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Abstract

The absence of data has, until now, precluded virtually all research on trading volume in the foreign exchange market. This paper introduces a new high-frequency foreign exchange dataset from EBS (Electronic Broking Service) that includes trading volume in the global interdealer spot market. The dataset gives volumes and prices at the one-minute frequency over a five-year time period in the euro-dollar and dollar-yen currency pairs. We first document intraday volume patterns in euro-dollar and dollar-yen trading, noting the effects of macroeconomic news announcements but also purely institutional factors. We study the effects of UK-specific holidays on euro-dollar and dollar-yen trading volume and find that these holidays cause a sharp decline in trading volume even among dealers outside the UK, a natural experiment that we interpret as further evidence that trading activity is not driven solely by the flow of news about fundamentals. Studying the reaction to U.S. macroeconomic announcements, we show that a sharp pickup in trading volume generally occurs in the minutes following news announcements. This rise in trading volume happens even if the data release is entirely in line with market expectations, and it is often negatively related to the dispersion of *ex-ante* market expectations. Finally, focusing on one particular data release at the one-second frequency, we document a two-stage reaction whereby the price jumps immediately after the announcement without much trading volume, while trading volume and volatility then surge about 15 seconds after the data release.

Keywords: Trading Volume, Foreign Exchange, High-Frequency Data, News Announcements.
JEL Classification: F31, G14.

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1. Introduction.

There has been a great deal of empirical work on trading volume in the bond and equity markets, including description of intradaily patterns in trading volume (e.g. Jain and Joh (1988)), examining the relationship between volume and volatility (e.g. Tauchen and Pitts (1983)), and the analysis of the impact of news announcements on trading volume. In theory, the impact of public news announcements on trading volume is ambiguous. On the one hand, if a public data release affects the fundamental value of an asset in a way that everyone agrees on, then the price of that asset should jump to its new level without requiring any trading activity (French and Roll (1986)). On the other hand, if traders disagree about the impact of a given piece of news, then there could be a surge in trading following the news announcement, and it may well be that the effects of the data release are capitalized into prices only via this trading. Focusing on the Treasury market, Fleming and Remolona (1999) study the high-frequency effects of news announcements on the conditional mean and variance of returns and on trading volume. They find that news releases have a two-stage effect on the Treasury market. First, trading activity is subdued, and prices move very sharply. This movement is effectively a jump. Then volatility and trading volume pick up, and remain elevated for several hours.

In the foreign exchange market, which is over-the-counter and geographically dispersed, the absence of data on market-wide trading volume has precluded almost all such research on trading volume. Some researchers have attempted to proxy for actual transaction volume data by using futures exchange volume data (e.g. Chaboud and LeBaron (2001)), or the frequency of indicative quotes on Reuters data screens (e.g. Melvin and Yin (2000)), but these measures have clearly been very imperfect substitutes. Futures trading represents only a very small fraction of the overall activity in foreign exchange markets and the frequency of indicative quotes has been

shown to be only loosely related to actual trading volume, particularly at high frequency (Goodhart, Ito and Payne (1996), Evans (1998), Danielsson and Payne (2002)).

In this paper, we introduce a new high-frequency foreign exchange dataset from EBS (Electronic Broking System) that includes trading volume in the global interdealer spot market over several years, data not previously available to researchers. The dataset gives trading volume and prices at the one-minute frequency in the euro-dollar and dollar-yen currency pairs from January 1999 to February 2004. EBS has, in the last few years, become the *de facto* global marketplace for interdealer trading in foreign exchange in the euro-dollar and dollar-yen currency pairs. As a result, the data used in this paper represent the vast majority of global spot interdealer trading in the two most-traded currency pairs over the sample period.

We preview our key findings. First, we document the precise pattern of intradaily trading volume in the global foreign exchange market, and find that there are sharp spikes in volume at the times of scheduled macroeconomic data releases, as expected, but also at other specific times of the day, where trading volume tends to be elevated for purely institutional reasons such as spot foreign exchange fixings and the standard expiration times of foreign exchange options. Second, we study the effects of UK specific holidays (days when UK financial markets are closed but other important global financial centers are open) on trading activity in the euro-dollar and dollar-yen currency pairs. We find it reasonable to assume that UK specific holidays (such as the Queen's Jubilee) are events that should have no relationship with the flow of fundamental information affecting the relative values of the U.S. dollar, euro and Japanese yen. However, we find that trading volume is indeed greatly reduced on these days, including, importantly, among dealers in America and Asia. We interpret this as additional evidence that trading volume is driven not only by the flow of information about fundamentals (whether private or public), but

is also strongly affected by the trading process and the trading infrastructure in place. We focus next on the high-frequency reaction of foreign exchange trading volume to scheduled U.S. macroeconomic announcements. We first study the relationship between the extra trading volume following an announcement and the surprise component of the data release. We find that there is only a weak relationship. In sharp contrast to the reaction of the level and volatility of the exchange rate (found in Andersen, Bollerslev, Diebold and Vega (2003) (ABDV) and that can also be seen in our data), most of the extra trading volume occurs even if the data release is right in line with expectations. We then examine the impact of the dispersion of *ex-ante* market expectations of these data releases on trading volume in the wake of news announcements. Perhaps surprisingly, we find, in most cases, a negative relationship. Finally, we take a brief look in even more detail (at the second-by-second frequency) at the reaction of the euro-dollar market to one U.S. nonfarm payrolls announcement. We find that the initial price jump, in the first few seconds after the data release, is accompanied by relatively little additional trading volume. Trading volume and volatility then pick up sharply, but only after the initial jump has occurred.

The plan for the remainder of this paper is as follows. In section 2, we briefly describe the EBS system and introduce the data. In section 3, we describe the intraday patterns in global foreign exchange trading volume. Section 4 studies the effects of UK specific holidays on trading volume. Section 5 contains the analysis of the high-frequency effects of data releases on exchange rate trading volume. Section 6 focuses, at ultra-high frequency, on the trading volume reaction to one non-farm payroll announcement. Section 7 concludes. Throughout, this paper studies trading volume and not order flow, which is the focus of Berger et al. (2007).

2. The EBS System and the Data

Since their introduction in the foreign exchange market in the early 1990s, electronic broking systems—electronic limit order books that automatically match buyers and sellers—have gradually become the main avenue for trading between dealers in the major currency pairs. These systems have largely displaced voice brokers, who used to perform the same matching function, and direct dealing between traders, conducted either on the telephone or by electronic means (Chaboud and Weinberg, 2002).

Today, two electronic broking systems are used globally for interdealer spot trading, one offered by EBS, and one offered by Reuters. Importantly, over time, trading in each major currency pair has become very highly concentrated on only one of the two systems. Of the most-traded currency pairs, the top two (euro-dollar and dollar-yen) are traded primarily on EBS, while the third (sterling-dollar) is traded primarily on Reuters. The process of price discovery for each of these currency pairs now occurs within the computers of the respective electronic brokers -- the modern Walrasian auctioneers. As a result, the reference price at any moment for, say, spot interdealer euro-dollar is the current price on the EBS screen, and all dealers base the prices they quote to their customers on the EBS price.

