Intraday patterns in FX returns and order flow

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2011-4

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SWISS NATIONAL BANK

Swiss National Bank Working Papers

ISSN 1660-7716 (printed version)
ISSN 1660-7724 (online version)

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November 2010

ABSTRACT

Using 10 years of high-frequency foreign exchange data, we present evidence of time-of-day effects in foreign exchange returns through a significant tendency for currencies to depreciate during local trading hours. We confirm this pattern across a range of currencies and find that, in the case of EUR/USD, it can form a simple, profitable trading strategy. We also find that this pattern is present in order flow and suggest that both patterns relate to the tendency of market participants to be net purchasers of foreign exchange in their own trading hours. Data from alternative sources appear to corroborate that interpretation.

Keywords: Foreign Exchange, Microstructure, Order Flow, Liquidity.

JEL-keys: G15

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1. Introduction

In this paper, we present evidence of a predictable time-of-day pattern in FX order flow[1] and returns. As well as being important in its own right in explaining high-frequency exchange rate dynamics and trading behaviour, this effect has important implications for our overall understanding of FX markets. In particular, if the time-of-day pattern in returns is caused by regular patterns in order flow (which is what our analysis suggests), then our results give support for the traditional portfolio balance effect in FX markets where uninformative (and in this case predictable) changes in net demand have a significant impact on returns. Thus the results presented here make an important contribution to the growing evidence that order flow in general, and portfolio balance effects in particular, are important in FX markets. Recent evidence on liquidity effects has come from a range of sources such as transaction data (Breedon and Vitale (2010)), institutional flows (Froot and Ramadorai (2005)), events such as equity index rebalancing (Hau, Massa and Peress (2010)) and more recent intervention studies (e.g. Fatum and Hutchinson (2003)) and is beginning to overturn the traditional view that these effects are insignificant (cf., for example, Rogoff (1983)). In fact, it could be argued that this intraday pattern is amongst the strongest evidence yet for liquidity effects since it can be observed in a large sample (rather than one-off events like index changes) and seems a clear case of a deterministic trading pattern that cannot be related to private information so its impact on prices is uncontaminated by information effects. Therefore, our results provide further evidence of a liquidity effect from order flow in addition to the considerable evidence on its informational role found in studies such as Evans and Lyons (2005) and Rime et al (2010).

[1] Order flow is the net buying pressure for foreign currency and is signed positive or negative according to whether the initiating party in a transaction is buying or selling (Lyons, 2001).

Despite an extensive literature on time-of-day effects of other aspects of the FX market, such as volatility (e.g. Ballie and Bollerslev (1991), Andersen and Bollerslev (1998)) and turnover (e.g. Hartmann (1999), Ito and Hashimoto (2006)), there are, as far as we know, only two papers on time-of-day effects in returns, Cornett et al (1995) and Ranaldo (2009).[2] This gap is all the more surprising given that both these papers find very similar time-of-day patterns in FX returns whereby local currencies tend to depreciate during their own trading hours and appreciate outside them.

Cornett et al (1995) studies hourly data for US trading hours of FX futures from the IMM market for the period 1977 to 1991. Looking at the Deutsche mark, British pound, Swiss franc, Japanese yen and Canadian dollar, all against the US dollar, they find a significant tendency for the foreign currency to rise during US trading hours, with the majority of that rise occurring in the first and last two hours of trading. They also find that the foreign currency had a significant tendency to fall outside US trading hours such that the overall daily returns had no significant pattern. Ranaldo (2009) uses indicative quotes from the FX spot market to construct hourly data across the whole 24-hour trading period. He uses the same exchange rates as in Cornett et al (1995) in addition to Deutsche mark (euro) against the yen over a more recent period (from 1993 to 2005). He also finds a statistically significant tendency for the domestic currency to depreciate in its own trading hours.

