Macroeconomic news, order flows and exchange rates

Ryan Love Richard Payne*

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ABSTRACT

Under rational expectations and efficient markets, the news contained in public information announcements is directly impounded into prices with there being no role for trades in this process of information assimilation. This paper directly tests this assertion using transaction level exchange rate data and a sample of scheduled macroeconomic announcements. The main result of the paper is that even information that is publicly and simultaneously released to all market participants is largely impounded into prices via the key micro-level price determinant — order flow. We quantify the role that order flow plays and find that between a half and two thirds of price relevant information is incorporated into prices via the trading process.

*Both authors; Financial Markets Group, London School of Economics and Political Science.
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Traditional asset market models of exchange rate determination, based on rational expectations and efficient markets, imply that announcements of public information are directly impounded in prices with there being no role for trades in this process of information assimilation. More recent exchange rate analysis, based on microstructure considerations, stresses the role that trading plays in price formation via a concept called *order flow*. Order flow is defined to be the difference between buyer-initiated and seller-initiated trading interest in a given market and thus corresponds broadly to what practitioners might describe as aggressive buying or selling pressure. In the models of Lyons (1995), Perraudin and Vitale (1996) and Evans and Lyons (2002b) order flow explains contemporaneous exchange rate movements because it contains information, either about fundamentals or long-run risk premia, that was previously dispersed among market participants. Thus, one of the key differences between the microstructure level analysis and traditional exchange rate frameworks is that the same information is not shared by all market participants and/or is interpreted differently by participants.

This paper seeks to test the proposition that public information announcements alter exchange rates with no role for order flow. The test of this hypothesis is direct; using 10 months of transaction-level exchange rate information on USD/EUR (dollars per euro), GBP/EUR (pounds per euro) and USD/GBP (dollars per pound) and data on euro-area, UK and US macroeconomic announcements we examine whether announcement surprises have a systematic and significant effect on both order flow and prices. We also decompose the price reactions to announcements into a part that is direct and a part intermediated by order flow.

Our results are unambiguous. At a 1 minute sampling frequency, macroeconomic information releases do have systematic effects on order flow and, as established in previous studies, on exchange rate transaction prices. After releases of "good news", not only does the exchange rate tend to appreciate but order flow tends to be positive, reflecting an excess of agents aggressively buying over agents aggressively selling. Moreover, we show that in periods just after macroeconomic announcements,

the significance of order flow in exchange rate determination is much greater than in normal times. Finally, we estimate a multivariate VAR model in transaction price changes and order flow with a signed macroeconomic information surprise variable included as an exogenous right-hand side regressor. Via this model we are able to characterise the extent to which the final effect of macroeconomic information on prices is intermediated by order flow. Our results suggest that between 50 and 66% of the final price reaction to news comes via this order flow mechanism.

Thus, our analysis corroborates not only earlier results on the relevance of both macroeconomic news (Almeida, Goodhart, and Payne 1998, Andersen, Bollerslev, Diebold, and Vega 2001) and order flows (Lyons 1995, Yao 1998, Payne 2002) for high frequency exchange rate determination but it also ties in with recent lower frequency analysis, Evans and Lyons (2002a), which indicates that at least part of the response of exchange rates to news comes via order flow. These results are based on a four month sample of exchange rates and order flows and a news variable that is a count of the number of headline news items released that day. Methodologically, due to the inability to use their flow of news headlines to accurately construct a time-series of signed or sized news releases, Evans and Lyons (2002a) use a variance decomposition to identify the role that order flow has to play in the assimilation of news into prices. Thus, their paper provides no *direct* evidence on the effects of news releases on order flows or exchange rates.

The key result of this paper is that even macroeconomic information that is publicly and simultaneously released to all market participants is largely impounded into prices via the key micro-level price determinant — order flow. This is clearly at odds with rational expectations, efficient market models of asset price determination. However, despite the role for order flow in the assimilation of public information into prices, we do not suggest that FX markets are not efficient. Indeed we find that virtually all of the price changes associated with public/macro news announcements occur within the first two minutes of release. Within the context of exchange rate determination our results suggest that the recent distinctions drawn between macroe-

conomic and microstructure models are not clear cut; the modelling of exchange rates should incorporate both elements of macro and microstructure. Further effort needs to be expended on theoretical and empirical work to merge the two sides of exchange rate determination in an attempt to more accurately explain how exchange rates are determined.

The rest of the paper is set up as follows. Section 1 describes the data, Section 2 introduces our univariate and multivariate models, Section 3 discusses our results and Section 4 concludes.

1. Data

The exchange rate data set used in the paper comes from the brokered segment of the inter-dealer FX market. specifically from the Reuters D2000-2 system. Thus our data contains no information on customer-dealer FX trades or on direct (i.e. non-intermediated) trades between dealers. Moreover, it should be noted that the trades occurring on D2000-2 should be regarded as public in the sense that they are visible to any looking at a D2000-2 screen as they occur. For a full description of the segments of the spot FX market and the data available from each see the excellent descriptions contained in Lyons (2001)

The raw data set is composed of transaction level information, covering three major floating rates: USD/EUR (dollars per euro), GBP/EUR (pounds per euro) and USD/GBP (dollars per pound). Note that these three exchange rates form a triangular set, linked by an obvious absence of arbitrage condition. We use this condition in the empirical analysis of Section 3. Each transaction record contains a time stamp for the trade, a variable indicating whether the trade was a market buy or sell and the transaction price. Thus unlike many papers in equity market analysis, we do not need to make use of potentially inaccurate, ad hoc algorithms to assign trade direction. The samples for USD/EUR and USD/GBP cover a period of ten months from 28 September 1999 to 24 July 2000. The GBP/EUR sample is somewhat shorter,

covering the eight month period from 1 December 1999 to 24 July 2000. One limitation of the data supplied is a lack of information about the size of each trade. Thus our order flow measure is simply the difference between the number of buyer-initiated trades and seller-initiated trades in an interval, rather than the difference between traded quantities. To the extent that earlier work has shown little size variation in trades on this dealing system (Payne 2002) and that in other applications it is the number rather than aggregate size of trades that has been shown to matter for prices and volatility (Jones, Kaul, and Lipson 1994), we expect that this limitation will not distort our results.

In this analysis we choose a 1 minute sampling frequency, i.e. at the end of each minute of our sample we record the last transaction price in each exchange rate plus order flow as defined above. We also decide to remove certain sparse trading periods from our sample. These include weekends, the overnight period, defined as 1800 to 0600 GMT (BST in the summer months) where trading activity was found to be very thin and some public holidays including Christmas, New Year, Easter (Good Friday and Easter Monday) and the May Day bank holiday. Periods where the D2000-2 data feed broke down were also excluded. These periods are defined as those where no transactions (and hence no price changes) occurred for at least six hours during the day. This filtering process reduced the total number of observations to 124259 for the USD/EUR, 97158 for the GBP/EUR and 125013 for the USD/GBP FX markets.[1] For the cointegrating VAR model of Section 3 only the periods where no breakdowns in any of the three exchange rate data feeds were considered. This resulted in 96748 data observations. Table 1 contains statistical information on exchange rate returns, defined as 100 times the logarithmic difference in prices, transaction frequencies and order flows for our filtered data sample.