The data used in this paper consists of total trading volume per minute on EBS for the dollar-yen and euro-dollar currency pairs from January 1999 to February 2004, denominated in the base currency. The data do not contain any information on the identity or characteristics of any market participants. To preserve data confidentiality, we show trading volume data in index form rather than as actual amounts of base currency. [1] The euro-dollar volume index is

[1] EBS does not publish precise trading volume data per currency pair. As an indication of the order of magnitude of trading on EBS, in 2003 the average daily trading volume for the euro-dollar currency pair was in the range of $50 billion to $70 billion. The average daily trading volume for the dollar-yen currency pair was in the range of 20

normalized such that the average amount traded per minute in that currency pair over the whole sample is set at 100. Likewise, the dollar-yen volume index sets the average per-minute trading volume in dollar-yen to 100. This indexation leads to no loss of information about high-frequency patterns in trading volume. The dataset also includes price data (transactable quotes) allowing us to study intraday patterns in conditional mean and variance. These results are however very similar to those found by Andersen, Bollerslev, Diebold and Vega (2003) using a different dataset of indicative quotes, and are thus not the focus of this paper. Dealers in the EBS system are classified as being based in one of three regions: Europe, the Americas, and Asia.[2] Our dataset also parses trading volume into the volume transacted in each minute among dealers within and across each of these three regions for a total of six possible permutations: Europe-Europe, Europe-America, etc.[3]

We exclude data collected from Friday 17:00 through Sunday 17:00 New York time from our sample, as activity on the system during these "non-standard" hours is minimal and not encouraged by the foreign exchange community. We also drop certain holidays and days of unusually light volume: December 24-December 26, December 31-January 2, Good Friday, Easter Monday, Memorial Day, Labor Day, Thanksgiving and the following day, and July 4 (or, if this is on a weekend, the day on which the Independence Day holiday is observed).

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billion to $30 billion. As a comparison, the average total daily trading volume on the New York Stock Exchange in 2003 was just under $40 billion.

[2] These correspond to regional EBS computing centers in London, New York, and Tokyo, respectively.

[3] The size of individual deals on EBS is, almost always, between 1 and 10 million of the base currency, and it varies little over time. As a result, there is a very high correlation between the trading volume per unit of time and the numbers of deals per unit of time in the data.

3. Intraday Trading Volume Profile

Figure 1 plots trading volume in each minute of the day in the euro-dollar and dollar-yen currency pairs, averaged across all the days in our sample when U.S. daylight savings time is in effect (the summer). The bounds of 95% confidence intervals are also shown on the graphs. Note that all times throughout this paper are New York time.[4]

We observe that trading volume in euro-dollar and dollar-yen is particularly high between about 8am and noon New York time, as these are business hours in both Europe and North America. There is relatively high trading volume in dollar-yen during the night in New York, clearly due to trading activity in Asian markets. For both currency pairs, average one-minute volume spikes at or just after 8:30am, 10am and 11am. The 8:30am spike is caused by news announcements as most important U.S. macroeconomic data releases come out at this time. The 10am spike is likely related to the convention that this is the expiration time for most foreign currency options,[5] while the 11am spike is likely related to the WM/Reuters spot foreign exchange fixing at 4pm London time (WM Company (2004)). There are also smaller spikes in volume at or just after 8:20am and 3pm. These times are the start and close of regular trading hours in currency futures and options on the Chicago Mercantile Exchange (7:20am and 2:00pm Central Time). For dollar-yen only, the largest volume spike of the trading day comes in the New York evening, just ahead of the morning's foreign exchange fixing in Tokyo, widely known

[4] The pattern of trading is essentially the same in the other half of the year. Japan does not observe daylight savings time. Therefore, a display in New York time of global trading volume per minute averaged over the whole year would show, for instance, two peaks at the time of a given data announcement in Japan, where only one truly exists in Tokyo time. Or a full-year display in GMT or Tokyo time would show two peaks reflecting one U.S. macro announcement. Our choice of U.S. daylight savings time in the graph also circumvents issues caused by the difference between U.S. and European time zones for one week in the spring of each year.

[5] Note that some U.S. macroeconomic announcements do come out at 10am: consumer confidence, factory orders, the ISM index, and new and existing home sales. However, we computed the average daily one-minute volume dropping days of any of these releases and found that this lowers the trading volume around 10am by about one tenth -- there is still a substantial spike in trading volume at this time.

as the Bank of Tokyo Mitsubishi fixing, which is taken at 9:55am Tokyo time (8:55pm New York time in the summer).[6]

Many authors have looked at the correlation between trading volume and proxies for the flow of public information "news" (such as the frequency of Dow Jones or Reuters news stories). Berry and Howe (1994) and Mitchell and Mulherin (1994) find a moderately strong positive correlation between equity trading volume and the rate of flow of public information. Likewise, Melvin and Yin (2000) find a positive correlation between the frequency of indicative foreign exchange quotes and the rate of flow of public information. The volume spikes in Figure 1 shed some light on the question of the high-frequency correlation between foreign exchange trading volume and the arrival of news. On the one hand, the spikes in trading volume at the times of macroeconomic announcements indicate that there is some contemporaneous association between foreign exchange trading volume and economic news. On the other hand, the spikes in trading volume at other times are unlikely to be contemporaneously associated with any economic news, as there is no surge of public information at these times. Instead, these spikes in trading volume appear to reflect almost exclusively institutional features of the foreign exchange market.

4. UK Specific Holidays

London is the largest center of global foreign exchange trading.[7] As a very simple way to shed some light on the determinants of trading volume, we examine days when the London

[6] In contrast, at 8:50am Tokyo time (either 6:50pm or 7:50pm in New York), the time at which a number of major Japanese economic data are released (including GDP, industrial production, the Tankan survey and the trade balance), we see only a very small spike in trading volume.

[7] According to the BIS's 2004 Triennial Survey, the United Kingdom accounts for 31.3% of global foreign exchange trading volume, followed by the United States with 19.2% and Japan with 8.3%.

market is shut down but the flow of fundamental information about the relative values of the U.S. dollar, the euro and the Japanese yen is unaffected. To do so, we identify days on which there is a holiday that is purely UK-specific. In our sample, there are eight such days: the summer bank holiday in each year from 1999 to 2003, the holidays for the Queen's Jubilee on June 3 and 4, 2003 and the May Day holiday observed on May 7, 2001.[8] These were all regular business days in the U.S., Germany and Japan.

We calculated trading volume in each currency pair, both in aggregate and broken down by the six possible permutations of the location of the traders (remember that all traders are classified as being in Europe, the Americas, or Asia). We next indexed each of these 14 series so that the average daily value of each is 100. Finally, we estimated an AR(3) for each of these series, augmented with a dummy variable that is equal to 1 on days of UK-specific holidays. The coefficient estimates can be interpreted as the average percentage decline in trading volume relative to an AR(3) on days of UK-specific holidays. Note that inclusion of the autoregressive lags controls for the fact that these holidays occurred during periods of potentially light summer trading. The results are shown in Table 1. Global trading volume is clearly depressed on days of UK-specific holidays, and the magnitude of the reduction is very large: about 50 percent in euro-dollar and 40 percent in dollar-yen, which are both highly significant even though the number of UK-specific holidays is small. One might suppose that the fact that London dealers are on vacation might cause dealers elsewhere to "pick up the slack." However, the converse is true: not only does trading volume among European dealers (including UK dealers) decline fall by 2/3

[8] The last Friday in each August is a bank holiday in England and Wales. It is simply referred to as the summer bank holiday and has no religious significance and has no counterpart in other countries. The May Day holiday is observed in England and Wales on the first Monday each May. Germany observes a May Day holiday, but is in on the first day of May not the first Monday of May. Japan has public holidays around this time as well so it turned out that 1999 was the only year in our sample where the May Day holiday in the UK was not a holiday in the other countries. We obtained dates of bank holidays from the settlement calendar on Bloomberg.

or more, but trading volumes among dealers based in America and Asia drop substantially as well, although, with only 8 UK-specific holidays, the declines are mostly not statistically significant. Removing the pool of liquidity in London appears to cause euro-dollar and dollar-yen trading volume to dry up globally, even though the flow of fundamental news (whether private or public) in the eurozone, Japan and the United States is unaffected.

