized exchange rate volatility and the quoted bid-ask spread. These values stand out. Volatility and spreads are by far larger on September 11 than before or after.[3] E.g., whereas the daily USD/EUR bid-ask spread normally fluctuates between two and three pips[4] it amounts up to nearly 5 pips on September 11, which is huge in foreign exchange. In Panel D we have plotted the daily number of trades transacted at our bank. Although there is a peak on 09/11 it is by far not the highest.

Figure 2 shows the foreign exchange variables on a basis of 10-minute intervals. It closely tracks what actually happened on the USD/EUR market on 09/11. The first news about a plane-crash into the World Trade Center was received in Central Europe at 14:40 (MET). Our bank usually ended its business day before 18:00 (MET). We have highlighted this period in the graphs, i.e. 14:40 to 18:00 (MET) on September 11. Figure 2A shows that there was a sharp depreciation of the USD, though the exchange rate returned back to its normal level during the morning of the following day. In Figures 2B and 2C you can see that the realized exchange rate volatility and the spreads increase erratically in the afternoon of September 11. The total spread size roughly triples due to the events of 09/11. However, the curves calm down the very next day. Number of quotes increases rapidly, too (Figure 2D), but not beyond reason.

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[3] Simple t-tests show that volatility and spreads after the event are not generally different from those before (not reported here).

[4] A pip is the smallest unit in an exchange-rate quote. For USD/EUR it equals USD 0.0001.

Now we turn to the analysis of the relationship between volume and volatility for our joint data set on a daily basis. Therefore, we first regress realized volatility on a constant and on the number of trades in Logs for the whole sample period. The results are reported in Table 2. The coefficient on number of trades is positive and statistically significant. Thus, number of trades seems to be an appropriate proxy for measuring overall trading activity. The positive correlation between trading activity and volatility is in line with the literature. What effect did 09/11 have? In Table 2 we also test if the above relationship is disturbed at that time. Therefore, we generate a dummy-variable which takes a value equal to one on September 11 to September 14 and zero otherwise. We assume that effects of 09/11 could not have lasted longer than until September 17 as the financial business went back to normal on that Monday, when all the US financial markets reopened. Figure 1 and 2 further support this assumption.[5] Table 2 not only shows that the positive correlation between trading activity and volatility holds, but also that it actually intensifies. The strong significant positive coefficient of number of trades is almost doubled, the adjusted R^2 increases by more than 200 percent. This sharply contrasts with the mixed results of Galati (2003, Table 8, page 21). In his study this relationship breaks down in times of stress for some emerging market countries, indicating a lack of liquidity. Apparently, this is not the case here.

To further check whether there was a substantial change in the above relationship, we carry out a Chow (1960) Breakpoint Test on the volume-volatility-relation. The Chow Test is commonly used to test for structural breaks in the parameters of a model in cases where the disturbance term is assumed to be the same in both periods. Table 3 shows that we cannot reject the null hypothesis that the first 44 observations have the same linear structure as the last 42 observations. Thus, 09/11 did not have a permanent effect. There is no structural break in the data. The market proved to be very liquid given the assumed relations.

To test whether the volume-volatility-relation breaks down intraday, we carry out regressions similar to the ones in Table 2. Table 4 reports the results. As described in section 3.1 we now refer to number of quotes instead of number of trades. The results in Table 4 show that the positive correlations between volume and volatility does in fact boost during the attacks on September 11. The increasing influence of trading activity

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[5] In fact, Figures 1 and 2 suggest that the effect of 09/11 did not last longer than a day. However, this would make the analysis on a daily basis impossible and, thus, we accept the possible drawbacks from incorporating the morning of September 11 and other "calm" periods in our dummy-variable.

on volatility indicates the arrival of new information and the enormous rise in exchange rate risk due to general uncertainty. No doubt it was a hectic afternoon on the USD/EUR foreign exchange trading floors worldwide.[6] The uncertainty, however, did not last very long and the market pretty much returned to everyday life after only half a day.

How long did the USD/EUR foreign exchange market actually deal with the issue? To check the persistence of the events we carry out VAR analyses for the volatility and the spread on a daily basis (see Figure 3). Effects of 09/11 on the volatility and spreads vanish quickly after September 11. The impact becomes statistically insignificant after roughly one day for the volatility, two days for the spread respectively.[7] Ordinary least squares regressions using day-dummies confirm these results (not reported here). Summing up, the foreign USD/EUR exchange market functioned well. It easily digested the increased price risk after the tragedy.