The second component of our dataset consists of euro-area, UK and US macroeconomic information announcements along with expectations data for each of these releases. We use the expectations data to construct the "news" or "surprise" compo-

[1]The substantial reduction in the number of observations for the GBP/EUR market is due to the fact only eight, rather than ten, months of data were available.

nent of each individual announcement and from these numbers construct, also on a 1 minute sampling frequency, an aggregated news variable for each of the euro-area, UK and US respectively. We aggregate the announcement information as, with a maximum of 10 months of data (and thus ten releases for each individual announcement) we felt it would be difficult to identify statistically significant effects from the individual news series. The aggregated news variable is constructed by scaling each series of surprises by that series' surprise standard deviation. So the standardised news for series v is given by

$$S_{v,t} = \frac{A_{v,t} - E[A_{v,t}]}{\hat{\sigma}_v} \tag{1}$$

where $A_{v,t}$ is the actual announcement of the data, $E[A_{v,t}]$ is the market expectation of the announcement obtained from Standard and Poors and $\hat{\sigma}_v$ is the sample standard deviation of $A_{v,t}$.[2] Each surprise series is then signed (i.e. multiplied by +1 or -1) depending on its effect on the exchange rate.[3] The series is multiplied by +1 if greater than expected news causes the domestic currency to appreciate, and by -1 if it causes a depreciation. In what follows we therefore define "good" or "positive" news as any macro announcement which when released from one region, causes that region's domestic currency to appreciate. Then, to obtain our aggregated variable, we simply sum the signed, standardised surprise numbers across announcements. Of course, this technique will lead to the effects of more important announcements being diluted through the inclusion of less important releases, but this dilution is necessary to generate a meaningful sample size for news in each geographical area. The sets of macroeconomic announcements that we include for each of the areas are given in Table 2.

Note that we have chosen to focus on announcements that, via some individual announcement pre-testing and from inspection of existing literature and previous results

[2] An identical standardisation is performed in Andersen, Bollerslev, Diebold, and Vega (2001) and Balduzzi, Elton, and Green (2001).

[3] These signs were determined via standard event-study type analysis of exchange rate reactions to individual announcement surprises.

in this area, we are confident have significant effects on exchange rates.[4] This paper is not aimed at evaluating competing models of exchange rate determination via examination of the effects of news on rates. Nor do we try to evaluate the importance of different news releases via their effect on exchange rates. Our focus is simply on the role played by order flow in the reaction of exchange rates to news and thus we accept the way the markets appear to interpret the data releases without trying to explain the direction or strength of response to individual releases. However, to place our findings within the extant literature on exchange rate determination, we summarise the effects from each type of announcement (monetary/price, real/output and trade) in Table 3 and also give the predictions from a number of theoretical exchange rate models. For a more complete discussion of these issues, see Hoffman and Schlagenhauf (1985).

From our empirical analysis, there does not appear to be one theory which explains all the exchange rate responses to the different data releases. Indeed one might suggest that there is a contradiction in the way the markets appear to interpret price/money data emanating from the US compared to that from the UK and euro-land. An announcement of higher than expected inflation in the US tends to cause the dollar to depreciate, whereas similar data coming from the UK or euro-land leads to an appreciation of that region's currency. The US case is consistent with a monetary model of the exchange rate while the other two cases are consistent with a Central Bank reaction function where greater than expected inflation or output increases the likelihood of a rise in domestic interest rates causing an increase in the demand for the domestic currency. Although surprising, it is not inconceivable that different rates respond in different ways to the same type of news. Different macroeconomies *may* behave differently and it is quite possible that markets expect policy makers in

[4]We were somewhat restricted in our choice of euro-area data since, for a number of series, no market expectation data were available. This is largely due to the fact that these series were recently created and the lack of historical data meant that expectations could not be given accurately, if at all. Although interest rate changes seem an obvious candidate for our macro announcement dataset, it was decided that these releases would not be included since during this period there were very few interest rate changes and what changes there were, were largely anticipated by the markets, implying little or no "news".

different regions to respond differently to the same "shock".[5]

2. Empirical Analysis

1. The Effects of Macroeconomic News on Returns and Flows Separately

We begin our empirical analysis by characterizing the effects that news surprises have on exchange rate returns and on order flows, each in isolation. As outlined in the introduction, whilst, given previous results, we would expect macroeconomic news to immediately and significantly move exchange rates, standard models of exchange rate determination suggest that this adjustment should occur without the occurrence of one-sided aggressive trading. We also test a number of other hypotheses. For example, when examining Euro-Sterling behaviour, one would naturally expect UK and euro-area macroeconomic information to have strong effects while news emanating from the US should have a much smaller or zero effect on the rate.[6] Finally, standard efficient markets reasoning would imply that the reaction to news items should be very swift, i.e. completed within seconds or minutes of the announcement itself.

To test the preceding hypotheses we make use of standard time-series analysis. We estimate the following models for flows and returns for exchange rate k;

$$\Delta P_t^k = \alpha + \sum_{i=-m}^{m} \beta_i^k N_{t-i} + \epsilon_t^k \quad (2)$$

$$F_t^k = \lambda + \sum_{i=-m}^{m} \gamma_i^k N_{t-i} + \eta_t^k \quad (3)$$

[5]Indeed the monetary authorities in the UK and euro-area have explicit inflation targets. This is not so for the US. Hence the differing effects of inflation/monetary data on the regions' currencies may not be too surprising.

[6]Of course, in practice, US macroeconomic information might well move rates if it has information content for the state of other economies, perhaps because it indicates the well-being of the "global economy".

where P_t^k is 100 times the logarithm of exchange rate k at time t,[7] F_t^k is order flow in the market for exchange rate k in the observation period ending at t, positive order flow in the USD/EUR market for example indicates net euro purchases/dollar sales, and N_t is a 3×1 vector consisting of standardized euro-area, UK and US news measures, respectively, for the interval ending at t. These specifications then simply explain exchange rate movements or flows in terms of news from all three regions. We estimate them using OLS but correcting the coefficient variance/covariance matrix for autocorrelation and heteroscedasticity using the Newey-West method.

Table 4 and Figure 1 present estimation results for all three currency pairs for the preceding equations.[8] Looking first at the return equations for each exchange rate, a number of results emerge. As expected, in the majority of cases returns are significant in the minute immediately following a news surprise.[9] Seven of the nine coefficients on current news are significant at 10% and six at 5%. Leads of euro-area news are also significant for GBP/EUR and surprisingly also for USD/GBP but we do not believe that this represents compelling evidence of any information leakage. It is also the case that one of the first lags of news is significant, UK news on USD/GBP – possibly indicating a small amount of delayed reaction to information. It is also interesting to note that UK announcements are significant in all three return estimations such that UK data releases have a systematic effect on the USD/EUR rate. Similarly, euro-area announcements significantly change the USD/GBP rate, although only at the 10% level. In purely quantitative terms, for two of the three exchange rates the largest coefficient is on US news whilst UK news has the largest impact in the GBP/EUR

[7] Unsurprisingly each of the exchange rates were found to be I(1) so (100*) log first differences were used. ADF tests are not reported here.

[8] We estimate the specifications with m as ten minutes but for convenience Table 4 only gives the results for the minute pre and post announcement. The very low R^2s reported in the table are to be expected due to the small number of news announcements relative to the tens of thousands of return observations for each exchange rate.

[9] Recall that the news variables were signed so that greater than expected news causes an appreciation of the domestic exchange rate. Hence "good" UK news causes a negative return in the GBP/EUR market but a positive return for USD/GBP. Since only announcements that had significant impacts in the pre-testing were chosen and appropriately signed, it is not surprising that significant coefficients were found at this stage. However, this will not affect the subsequent analysis in Sections 2 and 3.

market. This final observation can also be seen in the component graphs of Figure 1 which plots the cumulative returns and flows from ten minutes pre announcement to ten minutes post announcement. This is done for each of the three foreign exchange markets we consider and examines the effects around announcements from each region.

Table 4 also presents results from the order flow estimations. Clearly, the statistical significance in these equations is much stronger than that in the return equations. All nine coefficients on current news are significant at the 10% level in the flow equations, eight of which are significant at 5%. US news has the largest effect in the EUR currency markets and UK news has the largest impact on USD/GBP flows. See Figure 1. Four of the nine coefficients on the first lead of news are significant, although only one is at the 5% level. However, four of the nine coefficients on the first lag of flow are also significant at 5%, providing fairly consistent evidence that news has both an instant and a slightly delayed effect on order flows.[10] This evidence is entirely novel and is at odds with the predictions of standard asset pricing or exchange rate determination theories.