5. Effects of U.S. Macroeconomic Data Releases on Trading Volume

As was seen in Figure 1, U.S. macroeconomic data releases at 8:30am are clearly accompanied by large spikes in trading volume. In fact, relative to days without data releases, the announcement-day spikes are actually even more pronounced than those shown in Figure 1, as the figure shows data averaged across all days, not just days with macroeconomic announcements.

We now focus on patterns in trading volume on the days of six different types of U.S. macroeconomic data releases: GDP (the advance release), the producer price index, nonfarm payrolls, the trade balance, retail sales and the Federal Reserve's announcement about the target Fed Funds rate on the day of an FOMC meeting. All of these releases come out precisely at 8:30am (New York time) except for the Fed Funds rate announcement which comes out at around 2:15pm.[9]

All of these data releases are monthly except for GDP (quarterly) and the Fed Funds rate (eight times a year). The units and source of each of these releases are listed in Table 2.

[9] The timing of the release of the FOMC announcement is not as precise, and it can be a few minutes early or late. We use as the FOMC announcement time the timestamp of the first Dow Jones newswire story describing the outcome of each FOMC meeting. The FOMC announcement times used here are recorded only to the minute -- for example an announcement recorded at 2:12pm could have been released by the wire service between 2:12:00 and 2:12:59. Release times varied from 2:11pm to 2:20pm in our sample.

Standard economic theory tells us that the unexpected component of these releases should be important, rather than the release itself. With the exception of the Fed Funds rate announcement, we measure the unexpected component of these releases as the difference between the actual release and the Money Market Services (MMS) median survey expectation, a widely-used source of market expectations data. For the Fed Funds rate, instead of using survey expectations, we measure the unexpected component of the announcement from the Fed Funds futures market. Table 2 also lists the standard deviation of the unexpected component of each type of data release, the number of announcements in our sample and the time of day when they occur.

5.1 The Effect of News Announcements on Trading Volume

Figure 2 plots the average euro-dollar trading volume by minute from 8:00am to 9:30am on days of announcements for GDP, nonfarm payrolls, PPI, retail sales and the trade balance.[10] The average trading volume per minute on days when there are no 8:30 announcements is also shown as a benchmark. Figure 2 also shows the average trading volume by minute on days of FOMC announcements, plotted from 30 minutes before the actual release time to 60 minutes after the release (which is approximately from 1:45pm to 3:15pm). In the graph, the actual FOMC release time is marked as *t*. For the FOMC release, the benchmark shown is volume on non-FOMC days from 1:45pm to 3:15pm instead. Here and henceforth, where we refer to days with "no 8:30 announcements", we mean days on which there is no release of business inventories, CPI, durable goods orders, GDP (advance, preliminary or final), housing starts, initial jobless claims, personal consumption expenditures, personal income, PPI, nonfarm

[10] Corresponding results for the dollar-yen currency pair are not shown, so as to conserve space, but are similar and are available from the authors on request.

payrolls, retail sales, or trade balance data. This is meant to be a fairly complete list of all of the market-sensitive U.S. data releases that come out at 8:30am.

Here are the key findings to notice from Figure 2:

1. Each of the 8:30am announcements generates a surge in trading volume within the first minute, which varies by the type of announcement. This surge dissipates only quite slowly. The extra volume on announcement days in the few minutes immediately following the data release is actually only a small fraction of the total extra volume on announcement days from 8:30am to 9:30am.

2. Of the five types of 8:30am announcements we study, quarterly GDP and monthly nonfarm payrolls releases are associated with especially large peaks in volume. Euro-dollar trading volume just after 8:30am is about six times higher on the days of either of these releases than on non-announcement days. Retail sales and trade balance releases have smaller effects on volume, and PPI releases have the smallest impact on volume of any of the five 8:30am announcements that we consider.[11]

3. The FOMC announcement generates trading volume that is also greatly elevated relative to the non-announcement day benchmark. The peak is not as high as for 8:30am announcements, but the extra volume dissipates slowly, and volume remains elevated for over an hour. Two points should however be borne in mind. Firstly, benchmark non-announcement day trading volume is much lower at this time of day than it is at 8:30am. The volume after the FOMC announcements is lower than it is around any of the 8:30am announcements, but is very high relative to the non-announcement day benchmark. Secondly, the timing of the fed funds rate announcement is not

[11] We also studied three other 8:30am announcements: CPI, housing starts and initial jobless claims, and found that that they had even smaller impacts on volume.

recorded as precisely as it is for the other announcements, which may cause a downward bias in the measured peak trading volume right after the announcement.[12]

4. For announcements other than nonfarm payrolls, the volume returns to close to normal after about an hour. We only show the volume for one hour after the announcements in Figures 2 and 3, but the average euro-dollar trading volume on the days of nonfarm payrolls announcements remains above the average on days without announcements for about two hours after the data release.

5. There is some tendency for volume to be lower right *before* some news announcements than it is at that same time on days without announcements.

5.2 Analysis of the Effect of the Magnitude of Data Surprises on Trading Volume

We next turn to the relationship between the unexpected component of macroeconomic announcements and foreign exchange trading volume. Let *t* index the times at which there was one or more data release (of the types that we study) and consider the regression:

$$V_{t,h} = \Sigma_{k=1}^{6} \alpha_{h,k} D_{k,t} + \Sigma_{k=1}^{6} \gamma_{h,k} \mid s_{k,t} \mid + \varepsilon_t \qquad (1)$$

where $D_{k,t}$ is a dummy that takes on the value 1 if the *t*th data-release event included an announcement of type *k* and 0 otherwise, $s_{k,t}$ is the unexpected component of the announcement of type *k* (that is set to zero if $D_{k,t} = 0$), and $V_{t,h}$ is the transacted volume in the one-minute window h minutes after the announcement time where *h* goes from -30 to 60 (five minutes

[12] For example, suppose that an FOMC announcement actually came out at 2:14:30. We would record the announcement as having come out at 2:14pm and would take the interval of time from 2:14:00 to 2:14:59 as the first minute after the announcement, but would probably measure only some extra volume during this minute. The first minute after the announcement is actually the interval of time from 2:14:30 to 2:15:29. But we only observe the times of FOMC announcements to the minute, and so cannot do this. The problem does not arise for the other announcements, as they are released within a few seconds of 8:30:00.

before the announcement time to one hour after). The index *k* runs from 1 to 6 because there are six different announcement types. This specification allows us to control for the possibility of multiple types of data releases coming out simultaneously.[13] The interpretation of the coefficient $\alpha_{h,k}$ is the effect of an announcement of type *k* that is line with expectations on trading volume h minutes after the release, and we refer to this as the intercept coefficient for an announcement of type *k*. The interpretation of the coefficient $\gamma_{h,k}$ is the effect of a one-unit absolute surprise in that announcement on the transactions volume *h* minutes after the release, and we refer to this as the slope coefficient for an announcement of type *k*.