4 Conclusion

This study of the relationship between foreign exchange trading activity and exchange rate volatility on the USD/EUR foreign exchange market around 09/11 was conducted on the basis of a unique data set, consisting of actual trading data of a small bank in Germany and market-wide quoted data. To our knowledge there is no other study which examines this relationship around September 11. We find that the general connection between trading volume and volatility does not break down due to the attacks. Whether we look at the daily data or at the intraday data does not make a difference. The positive correlation between number of trades, number of ticks respectively, and realized volatility becomes even stronger during the time of stress. Although some variables, such as volatility and spreads, multiply in the course of the events, there is no structural break in the data. The shock merely persists for up to two days.

We conclude that foreign exchange markets for key currencies, such as USD/EUR, can be considered as very liquid ones – unlike emerging markets' foreign exchange markets (see Galati, 2003). This is simply due to the huge number of market participants and due to the sheer size of their daily turnovers. Certainly, it can also be partially explained by the stable financial sectors in developed countries (Chen and

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[6] Bankers told us that they were actually still executing foreign exchange deals with their colleagues in the WTC, even after the first plane had crashed into one tower.

[7] We used the lagged volatility and spreads in order to be able to carry out an analysis of current variables as VAR analyses use only lagged terms.

Siems, 2004). Primarily, the decentralized build-up of these markets assures sufficient liquidity and the efficient processing of exogenous shocks.

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Table 1 Descriptive statistics

Table shows descriptive statistics of daily USD/EUR foreign exchange trading determinants of a small bank in Germany, i.e. numbers of trades and trading volumes, and the corresponding quoted Olsen data set, i.e. spread, realized volatility and number of quotes, respectively, over the 87 trading days between July 11 and November 9 2001.

USD/EUR	Spread (pips)	Realized volatility	Number of quotes	Number of trades	Trading volume (EUR millions)
Mean	2.40	0.3230	16,504	41	42.679
Median	2.34	0.2800	14,216	39	33.789
Maximum	4.62	1.8000	35,290	129	212.224
Minimum	1.73	0.1540	8,947	13	6.724
09/11	4.62	1.8000	31,694	63	118.888
Std. Dev.	0.46	0.1970	6,558	17.43	33.440
Observa-tions	87	87	87	87	87

Table 2 Volatility and number of trades

The dependent variable is realized exchange rate volatility each day. Number of trades is the overall number of foreign exchange deals transacted at a small bank in Germany each day. The second estimation uses a dummy-variable, which takes the value one for September 11 to 14, zero otherwise. Realized exchange rate volatility is calculated by summing up squared exchange rate returns every minute for a whole day using the Olsen data set. Estimation uses ordinary least squares with a Newey-West HAC standard errors and covariance controlling for heteroscedasticity. T-values are reported in the 3rd and 5th columns, and "***", "**" and "*" indicate significance at the 1%, 5% and 10%-level respectively.

Dependent Variable: Realized exchange rate volatility				
Variable	Coefficient	t-Statistic	Coefficient	t-Statistic
Constant	-0.394	-1.33	-0.324	-1.53
Log of number of trades, September 11 – 14			***0.315	3.18
Log of number of trades	**0.198	2.23	***0.172	2.89
AR(1)	***0.260	5.66	*0.164	1.76
Adjusted R^2		0.16		0.40
Observations		86		86

Table 3 Chow Breakpoint Tests for the volatility-volume relation

Chow (1960) Breakpoint Test tests for structural breaks in the parameters of the regression of number of trades on realized volatility. It is assumed that the disturbance term is the same in both periods. The F-statistic shows that we cannot reject the null hypothesis that the first 44 observations have the same linear structure as the last 42 observations.

Dependent Variable: Realized exchange rate volatility		
Variable	Coefficient	t-Statistic
Constant	-0.301	-1.54
Log of number of trades	***0.172	2.85
Adjusted R^2	0.11	
Observations	87	

Chow Breakpoint Test: September 11			
F-statistic	1.94	Probability	0.15

Table 4 Realized exchange rate volatility and number of quotes

Variables are summed up every ten minutes. Estimation uses a dummy-variable, which takes the value one for September 11 between 14:40 and 18:00 (MET), zero otherwise. The dependent variable is realized volatility. Number of quotes is the overall number of quotes every ten minutes taken from the Olsen data set. Estimation uses ordinary least squares with a Newey-West HAC standard errors and covariance controlling for heteroscedasticity. T-values are reported in the 3rd column, and "***", "**" and "*" indicate significance at the 1%, 5% and 10%-level respectively.