2. The role of order flow in exchange rate determination around announcements

The preceding analysis has demonstrated that announcements of macroeconomic information not only cause exchange rates to move, but also generate one-sided order flows. We now begin to focus on the manner in which flows and rates are jointly determined around announcement times. In this section we pose a simple question. Does order flow have a greater or smaller role to play in exchange rate determination when macroeconomic news is publicly released? Ex ante, one might have thought that the answer to this question was almost certainly negative; public information

[10]It is perhaps not surprising that order flow reacts for more than a minute. The initial order flow itself becomes information, which triggers yet more order flow. News releases will then have both an immediate and a delayed effect on order flows. For this point we thank Carol Osler.

releases would be expected to move rates in the absence of flows leading to high-frequency disconnection between these two variables. However, our prior analysis has shown a strong reaction of flow to news and thus perhaps this simple intuition is not valid. To answer our question we estimate the following specification for our three rates;

$$\Delta P_t^k = \alpha + \beta F_t^k + \sum_r \sum_{i=-m}^{m} \gamma_{i,r} \; F_t^k \cdot I^r(i)_t + \epsilon_t^k \tag{4}$$

where $I^r(i)_t$ is an indicator variable taking the value unity if and only if there was an announcement surprise for region r in period $t - i$. Thus, the terms forming the summation in the equation above simply pick out intervals around news releases and test whether the coefficient on flow changes relative to its normal level. For example, the coefficient on the product of flow and $I^{UK}(0)_t$ tells us whether, in a minute that has begun with a UK news announcement, flow matters more or less than usual.

In Table 5 we present the results for our nine exchange-rate/news combinations as well as the benchmark order flow coefficient ($\hat{\beta}$). Again, while we estimate equation 4 for i = -10 to +10, for convenience we only present results for i = -1 to +1. The results are clear cut, especially for US and UK news. Around the release of US (UK) information, order flow has a significantly larger effect on the determination of Dollar (Sterling) related exchange rates. Coefficients on the contemporaneous interaction terms are significant at the 5% level (at least) and positive. Their magnitudes are such that in the case of US news, the effect of order flow more than doubles at the time of release while for UK releases the order flow impact is almost doubled. Results are less impressive for euro-area news, however.[11]

Thus, contrary to what one might expect, we derive strong evidence that around US and UK macroeconomic announcements, exchange rates are more sensitive to

[11]The poor results for euro-area news may come from the smaller number of news releases available. As seen in Table 2, only 15 news releases are available for the GBP/EUR sample and 19 for the USD/EUR and USD/GBP samples. This is less than half the number of announcements from the UK and US.

order flow than at other times. Given this result and that of Section 1, that flows react strongly to announcements, it would seem that the effect of publicly released information on exchange rates is transmitted, at least partially, through order flow. The empirical analysis in the next section tests this assertion.

3. Multivariate VAR analysis of returns and flows with exogenous news variables

Finally, we move on to test whether any part of the exchange rate response to news can be characterised as intermediated by order flow. Our prior analysis has established that both rates and flows respond to news and also that flows are more important in exchange rate determination around news events. Now we seek to measure the contribution of order flows to the overall exchange rate response to news. For this task, since our data cover the triangle of exchange rates, USD/EUR, GBP/EUR and USD/GBP, it seems natural to estimate a VAR for rates and flows, imposing the obvious cointegrating vector for the exchange rates that is implied by absence of triangular arbitrage. In logarithms, this arbitrage condition implies a cointegrating vector of $[1 \quad -1 \quad -1]'$ for the three exchange rates. Thus our model allows us to characterise the effects of news announcements on all three exchange rates and respective order flows simultaneously.[12]

$$\begin{bmatrix} \Delta P_t \\ F_t \end{bmatrix} = \alpha + \delta\left(z_{t-1}\right) + \begin{bmatrix} \beta \\ 0 \end{bmatrix} F_t + \sum_{i=1}^{m} \Gamma_{(i)} \begin{bmatrix} \Delta P_{t-i} \\ F_{t-i} \end{bmatrix} + \sum_{j=0}^{n} \Theta_{(j)} N_{t-j} + \varepsilon_t \qquad (5)$$

where ΔP_t is the 3×1 vector of USD/EUR, GBP/EUR and USD/GBP exchange rate returns, F_t is the corresponding (3 by 1) vector of order flows and and N_t is again the 3×1 vector of standardized euro-area, UK and US news. Hence we allow

[12] ADF tests, not presented so as to save space, indicate that each individual exchange rate is I(1) and further indicate that the three exchange rates are indeed cointegrated.

news from all three regions to affect a given exchange rate's returns. Finally z_{t-1} is the equilibrium error defined, by imposing the above theoretical cointegrating vector, as:

$$z_{t-1} = \ln(USD/EUR_{t-1}) - \ln(GBP/EUR_{t-1}) - \ln(USD/GBP_{t-1}) \qquad (6)$$

with δ being a (6 by 1) vector of speed of adjustment coefficients. Note that we allow order flow at date t to be affected by the equilibrium error at date t-1 due to the absence of triangular arbitrage argument. To see why, assume for simplicity that all three exchange rates initially equal unity. Now allow the euro to appreciate only against the dollar at date t-1 to 1.02 dollars per euro. To exploit the arbitrage opportunity a simple strategy would be to sell E1, buying \$1.02. With this you can buy £1.02 and then buy E1.02 making a pure profit of E0.02 for every E1 traded. Note that exploitation of the existence of a positive equilibrium error at t-1 induces a net sale of euros for dollars (negative USD/EUR order flow), a net sale of dollars for sterling (positive USD/GBP order flow) and a net sale of sterling for euro (positive GBP/EUR order flow). Therefore we hypothesize that the six coefficients in the speed of adjustment vector, δ, will have the following signs: [- ,+ , + , - , + , +].

The key assumptions in our VAR formulation are that order flows do not depend on contemporaneous exchange rate returns and also that the returns for exchange rate k do not depend on contemporaneous returns for exchange rate l ($\neq k$). Finally we also assume that order flows do not depend on the contemporaneous realisation of other order flows. The restriction that flows are not affected by contemporaneous returns implies that each element of F_t is not correlated with the error in any of the return equations. Hence, making the assumption that the variance/covariance matrix of the (6 by 1) error vector ε_t is diagonal, allows us to estimate the structural VAR equation-by-equation using OLS. However, we correct the coefficient covariance matrix for autocorrelation and heteroscedasticity using the Newey-West technique and the lag length for exchange rate returns, order flow and news were chosen using

the Schwartz information criterion. The recursive ordering that allows flows to contemporaneously affect returns but which rules out the converse seems, to the authors, to be a reasonable economic restriction, especially at the very high frequency considered in the paper. We feel that the notion of feedback trading, which allows flows to respond to price movements, at a frequency of less than a minute is somewhat dubious. Table 6 gives a summary of the VAR estimations and for convenience, only the parameter estimates and t-stats are given for the constant, the equilibrium error, contemporaneous flows and news.[13] The coefficients on the news variables are to be interpreted as follows: after a one standard deviation announcement of good euro-area news for example, this causes the USD/EUR exchange rate to increase (euro appreciates) by 0.98 basis points and for an increase in net USD/EUR order flow (purchase of euros) of 2.46.

Some general comments are as follows. First there are indications of high-frequency negative autocorrelation in returns for all three rates and also a positive effect of contemporaneous order flow in the return equations, as expected. Interestingly, order flow exhibits high-frequency positive autocorrelation and also high frequency positive dependence on recent returns. These parameters might be interpreted as indicating high-frequency momentum trading by market participants. More importantly, news effects are strong in the return and flow equations. These are summarised below.