The OLS estimates of the intercept and slope coefficients for the euro-dollar currency pair are plotted in Figures 3 and 4 respectively, along with 95% confidence intervals.[14] The plot of any of the intercept coefficients against h has the interpretation of the predicted volume trajectory following an announcement that turned out to be in line with expectations. Meanwhile, the plot of any of the slope coefficients against h is the predicted *extra* volume that is generated when the actual data release is one unit different from expectations (either above or below).

The estimated intercept coefficients account for a large share of the surge in volume after announcements. In contrast, the estimated slope coefficients are rather small, and are often not significantly different from zero. Both sets of coefficients peak in the first minute following the announcement time. To get a sense of the relative magnitudes of these coefficients, consider, for example, the effect of nonfarm payrolls announcements on volume. The predicted peak effect of

[13] In our sample, PPI announcements come out at the same time as retail sales in 23 cases and at the same time as the trade balance in 7 cases, out of a total of 61 announcements. There are no other cases of overlapping announcements in our sample (including no overlap of retail sales and trade balance).

[14] White standard errors were used. Corresponding results for the dollar-yen currency pair are not shown, so as to conserve space, but are similar and are available from the authors on request.

an announcement right in line with median market expectations is to immediately raise the trading volume index to 1,800, or to 18 times the average per-minute volume. If the announcement surprise is plus or minus 100,000 (close to a one standard deviation surprise over our sample), then the volume index is further elevated, but only by about another 400, making a predicted peak volume of 2,200, or 22 times the average per minute volume. Data releases with a large unexpected component (whether positive or negative) have large effects on the conditional mean and variance of exchange rate returns, according to the results of ABDV and others, but, in contrast, we find that they do not generate much more trading volume than releases that are close to market expectations.

5.3 Effect of the Heterogeneity of Market Expectations on Trading Volume

Heterogeneity among economic agents is widely accepted in the literature as a central explanation for trade in financial markets. One possible source of heterogeneity is the difference in *ex-ante* beliefs about upcoming data releases among market participants. Greater dispersion of *ex-ante* market expectations might be expected to be associated with a higher trading volume (Kim and Verrechia (1994), Harris and Raviv (1993)). A proxy for the dispersion of *ex-ante* market expectations is the standard deviation of MMS survey responses about data releases which we have used to assess the information content of data releases; these standard deviations have been used by other researchers to measure heterogeneity.

To investigate the relationship between the heterogeneity of market expectations and trading volume, we computed the total trading volume in euro-dollar and dollar-yen from 8:30am to 8:45am on days of PPI, nonfarm payrolls, GDP and retail sales releases, and the total trading volume from 2:10pm to 2:25pm on days of FOMC releases of the target federal funds rate.

Then, on days of each of these announcement types, we regressed the total volume over this 15 minute window in each currency pair on the absolute value of the surprise component of the announcement (as before), but augmented this regression with the standard deviation of MMS survey responses.[15] We run the regression for all announcement types jointly (as in equation (1)) to control for multiple types of data releases coming out simultaneously). Our regression is

$$V_t^* = \Sigma_{k=1}^5 \alpha_{h,k} D_{k,t} + \Sigma_{k=1}^5 \gamma_{h,k} \mid s_{k,t} \mid + \Sigma_{k=1}^5 \zeta_{h,k} \mid d_{k,t} \mid + \varepsilon_t \qquad (2)$$

where V_t^* is the transacted volume in the fifteen-minute window following the announcement time, $D_{k,t}$ and $s_{k,t}$ are as defined above, and $d_{k,t}$ is the dispersion of survey expectations for the announcement of type *k* (that is set to zero if $D_{k,t} = 0$).

The results are shown in Table 3. Somewhat surprisingly, the coefficient on the standard deviation of survey responses is in most cases negative, although not always significantly so. It appears that, in our sample, the *ex-ante* disagreement among analysts does have a negative relationship with trading volume, contrary to the standard theoretical view. This finding is not entirely isolated. A recent paper (Pasquariello and Vega (2007)), for instance, finds a similar relationship between the standard deviation of MMS survey expectations and trading volume in the Treasury market. One possible explanation for these findings is that the dispersion of survey expectations reflects the heterogeneity of beliefs among market participants but is also correlated with the aggregate level of uncertainty of the individual forecasts. A higher level of uncertainty may lead market participants to trade less aggressively after a data release, more than offsetting the direct effect of greater heterogeneity.

[15] We omit the trade balance releases because of the lack of data on the standard deviation of survey expectations for these releases.

6. One Data Release under the Microscope

Finally, we briefly focus on the impact of one particular macroeconomic news announcement: the weaker-than-expected nonfarm payrolls number released on August 6, 2004. For the three minutes bracketing this particular data release, we have data on the trading volume in the euro-dollar currency pair in each *second* at each price. Switching to this still higher frequency allows us to understand more precisely the timing of the price movement and increase in trading volume immediately following a data release.[16] The employment report on August 6, 2004 was moreover a big surprise as it showed that private nonfarm payrolls had risen by only 32,000 in July versus market expectations of 240,000, an especially large surprise.

Figure 5 shows a three-dimensional representation of the market reaction. Time is shown on the bottom, in seconds, running from 8:29 to 8:32. The exchange rate, in dollars per euro, is on the right. Finally, trading volume is shown by the numbers on the vertical axis, on the left, in millions of euro. The height of each bar on the graph therefore represents the volume transacted at each price in each second. We see that from 8:29 until the announcement, trading volume was low, and the exchange rate was around 1.2060 dollars per euro. As soon as the data were released, a few seconds before 8:30, the euro appreciated sharply relative to the dollar, and the exchange rate moved within about fifteen seconds to around 1.2190 dollars per euro. This jump in the exchange rate was not accompanied by a particularly large amount of trading volume. Afterwards, however, volume picked up as prices remained volatile, and the minute from 8:30 to 8:31, as a whole, was in fact the busiest in the history of the EBS system to that point, with volume in the euro-dollar currency pair exceeding 2.4 billion euros in these sixty seconds. So,

[16] We have these second-by-second data for both currency pairs but only around a few nonfarm payrolls releases. While our discussion in this section focuses on one particular release on the euro-dollar market, results for four other employment report releases are similar and are available from the authors on request.

while a minute-by-minute analysis would show a very high correlation between price movement and trading volume, switching to a higher frequency yields a very different picture.