Dependent Variable: Realized exchange rate volatility				
Variable	Coefficient	t-Statistic	Coefficient	t-Statistic
Constant	**-0.168	-2.10	*-0.043	-1.73
Log of number of quotes	**0.030	2.21	**0.008	1.98
Log of number of quotes during the events of 09/11			***0.019	4.29
AR(1)	***0.335	2.80	***-0.233	-3.05
Adjusted R^2		0.20		0.55
Observations		179		179

Figure 1 09/11 and daily USD/EUR foreign exchange trading determinants

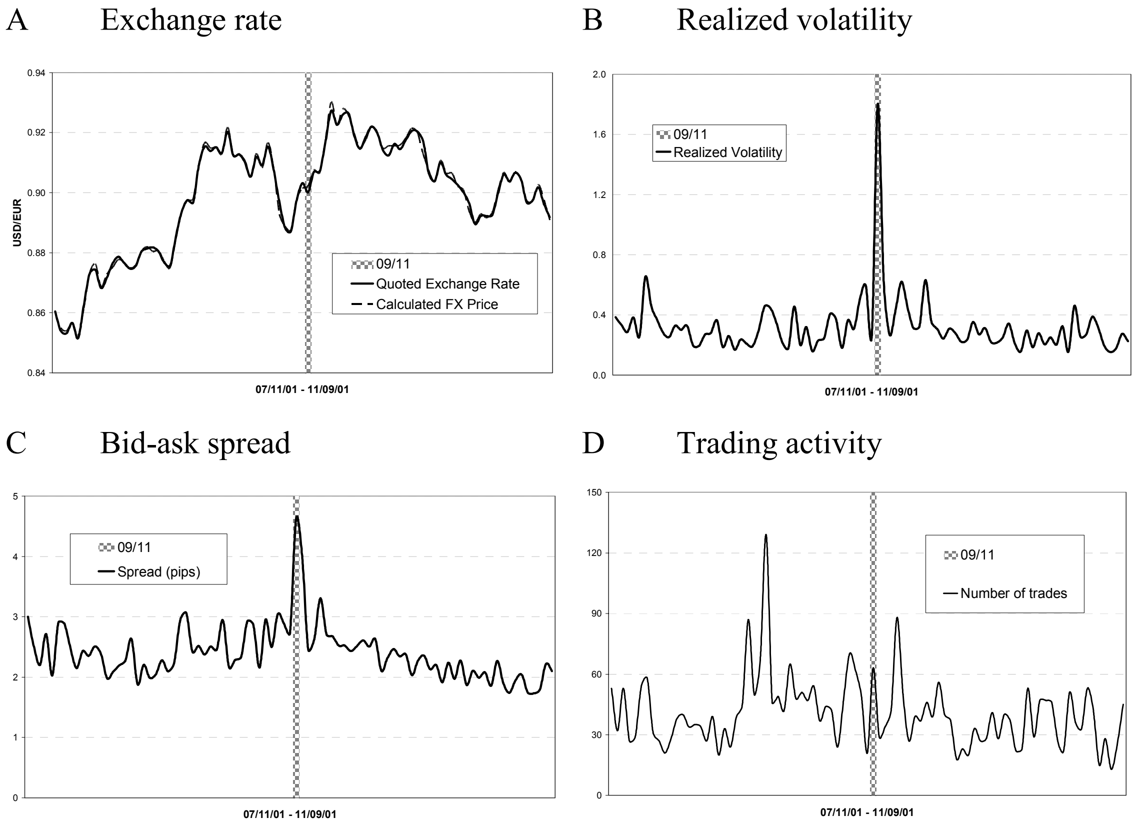
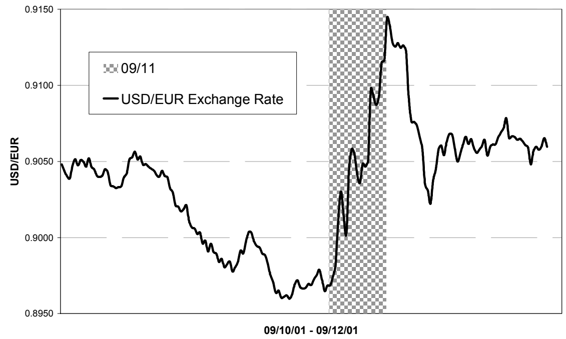