- USD/EUR exchange rate returns are only affected by euro-area data. Flows are weakly positively affected by EU news and weakly negatively affected by US news.

- UK news strongly affects GBP/EUR exchange rate returns (5% level) and flows (10% level) in the predicted directions but euro-area news causes GBP/EUR returns to move in the 'wrong' direction.

- The results for the USD/GBP exchange rate returns are as expected with US and UK releases causing significant changes in the directions predicted. How-

[13]The lag length on returns, flows and news were chosen to be 7, 3 and 0 respectively.

ever, UK news has a strong effect on flows while US news does not have a significant impact.

In addition to these effects, "good" US data announcements tend to induce a net purchase of sterling in the GBP/EUR market and good euro-area data likewise in the USD/GBP market.[14] The fact that these effects are significant in the flow equations suggests exploitation of arbitrage opportunities in the seconds (minutes) following the data releases. The estimates of the speed of adjustment coefficients in the cointegrating VAR are also consistent with these arbitrage strategies. The sign of the δ coefficients are as expected (and significant) in the return equations and are as expected in the GBP/EUR and USD/GBP flow equations, although only significant at the 10% level in the latter. This suggests that in the period immediately following an announcement of news, traders try to exploit the profitable opportunities that exist when the equilibrium error is non zero.[15] For example, if following an announcement of good US data, the dollar appreciates more against the euro than it does against sterling,[16] this will cause the equilibrium error, to become negative inducing a net sale of euro for sterling as market participants try to exploit the arbitrage opportunities explained above. This would explain the statistically significant negative coefficient of US news on GBP/EUR order flow. Similar arguments can be used to explain the significant coefficients of euro-area news in the USD/GBP flow equation.[17] However, it is interesting to note that the order flow generated by this 'non-relevant' news does not translate into the exchange rate changes that one would expect. For example, good US news causes negative GBP/EUR order flow but does not have any significant effect on GBP/EUR exchange rate returns.

[14]Bivariate VARs were also estimated for each currency pair in a similar fashion to equation 5. However, the results, including the cross effects of news on 'non-relevant' returns, were, for all intents and purposes, the same.

[15]However the arbitrage opportunities must be great enough to cover the spread associated with the round trip series of trades. The equilibrium error may differ from zero with no arbitrage order flow induced.

[16]This is indeed the case. The dollar appreciates by 4.48 basis points points against the euro (Figure 2, bottom left) and 2.61 basis points against sterling (Figure 2, bottom right).

[17]Good euro-area news causes an appreciation of 2.61 basis points against the dollar (Figure 2, top left) and an appreciation of 0.21 basis points against sterling (Figure 2, top middle). Hence significant positive USD/GBP order flow is not surprising.

In order to evaluate the role that order flow plays in the reaction of exchange rates to news we compare the actual impulse response of the exchange rate following news releases from each region to that which would occur if (counterfactually) all coefficients on news in the structural order flow equation were restricted to be zero, i.e. we set the bottom 3 by 3 sub-matrix of each $\Theta_{(j)}$ in equation 5 equal to the null matrix. By doing this, flows are not given any role in the assimilation of public information into prices and hence it gives us a measure of the extent to which the equilibrium exchange rate response is driven by the impact of news on flows. To calculate the IRF we introduce a one standard deviation surprise announcement of news in the N_t vector from one region only and examine the effects on each of the returns through time. The impulse response functions are plotted in Figure 2 for cumulated returns and Figure 3 for flows. The solid line shows the IRF following the hypothetical announcement and the dashed lines bound the 95% confidence interval, found by bootstrapping over a thousand iterations. For example, following a hypothetical announcement of positive, one standard deviation, euro-area news, the USD/EUR exchange rate increases (euro appreciates) by 2.5 basis points on announcement and is still close to 2 basis points higher after 20 minutes. (See Figure 2, top left). In all but one case where the news release comes from one of the regions associated with the currency pair, the cumulated exchange rate return is significant and in the direction expected. The only exception is the effect of euro-area data on GBP/EUR. Although in the correct direction, the exchange rate change is insignificantly different from zero. However, in two of the three cases where the news emanates from areas which are not associated with the currency pair, the hypothetical announcement causes a significant exchange rate change: positive US data causes sterling to significantly appreciate against the euro and positive euro-area data causes a significant appreciation of sterling against the dollar. The IRF figures also show the hypothetical exchange rate responses that would occur if all news coefficients in the structural order flow equations were set to zero, shown as circled lines and denoted 'no flow'. Thus comparison of solid and circled lines give some indication of the importance of flow in transmitting news to rates. In all cases, the hypothetical response to news with 'no flow' is less than that where

flows are allowed to be influenced by news, indicating that the mechanism through which information affects price directly does not explain the full story of (public) information assimilation. Order flows and the trading process therefore account for at least some of the price movements following releases of public information.

In order to give a quantitative assessment of the role order flow plays in the assimilation of news into foreign exchange prices, we break down the exchange rate change into the component coming directly from news into price (shown by the IRF when order flow is constrained not to be affected by news) and that coming via order flow, the difference between the original IRF and the 'no flow' IRF. This is shown in Table 7, which also decomposes the effect for each of the three currency pairs, for each news announcement and also examines the breakdown at the time of the announcement, 5 minutes after announcement and finally 20 minutes after. Note, if the 'no flow' IRF is negative, and the original IRF is positive, the portion of the news announcement attributed to flow will be greater than 100% and that attributed to direct impounding into price will be negative since without order flow, the effect is to move the exchange rate in the 'wrong' direction. As can be seen in Figure 2 (top middle), this is only the case for euro-area news on GBP/EUR returns. Good news causes a euro appreciation but when we rule out the possibility of information entering via flows, a simulated depreciation is seen. This is because as seen in Table 6, euro-area news causes a positive flow in the GBP/EUR market but a negative return. The net effect, however, is a positive return since the indirect effect of news on returns coming via the contemporaneous flow variable outweighs the negative effect of news on returns directly. However, since the cumulative return IRF is not significantly different from zero (see Figure 2, top middle) and the 'no flow' IRF does not lie outside the 95% confidence interval, little should be taken or inferred from the fact that the share of price changes coming via flows is over 100% in the GBP/EUR market. For this reason we ignore the effect of euro-area news on GBP/EUR returns when decomposing the price movements. When averaging over all currency pairs and over all announcements but excluding the spurious euro-area news effect, the assimilation of information coming via the trading process is substantial. The share that flows

have in the impounding of news into price is 58.88% on announcement, 58.94% after five minutes and 64.24% twenty minutes after announcement. This decomposition appears stable through time following the announcement but when we look at the breakdown for each country's news release and the effect on each currency pair, the results are more erratic. However, it certainly appears to be the case that the role played by order flow is substantial; up to twice as important, or at least just as important, as the direct effect of news being impounded into price.

3. Discussion and interpretation

Theory suggests that under the assumptions of rational expectations and efficient markets, public information should be incorporated into asset prices immediately and without a need for trading activity. Indeed French and Roll (1986) define public information as that which is incorporated into prices before any market participant can trade on it. Whereas equity values are determined by both public (macro) and firm specific information, exchange rate determination, it has been argued, is primarily concerned with macroeconomic information, see for example Bessembinder (1994). The release of unexpected, publicly announced, macroeconomic information should then be the major cause of exchange rate changes.[18] Our results are not inconsistent with this hypothesis. Unexpected macroeconomic data releases have significant effects on exchange rate levels. However, we also find that the same news has significant impacts on order flow and what is more, these impacts are in the same direction as the associated exchange rate changes. Further analysis demonstrates that the price impact of order flow is significantly increased around announcement times, especially for UK and US data releases. This suggests that at least part of the process whereby public information is incorporated into prices, comes via trading. This is explicitly tested in Section 3 and the hypothesis that public information is impounded into price without the need for trading is decisively rejected. On average over half of

[18]However Lyons (1995) and Payne (2002), amongst others, find evidence suggesting a large role played by asymmetric (private) information in the foreign exchange markets.

the price adjustment comes via order flow, a result that is entirely inconsistent with standard efficient markets, rational expectations hypotheses of asset price determination.[19] Although we demonstrate a role for the trading process in the impounding of public information into prices, we find no evidence to suggest that foreign exchange markets are not efficient. Virtually all of the associated price changes occur within two minutes of announcement.