The initial jump in prices without much trading volume is indeed what one would expect under efficient markets for an important scheduled data release. Under this view, dealers have a preset view about the likely effect of any given headline surprise on the exchange rate. When the data come out, the price jumps very fast to this predicted level, and it does not take much trading volume for this price adjustment to occur. The alternative view—that substantial trading volume is necessary for a large price movement—does not seem to be borne out by the market reaction to this payroll release.[17]

About fifteen seconds after the announcement, trading volume did pick up substantially amid volatile trading. This may reflect disagreement among traders about whether the initial price change was precisely the appropriate adjustment to the headline surprise, leading to both higher volume and volatility. Or it could be because the news announcement was complex and contained more information than just the headline surprise. The heightened volume and volatility would then represent the process of dealers working out the details of the release and its implications, which could help explain why data releases with no headline surprise still generate heightened trading volume. Data releases might also be thought of as giving each dealer a noisy signal, with traders subsequently learning the signals of others through the trading process, as in the noisy rational expectations equilibrium model of Bachetta and van Wincoop (2006). Finally, the rise in volume could simply reflect the need for investors to trade so as to rebalance their portfolios following the exchange rate adjustment. Note that this two-stage

[17] Nonetheless, it remains true that some quotes that were left in EBS at the time of the payrolls announcement were then swept out by the initial reaction to the news. It seems puzzling that dealers leave binding quotes in the order book at the moment of a scheduled news announcement because this effectively amounts to dealers taking one-sided bets against themselves See Berger et al. (2007) for more discussion of this point

response of euro-dollar trading activity to this employment report release is very similar to the Treasury market response to news announcements found by Fleming and Remolona (1999), although the period of relatively light trading activity after the data release is shorter in the foreign exchange market.

7. Conclusions

We have described high-frequency intraday patterns in global foreign exchange trading volume and have studied the impact of U.S. macroeconomic data announcements on volume, using spot interdealer trading data from EBS. These data, covering euro-dollar and dollar-yen trading from January 1999 through January 2004, represent the majority of global interdealer trading in these currency pairs. Our key findings are as follows:

1. We document that there are sharp spikes in trading volume at the time of scheduled macroeconomic data releases and also at other times of the day, where trading volume tends to be elevated for purely institutional reasons.

2. UK-specific holidays dampen trading in the euro-dollar and dollar-yen currency pairs, including trading among dealers located in America and Asia. We interpret this as a natural experiment indicating that foreign exchange trading activity is not driven solely by the flow of information about fundamentals.

3. We relate the extra trading volume following macroeconomic announcements to the magnitude of the surprise component of each announcement and find that there is a relationship, but that it is quite weak. Most of the extra trading volume occurs even if the data release is right in line with expectations. By contrast, previous researchers found

that announcements that contain little surprise have little effect on the conditional mean or variance of exchange rates.

4. We find that a commonly-used measure of the heterogeneity of *ex-ante* market expectations about data releases—the standard deviation of survey responses—is often negatively associated with trading volume.

5. Focusing on ultra-high frequency data around one macroeconomic announcement with a very large surprise component, we document a two-stage reaction whereby the price jumps immediately after the announcement without much trading volume, while trading volume and volatility then surge about 15 seconds after the data release.

Overall, our study of trading volume in the global foreign exchange market has yielded a number of results in line with standard theoretical predictions but also several findings which are perhaps more surprising. We show that the flow of fundamental information is an important driver of trading volume, as would generally be expected, but also document the important impact on global trading volume of purely institutional factors that have nothing to do with the flow of fundamental information, such as UK-specific holidays. Scheduled U.S. macroeconomic announcements, in particular, are clearly associated with spikes in trading volume but these spikes tend to occur even if the announcements are in line with market expectations (and therefore generate little price response). Our finding of a negative relationship between the *ex-ante* dispersion of market expectations and the magnitude of the volume response to a data surprise is somewhat surprising, and it may be evidence that a higher level of uncertainty may lead market participants to trade less aggressively after a data release, more than offsetting the direct effect of greater heterogeneity. Finally, our observation that, in reaction to one very large

data surprise, the jump in the price preceded the surge in trading volume, may provide some comfort to believers in traditional efficient-market theory.

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Table 1: Average percent deviation in trading volume from AR(3) on London-specific holidays

Region	Euro-Dollar	Dollar-Yen
Europe-Europe	-67%***	-79%***
America-America	-17%	-16%
Asia-Asia	-18%*	-20%
Europe-America	-54%***	-66%***
Europe-Asia	-54%***	-64%***
America-Asia	-26%**	-17%
Total	-47%***	-42%***

Notes: We expressed each of the 14 daily trading volume series in index form (average daily volume=100) and then estimated an AR(3) for each index, augmented by a dummy that is equal to 1 on UK specific holidays. The dates of the UK specific holidays are: August 30 1999, August 28 2000, May 7 2001, August 27 2001, June 3 2002, June 4 2002, August 26 2002 and August 25 2003. The entries in the table are the OLS estimates of the dummy variable coefficients in these regressions. One, two and three asterisks denote significance at the 10, 5 and 1 percent levels respectively, from t-tests on the dummy variable using White standard errors.

Table 2
Macroeconomic Announcements

Data Release	Source[1]	Frequency[3]	Release Time	Units	Surprise Standard Deviation	Number in Sample
Fed Funds Rate (Target)	Fed	8 per year	2:15pm	Change in basis points	4.9	41
GDP (Advance Release)	BEA	Quarterly	8:30am	% change qoq[2]	0.91	20
Nonfarm Payrolls	BLS	Monthly	8:30am	Change in thousands	107.0	61
PPI	BLS	Monthly	8:30am	% change mom	0.42	61
Retail Sales	Census	Monthly	8:30am	% change mom	0.52	61
Trade Balance	BEA	Monthly	8:30am	$ billion	2.3	61

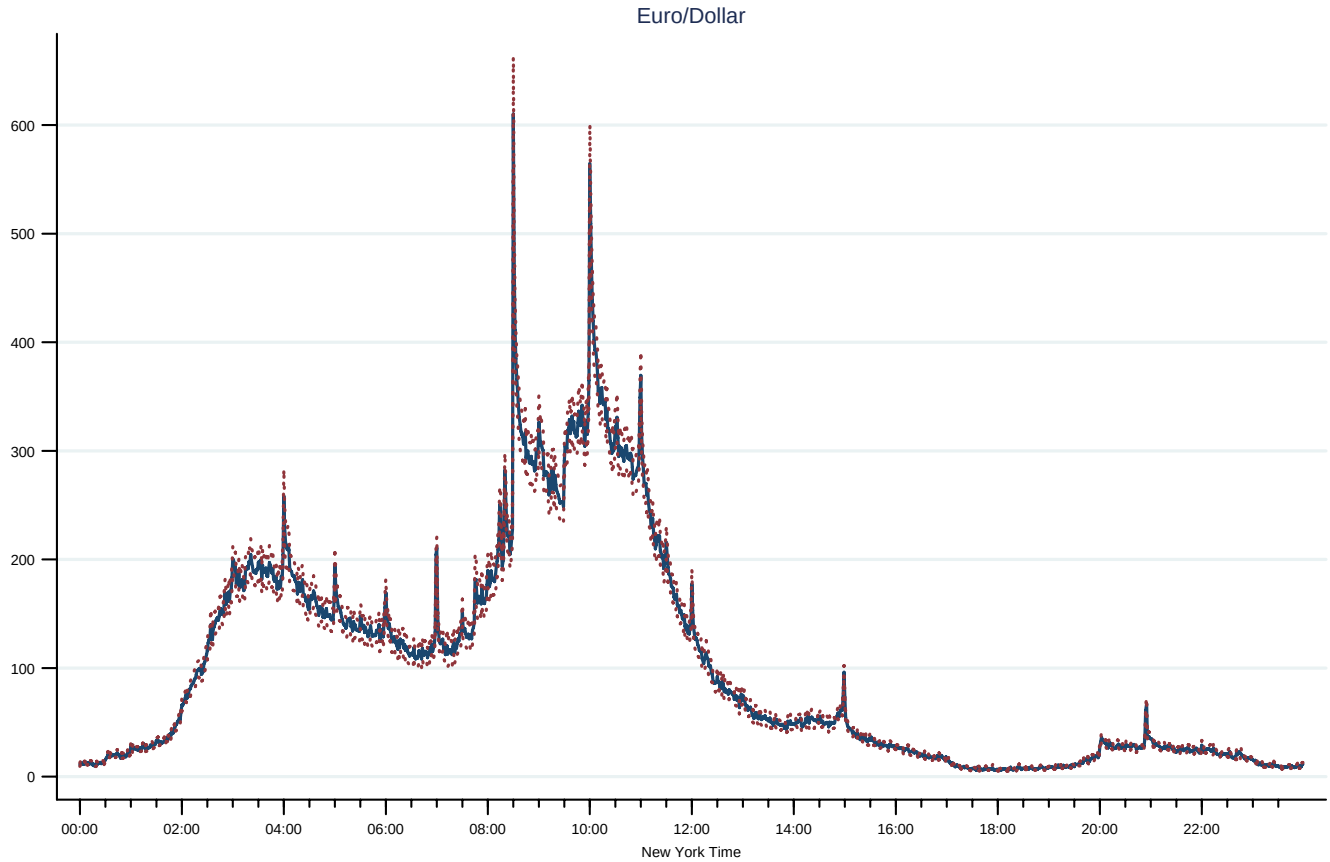
[1] Acronyms for the sources are as follows: BEA (Bureau of Economic Analysis), BLS (Bureau of Labor Statistics), Census (Bureau of the Census), Fed (Federal Reserve Board of Governors).
[2] Expressed at an annualized rate.
[3] Release dates are as follows: Fed Funds Rate Target is released on days of FOMC meetings, GDP is released about 30 days after the end of the quarter, nonfarm payrolls are usually released on the first Friday of the next month, PPI and retail sales are released in the middle of the next month, trade balance is released in the middle of the month after the next month.