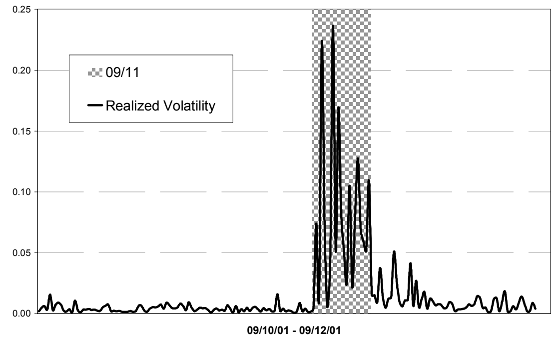
Figure shows daily USD/EUR foreign exchange trading determinants taken from the Olsen data set and from the small bank's trading record over the whole sample period (07/11/01 – 11/09/01). 09/11 is marked with the grey vertical line.

Figure 2 09/11 and foreign exchange trading determinants, September 10 – 12

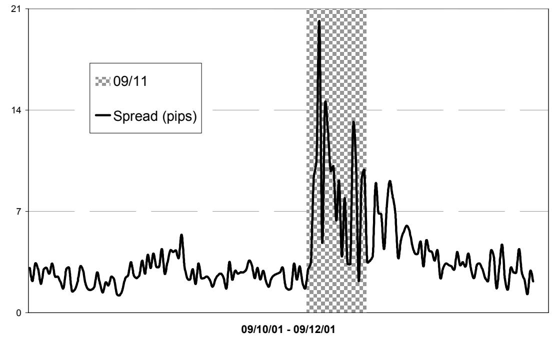
A Exchange rate



B Realized volatility



C Bid-ask spread



D Number of quotes

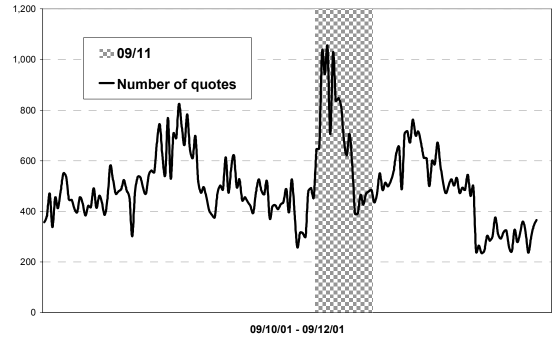
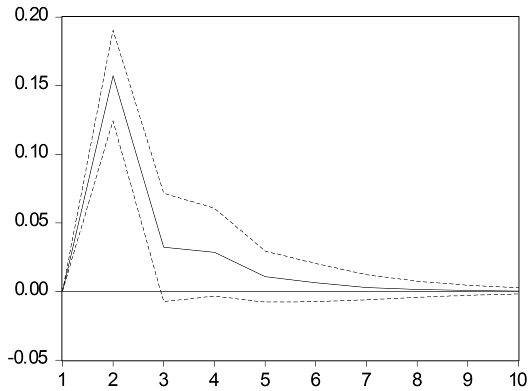


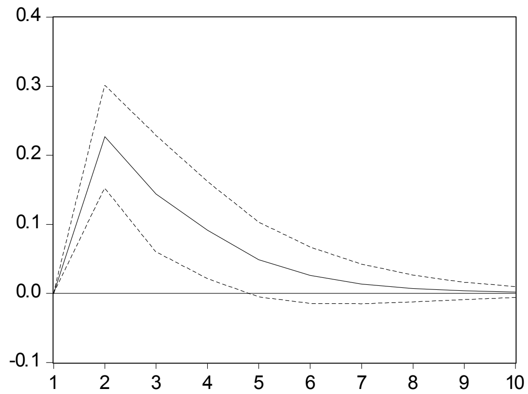
Figure shows USD/EUR foreign exchange trading determinants taken from the Olsen data set from September 10 to September 12 2001 on a basis of ten minutes intervals. September 11 2001, 14:40 – 18:00 (MET) is marked grey.

Figure 3 Persistence of the 09/11 shock by means of VAR impulse responses

A Realized volatility



B Bid-ask spread



Plot shows simultaneous VAR impulse responses of realized volatility and spread for USD/EUR to 09/11, i.e. a dummy-variable which takes the value one on September 11, zero otherwise, on a daily basis.