Why order flow is so important in the formation of prices around releases of public information is a separate, important question and our results can be interpreted in a number of different ways. First, it could be argued that the agents trading on the system from which our data are drawn are slow to update the prices at which they are willing to trade and thus individuals who learn the implications of macroeconomic news more quickly can trade profitably on this information. In such a case, some public information will appear to get into prices via order flow. This scenario seems unlikely to us given the frequency of trading and order updating we observe on the system. In a related argument Carlson and Lo (2002) suggest that after an announcement of public information, dealers can lock in profits by posting a bid or ask price that is only a partial move to the new equilibrium price. If there exist a number of dealers who differ in their risk aversion/desire to make profits, then as these prices get hit and cleared from the market, it becomes apparent that public information will be incorporated into prices via the trading process. Alternatively, perhaps it is the case that groups of agents, because they have differing views of exchange rate determination, disagree on the implications of a release for rates and this disagreement generates a motive for trade. When the mapping of fundamentals/macroeconomic announcements to price is known and common across agents, the associated price movements should be independent of order flow. By relaxing the assumption that

[19]Evans and Lyons (2002a), looking at four months of foreign exchange data, suggest that the channel through which public information is incorporated into prices via order flow is around twice as important as the direct channel whereby information is impounded into prices with no need for trading. Whereas ours and Evans and Lyons' work in the foreign exchange market suggest a very important role for order flow in the assimilation of information into price, Fleming and Remolona (1999) find that prices in the US Treasury market incorporate macroeconomic information without the need for trading. This is also so the case for stock returns. See for example Jain (1988), who finds that stock prices adjust to macro news announcements without significant increases in trading.

this mapping is perfectly understood, perhaps because it is costly to discover the true mapping process, then after a news release the differing beliefs will induce order flow that will move prices to the new equilibrium.[20]

Regardless of the reasons for our findings, our results are very strong. Information that is publicly and simultaneously released to all market participants is only fully assimilated into prices via the trading process. As such, our results suggest that the recent separation of macroeconomic and microstructure models for exchange rates is somewhat artificial. More realistic models of exchange rates that merge both macro and microstructure elements should be developed to more accurately explain how exchange rates are determined. Furthermore, our results imply that the distinction made in the microstructure literature between public and private information is not clear cut. Since the public information we study enters price primarily through the trading process, rather than entering directly, then it might be argued that public information annoucements create informational asymmetries across the population of traders. French and Roll's definition of 'public' information, that which is incorporated into prices before anyone can trade on it, may still be valid, but what constitutes 'public' information may differ from that which is commonly believed.

4. Conclusions

Under rational expectations, efficient markets hypotheses, there should be no role for order flow in the assimilation of public information into prices. This paper shows that these ideas are not correct. We show that in the three floating foreign exchange markets, USD/EUR, GBP/EUR and USD/GBP, using data sampled at the one minute frequency, publicly announced macroeconomic information not only causes exchange

[20]Not only are there differing beliefs in the mapping of information to price, but also in the forecasts of fundamentals used in this mapping. The unanticipated component of news in our data was created from consensus forecasts obtained from Standard and Poors. The data/shocks we use are therefore the average of shocks across participants, implying that there may exist a positive shock for one trader and a negative shock for another. These heterogeneous forecasts will therefore generate a motive for trade following announcements of public information even if the mapping of information to price is common knowledge.

rates to move but also causes order flow to significantly change in directions consistent with the exchange rate movements. Indeed, the main driver of exchange rate movements in the microstructure literature, namely order flow, is found to be more informative around macroeconomic data releases. We test the assertion that public information is impounded into prices without the need for order flow and strongly reject these claims. Using impulse response analysis we find that up to two thirds of information is impounded into prices via order flow. This is at odds with standard theory.

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Table 1: Summary Statistics on Exchange Rate Returns and Flows

Variable	Mean	Variance	Skewness	Kurtosis	Autocorrelation (lags) 1	5	10	20
USD/EUR								
returns	-0.000154	0.000725	0.223	31.2	-0.0222*	-0.0141*	-0.0123*	0.0000928
absolutereturns	0.0151	0.000498	4.53	50.8	0.240*	0.153*	0.131*	0.109*
flows	0.0398	11.4	-0.283	18.9	0.231*	0.0291*	0.000498	-0.00242
trades	3.84	19.1	2.35	14.8	0.593*	0.445*	0.388*	0.324*
GBP/EUR								
returns	-0.0000443	0.0000616	0.169	41.6	-0.0149*	-0.00347	-0.00721*	-0.00141
absolutereturns	0.0142	0.000415	5.11	74.1	0.245*	0.139*	0.121*	0.100*
flows	0.142	6.70	0.178	7.42	0.186*	0.0173*	0.00522	0.00537
trades	3.44	14.6	2.13	10.7	0.628*	0.461*	0.396*	0.341*
USD/GBP								
returns	-0.0000993	0.000311	-0.176	26.8	0.00226*	-0.00684*	-0.0119*	-0.00463
absolutereturns	0.0106	0.000199	4.09	49.8	0.249*	0.143*	0.116*	0.101*
flows	0.0774	7.90	-0.0127	8.28	0.163*	-0.00205	-0.00120	-0.00334
trades	4.05	20.7	2.47	13.5	0.649*	0.440*	0.362*	0.290*

Notes: All statistics are based on data sampled at the one minute frequency. The USD/EUR exchange rate is defined as the number of dollars (numerator currency) per euro (denominator currency) and similarly for the other rates. Returns are defined as 100 times the first difference of the logarithm of the exchange rate. Positive order flow in the USD/EUR market implies net purchases of euro, the denominator currency. * denotes significance at the 5% level or less.

Table 2
Description of Macroeconomic Data releases

Euro-area announcements[1]

Announcement	Sign[2]	Reported as[3]	Obs.[4]	Dates	Local time
Ind. Prod.	+1	3M/3M % change[5]	10 (8)	10/99 - 7/00	10:00/11:00GMT
M3	+1	Y/Y % change	9 (7)	10/99 - 6/00	08:00/09:00GMT

UK announcements[6]

Announcement	Sign[2]	Reported as[3]	Obs.[4]	Dates	Local time
RPIX	+1	Y/Y % change	10 (8)	10/99 - 7/00	08:30/09:30GMT
Retail Sales	+1	M/M % change	10 (8)	10/99 - 7/00	08:30/09:30GMT
Global Trade	+1	GBP (bn.)	9 (7)	10/99 - 6/00	08:30/09:30GMT
Prov. M4	+1	M/M % change	10 (8)	10/99 - 7/00	08:30/09:30GMT

US announcements[7]

Announcement	Sign[2]	Reported as[3]	Obs.[4]	Dates	Local time
CPI	-1	M/M % change	10 (8)	10/99 - 7/00	08:30ET
PPI	-1	M/M % change	10 (8)	10/99 - 7/00	08:30ET
Unemployment	-1	%	10 (8)	10/99 - 7/00	08:30ET
Trade bal.	+1	USD (bn.)	10 (8)	10/99 - 7/00	08:30ET

Notes:

1. Euro-area Harmonised CPI, PPI, Retail Sales, Unemployment Rate and Ex EMU Balance of Trade, both preliminary and final were also considered in pre-testing but not included when forming standardised news due to insignificant or inconsistent exchange rates effects.