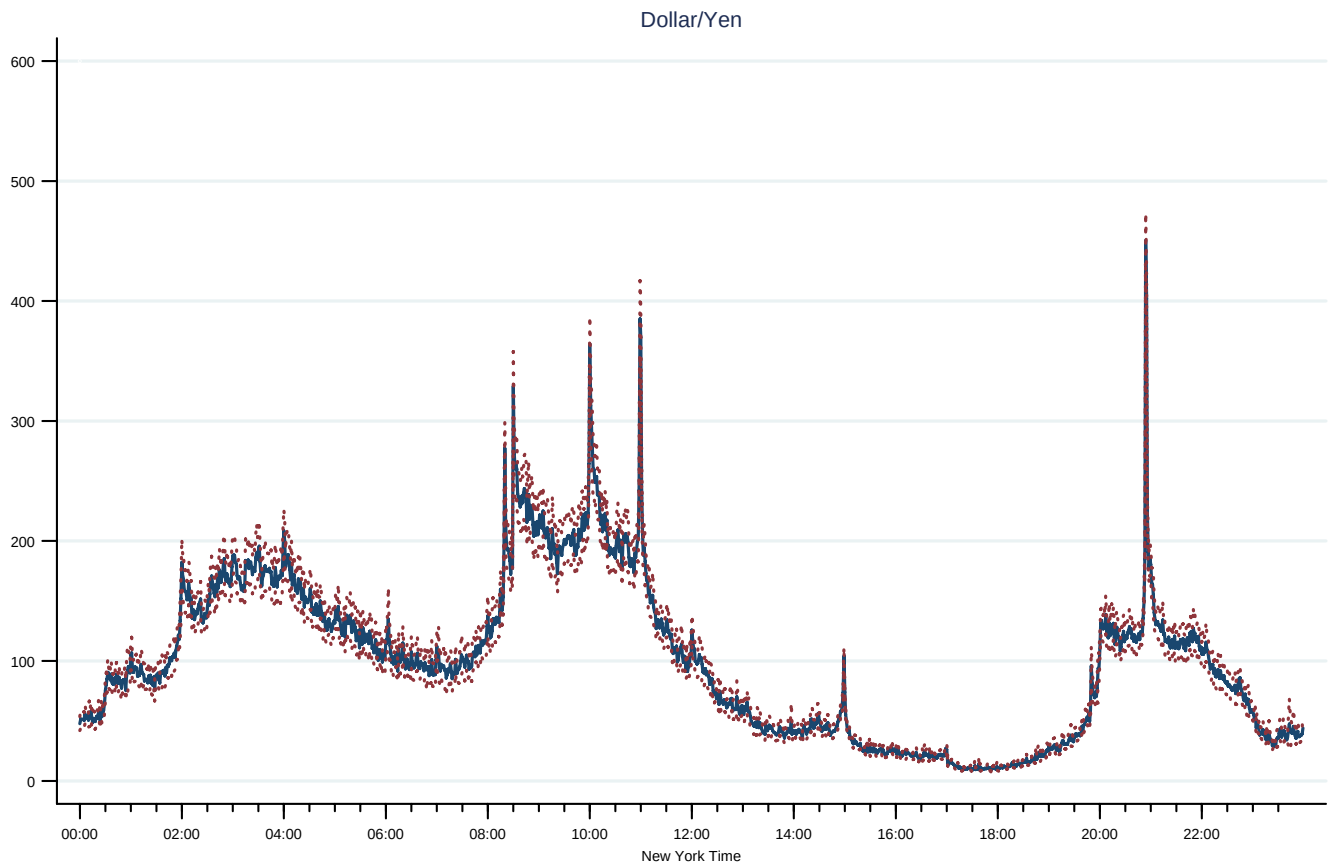
Table 3: Regression of Total Trading Volume in 15 mins Around Data Releases on the absolute value of the headline surprise & on the survey standard deviation

Announcement	Coefficient on Absolute Surprise	Coefficient on Survey St. Dev. (Standard Error)
	Euro-Dollar	
GDP	1107.8	-10650.1**
	(2275.6)	(4144.7)
Payrolls	7.6	-92.2**
	(7.9)	(41.6)
PPI	2947.5	-6945.5
	(1938.0)	(8537.7)
Retail Sales	2052.9	497.3
	(1725.8)	(2344.9)
FOMC	194.9*	7102.3
	(103.5)	(8550.4)
	Dollar-Yen	
GDP	1572.2	-9719.8**
	(1466.1)	(3917.4)
Payrolls	8.1	-47.9*
	(7.6)	(28.7)
PPI	3295.0***	-4821.1
	(1102.9)	(5365.4)
Retail Sales	1477.4	-146.7
	(1160.5)	(1548.6)
FOMC	352.8***	-10558.6
	(103.0)	(9270.1)

Notes: * denotes significance at the 10% level, ** denotes significance at the 5% level and *** denotes significance at the 1% level. The total trading volume is measured in index terms where the average per-minute trading volume is normalized to 100. The headline surprise and standard deviation of the survey expectations are both measured in the units listed in Table 1.