2. When forming the aggregate news variable, each series was multiplied by +1 (-1) if greater than expected news causes the domestic currency to appreciate (depreciate).

3. M/M % change: month on month percentage change. 3M/3M % change: three month on three month percentage change. Y/Y % change: year on year percentage change.

4. The USD/EUR and USD/GBP data spans 10 months, implying 10 observations for each release. The bracketed figure gives the number of observations for the 8 months of GBP/EUR data.

5. Industrial Production was reported as 3M/3M % change for October 1999 - March 2000 and M/M seasonally adjusted % change for April 2000 - July 2000.

6. The following announcements were also considered: PPI, Industrial Production, Unemployment, Current Account, EX EU Trade. They were not included when forming the standardised UK news because they had either insignificant or inconsistent effects on sterling exchange rates.

7. US Retail Sales, Industrial Production, Nonfarm Payroll Employment and Monthly M3 were also considered in the pre-testing, but found to have insignificant effects on the dollar rates.

Table 3: The Effect of a Country's Data Releases on its Exchange Rates

News emanating from	News in the form of		
	Increase in Prices/Money	Increased Output	Increased Trade Balance
Euro-area (effect on EUR)	Appreciation	Appreciation	
UK (effect on GBP)	Appreciation	Appreciation	Appreciation
US (effect on USD)	Depreciation	Appreciation	Appreciation
Theoretical predictions:			
Pure monetary model	Depreciation	Appreciation	
Portfolio balance (monetary)	Depreciation	Appreciation	Appreciation
Keynesian model		Depreciation	Appreciation
Central bank reaction function	Appreciation	Appreciation	

Table 4: The Effects of Macroeconomic News on Returns and Flows Separately

	USD/EUR returns	GBP/EUR returns	USD/GBP returns	USD/EUR flows	GBP/EUR flows	USD/GBP flows
constant	-0.00016^b	-0.0000450	-0.000104^b	0.0388^a	0.142^a	0.0768^a
	(-2.14)	(-0.57)	(-2.07)	(3.19)	(14.11)	(8.26)
Euro (1 min lead)	0.0000676	0.0258^a	-0.00664^b	-0.485	1.35^a	-1.41^c
	(0.03)	(3.50)	(-2.54)	(-0.95)	(4.24)	(-1.94)
Euro news	0.0404^b	0.000334	0.0113^c	3.47^b	2.09^b	1.85^b
	(2.51)	(0.04)	(1.77)	(2.17)	(2.15)	(2.08)
Euro (1 min lag)	0.000364	0.00243	0.00497	2.73^b	0.677	2.10^b
	(0.07)	(0.30)	(0.85)	(2.32)	(1.57)	(2.35)
UK (1 min lead)	0.00549	-0.00301	0.0105	1.33	-0.797	1.39
	(1.34)	(-0.62)	(1.29)	(1.55)	(-1.24)	(1.59)
UK news	0.0120^b	-0.0300^a	0.0506^a	1.91^b	-2.55^b	7.22^a
	(2.49)	(-2.59)	(4.88)	(2.23)	(-1.79)	(5.53)
UK (1 min lag)	-0.00190	-0.0120	0.0159^b	-0.271	0.513	4.52^a
	(-0.21)	(-0.97)	(2.11)	(-0.19)	(0.22)	(3.45)
US (1 min lead)	-0.0000607	-0.000572	0.000125	-1.43^c	1.21^c	-0.166
	(-0.01)	(-0.13)	(0.03)	(-1.74)	(1.65)	(-0.20)
US news	-0.109^b	-0.0282	-0.0603^a	-6.74^b	-4.63^b	-5.25^b
	(-2.52)	(-1.21)	(-2.89)	(-2.01)	(-2.24)	(-2.27)
US (1 min lag)	-0.0287^c	-0.00545	-0.00750	-6.31^b	-1.75	-1.34
	(-1.68)	(-0.62)	(-0.82)	(-2.08)	(-0.75)	(-1.30)
R^2	0.00229	0.00165	0.00246	0.00172	0.00123	0.00208

Notes: The USD/EUR exchange rate is defined as the number of dollars (numerator currency) per euro (denominator currency) and similarly for the other rates. Returns are defined as 100 times the first difference of the logarithm of the exchange rate. Positive order flow in the USD/EUR market implies net purchases of euro, the denominator currency. a, b, c denote significance at the 1%, 5% and 10% levels respectively. T-stats in parentheses.

Table 5
The Role of Order Flow in Exchange Rate Determination Around Announcements

	USD/EUR return	GBP/EUR return	USD/GBP return
constant	-0.000322^a	-0.000613^a	-0.000325^a
	(-5.79)	(-9.19)	(-7.92)
Flow_t	0.00413^a	0.00397^a	0.00291^a
	(72.80)	(91.49)	(119.53)
$F_t \cdot I^{euro}$ $(1lead)$	-0.00100	0.00809^b	0.000127
	(-0.90)	(2.45)	(0.10)
$F_t \cdot I^{euro}$	0.00626^c	0.000544	0.00206
	(1.77)	(0.34)	(0.75)
$F_t \cdot I^{euro}$ $(1lag)$	-0.00205^a	0.00234	0.000533
	(-2.57)	(0.65)	(0.29)
$F_t \cdot I^{UK}$ $(1lead)$	-0.00207^a	-0.00170^b	0.00181
	(-2.81)	(-2.27)	(1.36)
$F_t \cdot I^{UK}$	0.000531	0.00339^a	0.00322^a
	(0.69)	(3.27)	(3.89)
$F_t \cdot I^{UK}$ $(1lag)$	-0.000583	-0.00330	-0.000447
	(-0.65)	(-1.59)	(-0.58)
$F_t \cdot I^{US}$ $(1lead)$	-0.000952	0.000338	-0.000921
	(-0.98)	(0.20)	(-0.78)
$F_t \cdot I^{US}$	0.00701^a	0.00204	0.00342^b
	(4.09)	(0.89)	(2.17)
$F_t \cdot I^{US}$ $(1lag)$	0.00127	-0.00142	0.00182
	(1.22)	(-1.20)	(1.41)
R^2	0.272	0.173	0.219

Notes: The USD/EUR exchange rate is defined as the number of dollars (numerator currency) per euro (denominator currency) and similarly for the other rates. Returns are defined as 100 times the first difference of the logarithm of the exchange rate. a, b, c denote significance at the 1%, 5% and 10% levels respectively. T-stats in parentheses.

Table 6: Multivariate VAR Analysis of Returns and Flows with Exogenous News Variables