Figure 1: Average One-Minute Trading Volume

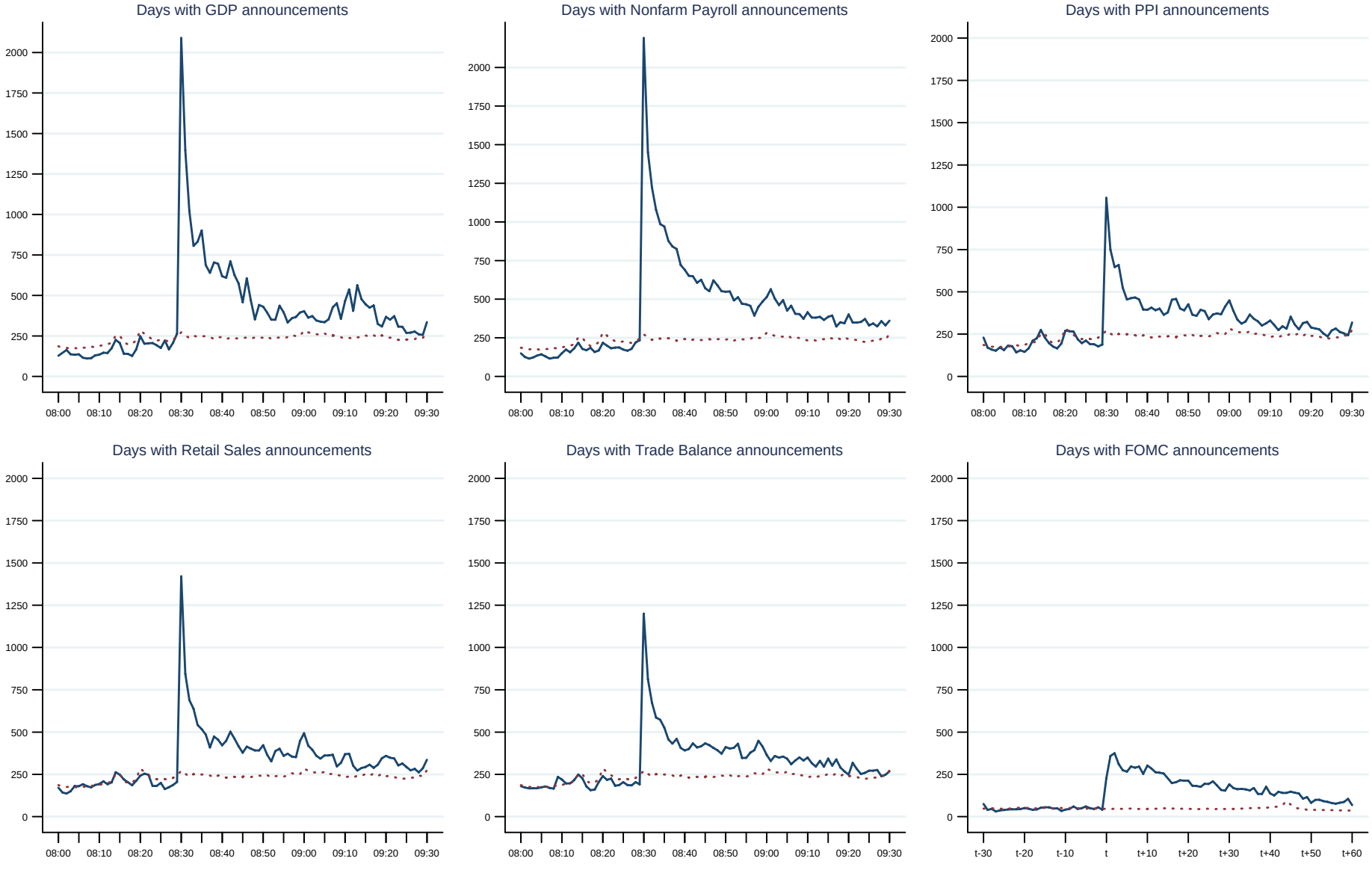




Index: 100 = Average volume per one-minute period over the whole sample (separate index for each currency pair)
Dotted lines indicate 95% confidence intervals

Figure 2: Euro/Dollar: Average One-Minute Trading Volume on Announcement Days

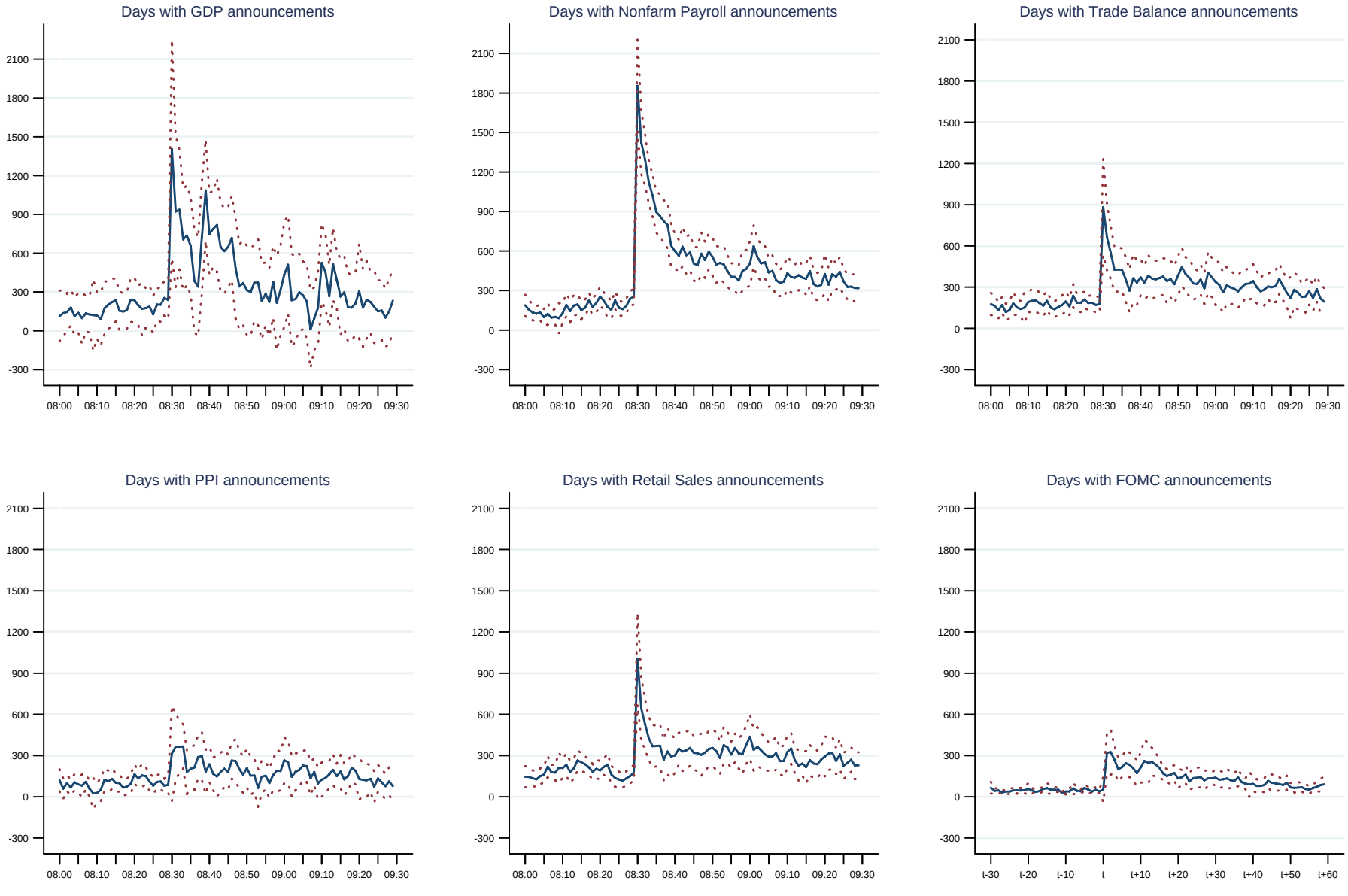
(Index:100 = average volume per minute)



t denotes the time of an FOMC announcement

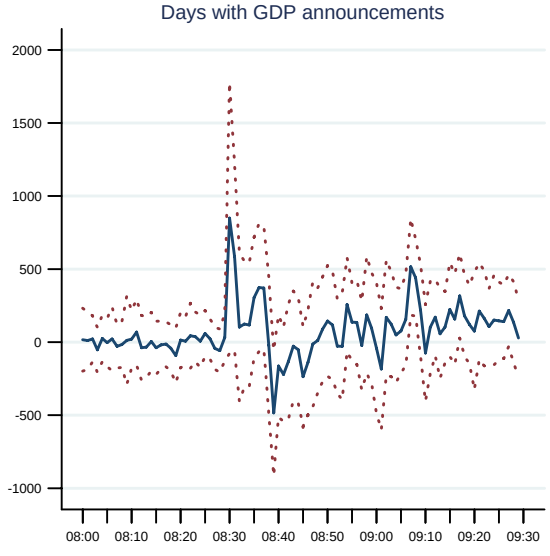
Average volume on announcement days: solid lines
Average volume on nonannouncemment days: dotted lines

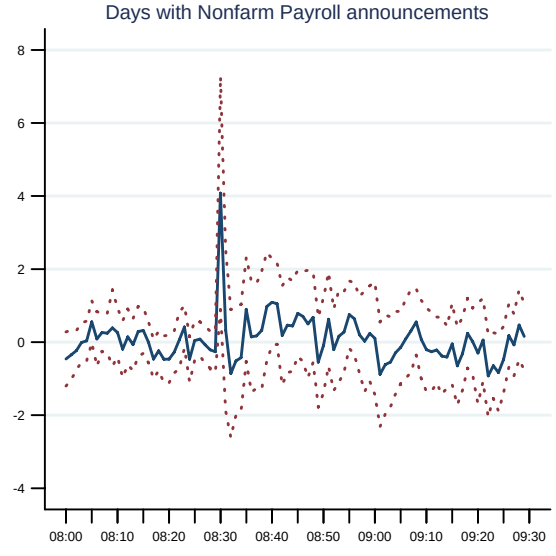
Figure 3: Euro/Dollar: Intercept Coefficients in Regression of One-Minute Volume on Absolute Size of an Announcement Surprise
(Index:100 = average volume per minute)

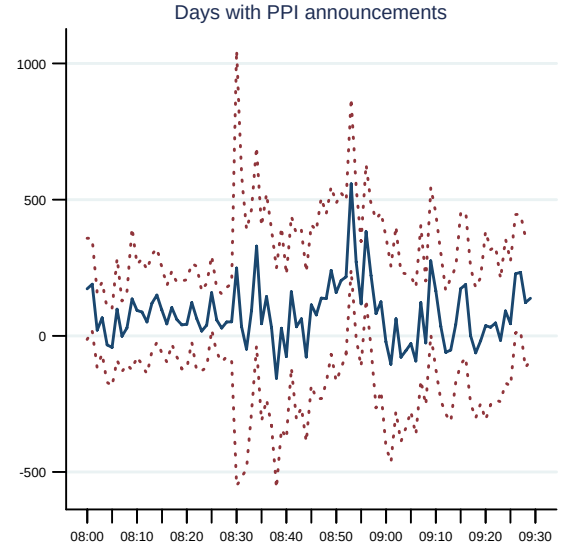


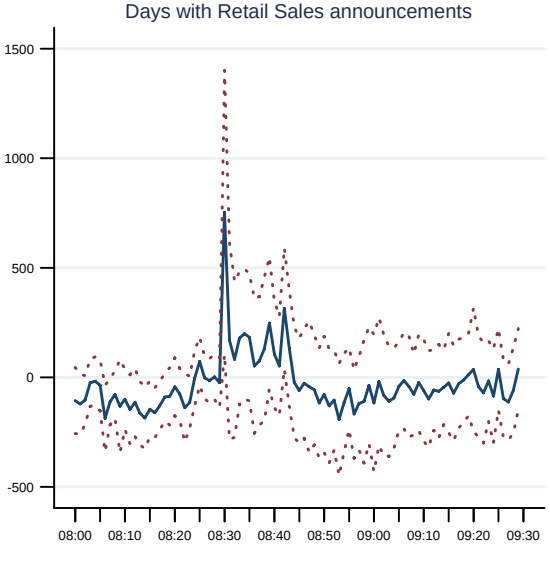
t denotes the time of an FOMC announcement

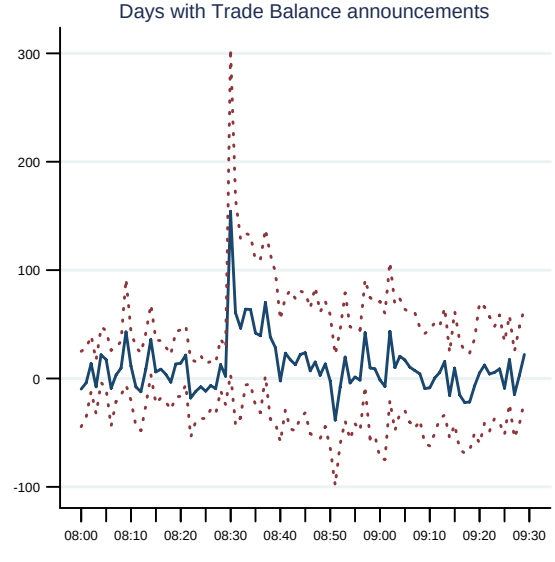
Figure 4: Euro/Dollar: Slope Coefficients in Regression of One-Minute Volume on Absolute Size of an Announcement Surprise
(Index:100 = average volume per minute)

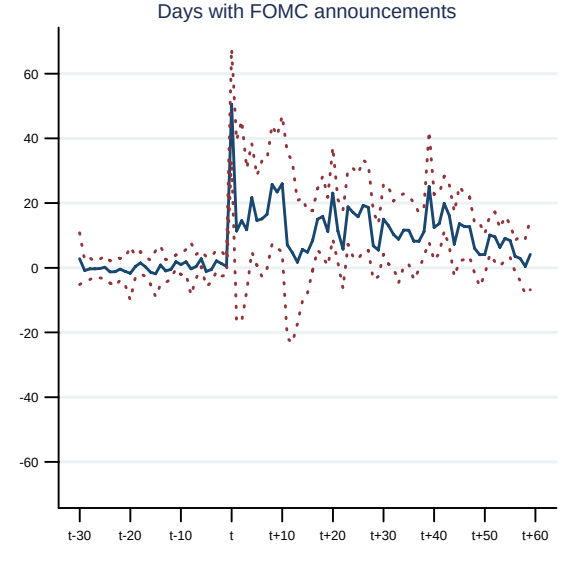












t denotes the time of an FOMC announcement

Figure 5: Price and Volume (EUR/USD)

8:29 to 8:32 , 6-Aug-2004