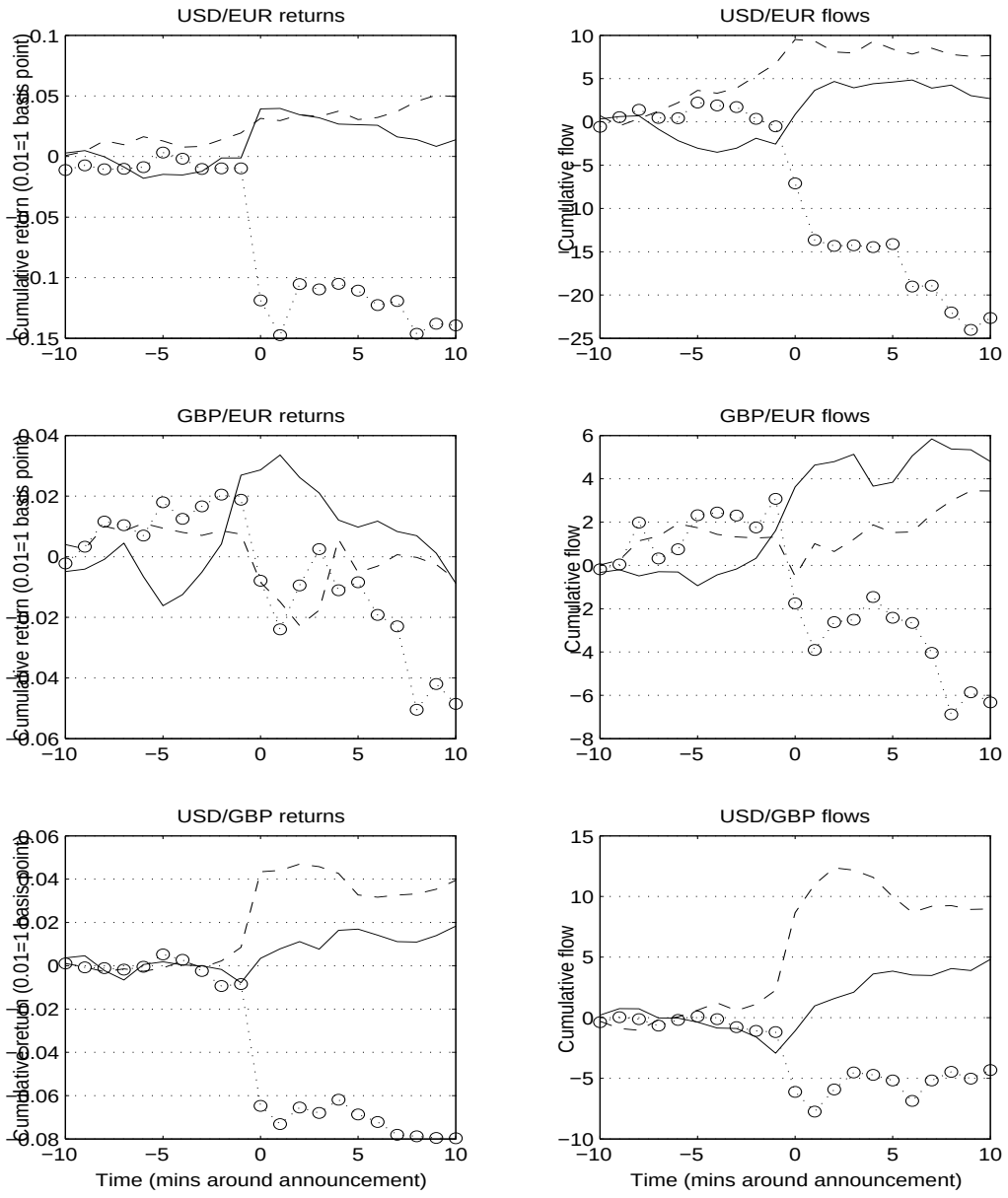
	USD/EUR returns	GBP/EUR returns	USD/GBP returns	USD/EUR flows	GBP/EUR flows	USD/GBP flows
constant	-0.000644^a	-0.000450^a	-0.000188^a	0.0370^a	0.121^a	0.0495^a
	(-8.95)	(-6.58)	(-3.75)	(3.55)	(14.97)	(5.50)
δ	-3.60^a	2.27^a	0.702^a	27.46^b	42.49^a	20.71^c
	(-3.95)	(4.83)	(4.63)	(2.45)	(3.87)	(1.74)
$F_{USD/EUR,t}$	0.00383^a	0.00208^a	0.00101^a			
	(50.42)	(39.32)	(35.94)			
$F_{GBP/EUR,t}$	0.00206^a	0.00328^a	-0.000785^a			
	(40.28)	(67.65)	(-23.36)			
$F_{USD/GBP,t}$	0.00146^a	-0.00101^a	0.00287^a			
	(36.78)	(-24.57)	(100.17)			
$N_{euro,t}$	0.00980^b	-0.00587^b	-0.00130	2.46	1.66	2.48^a
	(2.39)	(-1.99)	(-0.62)	(1.40)	(1.58)	(2.75)
$N_{UK,t}$	0.00204	-0.0184^a	0.0272^a	1.21	-2.47^c	6.38^a
	(0.66)	(-2.61)	(3.27)	(1.45)	(-1.82)	(4.43)
$N_{US,t}$	-0.0248	-0.00927	-0.0228^c	-2.14	-4.56^b	-1.59
	(-1.25)	(-0.61)	(-1.91)	(-0.59)	(-2.23)	(-0.96)
R^2	0.369	0.276	0.272	0.084	0.066	0.054

Notes: The USD/EUR exchange rate is defined as the number of dollars (numerator currency) per euro (denominator currency) and similarly for the other rates. Returns are defined as 100 times the first difference of the logarithm of the exchange rate. Positive order flow in the USD/EUR market implies net purchases of euro, the denominator currency. a, b, c denote significance at the 1%, 5% and 10% levels respectively. T-stats in parentheses.

Table 7: Breakdown of Information Assimilation into 'Flow' and 'Direct' Effects for the Multivariate VAR

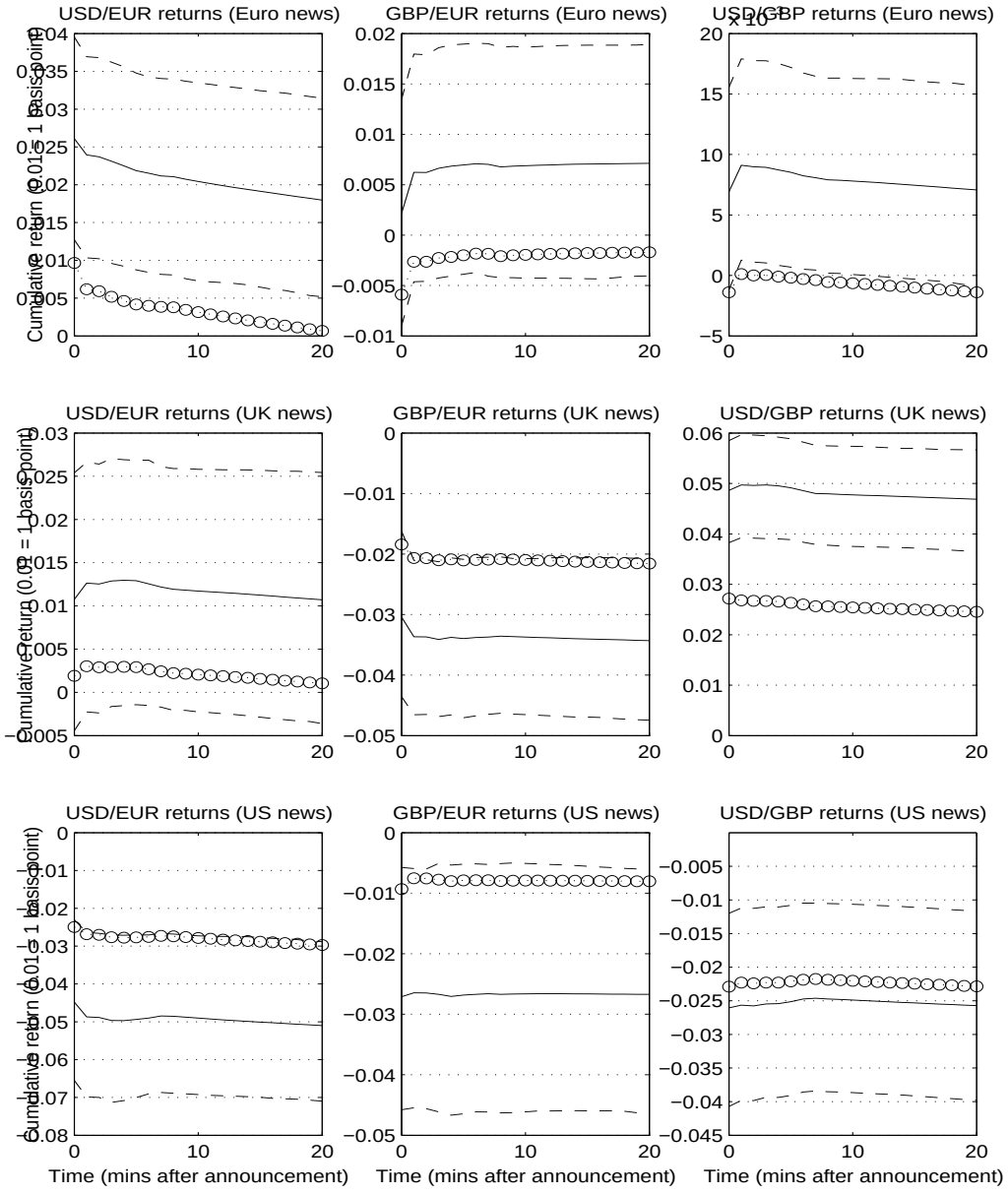
	Time after announcement (mins)	USD/EUR 'Flow' (% share)	USD/EUR 'Direct' (% share)	GBP/EUR 'Flow' (% share)	GBP/EUR 'Direct' (% share)	USD/GBP 'Flow' (% share)	USD/GBP 'Direct' (% share)	Average over all pairs 'Flow' (% share)	Average over all pairs 'Direct' (% share)
Euro	0	62.98	37.02			120.04	-20.04	**91.51**	**8.49**
data	5	80.97	19.03			102.14	-2.14	**91.56**	**8.44**
	20	96.33	3.67			119.74	-19.74	**108.04**	**-8.04**
UK	0	82.29	17.71	39.45	60.55	44.14	55.86	**55.29**	**44.71**
data	5	77.44	22.56	38.06	61.94	46.38	53.62	**53.96**	**46.04**
	20	90.34	9.66	37.12	62.88	47.66	52.34	**58.37**	**41.63**
US	0	44.38	55.62	65.64	34.36	12.12	87.88	**40.71**	**59.29**
data	5	43.89	56.11	70.66	29.34	12.01	87.99	**42.19**	**57.81**
	20	41.75	58.25	69.88	30.12	11.13	88.87	**40.92**	**59.08**
Average	0	**63.22**	**36.78**	**71.54**	**28.46**	**58.77**	**41.23**	**58.88**	**41.12**
over all	5	**67.43**	**32.57**	**54.36**	**45.64**	**53.51**	**46.49**	**58.94**	**41.06**
news	20	**76.14**	**23.86**	**53.50**	**46.50**	**59.51**	**40.49**	**64.24**	**35.76**

Figure 1. Effects of News Releases on Exchange Rate Returns and Flows



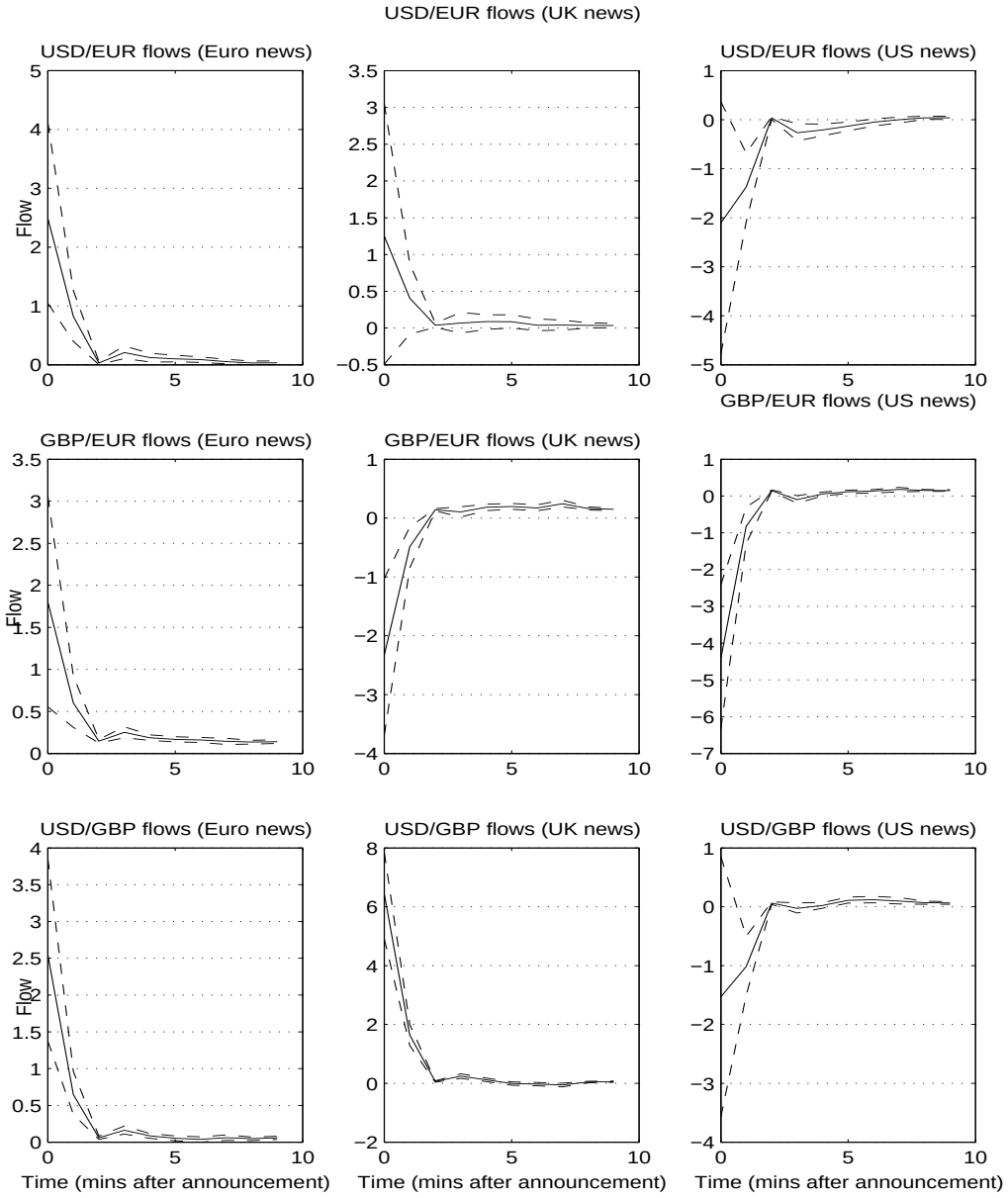
Notes: The figures plot the cumulative returns and flows from ten minutes pre announcement to ten minutes post announcement for each of the foreign exchange markets we consider. The cumulative returns are plotted by firstly regressing returns on leads and lags of news from each region and then summing the coefficients on news over the twenty-one minute time period. In all plots, the solid lines give the responses to euro-area data, the dashed lines give responses to UK data and the lines with circles give effects of US data.

Figure 2. Multivariate VAR Impulse Response Analysis of News on Cumulative Returns



Notes: The figures plot the impulse response functions following a one standard deviation announcement of news from each region. The news shock was introduced into the estimated VAR of equation 5 and the cumulative return calculated. In all plots, the solid lines give the actual impulse response function and the dashed lines trace out a 95% confidence interval for the IRF found by bootstrapping over a thousand iterations. The circles give the implied impulse response when all news coefficients in the order flow equations are set to zero.

Figure 3. Multivariate VAR Impulse Response Analysis of News on Exchange Rate Flows



Notes: The figures plot the impulse response functions following a one standard deviation announcement of news from each region. The news shock was introduced into the estimated VAR of equation 5 and the cumulative flows calculated. In all plots, the solid lines give the actual impulse response function and the dashed lines trace out a 95% confidence interval for the IRF found by bootstrapping over a thousand iterations.