In this paper, we look in more detail at this phenomenon over the period 1997 to 2007 using data on FX spot rates and order flow from EBS – the main interdealer electronic broker for the major currencies. This EBS data gives us two important advantages over the two studies described above. First, EBS gives data on *firm* bid and offer prices throughout the trading day, ensuring a more accurate measure of

[2] The issue of time-of-day effect on returns has received more attention in equity markets (cf., for example, Harris (1986), Smirlock and Starks (1986) and Yadav and Pope (1992)). This is slightly surprising, given the comparatively short trading hours and less promising results found in this market. These studies do not consistently find a strong intraday pattern in equity markets except perhaps for lower returns toward the end of the trading day.

returns and allowing us to measure precisely the potential trading profits (for a member of the interdealer market trading at normal market size) from strategies that exploit the predictable intraday pattern discussed above. Second, our dataset also offers information on trades executed through EBS, allowing us to track a significant portion of total order flow in the market, and so allows us to explore the role of order flow in explaining the intraday pattern in returns. We then supplement this data with more detailed data from a single market maker as well as capital flow data from the US Treasury international capital system. Our approach is entirely empirical and we favour simple models throughout, though the phenomena we discuss here could in principle be modelled as some form of rational inattention, perhaps incorporating time-dependence and observation costs such as in Abel, Eberly and Panageas (2009).

The rest of this paper is organised as follows. Section 2 describes our data and the statistical properties of the time-of-day effect in returns. Section 3 then investigates whether this pattern is related to FX order flow. Section 4 offers more insight on this phenomenon from more detailed data provided by a single market maker and capital flow data. Section 5 concludes.

2 Data and time-of-day effects

2.1 Data

We employ a detailed transactions data set for the period January 1997 to the beginning of June 2007 from EBS the dominant electronic broker in major crosses. Along with Reuters, the EBS electronic order book has now effectively displaced voice brokers and direct dealing between traders. In practice EBS has become dominant in the major currency pairs (EUR/USD and USD/JPY), while Reuters dominates in most of the minor crosses. In this paper we analyse six crosses (EUR/USD, USD/JPY, GBP/USD, EUR/JPY, USD/CHF and AUD/USD) in order to give results for a range of different time zones, while focussing

mainly on the major crosses in which EBS is dominant. By combining data from the BIS triennial survey of foreign exchange turnover with data from Breedon and Vitale (2004) on the relative position of EBS and Reuters in electronic trading, we estimate that our EBS data covers roughly one half of total turnover in EUR/USD, USD/JPY, EUR/JPY and USD/CHF but less than 5% of GBP/USD and AUD/USD turnover (where Reuters dominates).

Over the whole sample we have the number of customer-initiated buy and sells and the price at which each trade was undertaken. We also have data on the best bid and offer available over the full sample, barring a few periods when no trading occurs and none is expected (e.g. Saturday morning GMT). For most crosses we exclude weekends from our analysis, from Friday 24:00 to Saturday 24:00 GMT, though in the case of JPY and AUD, the week is extended from Saturday 18:00 GMT to Friday 24:00 GMT.[3] For the main results in this paper we include holidays, except where no trading occurs whatsoever[4]. For the purposes of this paper we aggregate the transaction data into hourly data so that we work with the end-hour bid and ask prices and the cumulative trades over the hour.

2.2 Time of Day effects

We begin by testing the relationship between both hourly returns and trading session returns over the average trading day for our sample of currencies. Throughout this section we define returns using the prevailing midquote price at the end of each hour/session. Our initial goal is to confirm the results of Cornett et al (1995) and Ranaldo (2009), that local currencies tend to depreciate in their own trading hours and to appreciate outside them, and to establish any hourly patterns that contribute to that effect.

[3] These definitions of working time match the main trading activity in the different world regions. Other definitions have been considered and the results remain unchanged.

[4] In particular, we checked all the tests both including and excluding periods of no transactions. This control test guarantees that all the patterns are related to the trading activity and all trading rules are tradable.

Table 1: Estimated trading hours in FX markets

Trading centre	Trading hours (local time)	Relative to New York time (standard/daylight saving)	Futures markets
United States	08.00-16.00	-	NYBOT, CME. PHLX
Europe	07.00-15.00	+5 hours†	NYBOT(Dublin)
Japan	8.00-15.00	+13/+14 hours	TIF (no FX)
Australia	10.00-16.00	+14/+16 hours†	ASX (FX Warrant)

† For these regions, daylight saving does not begin/end on the same date as New York; we allow for this in our calculations

As an OTC market that trades across several time zones, the foreign exchange market does not have precise trading hours, though it is clear that traders in particular locations tend to operate over fairly fixed trading hours. We take futures trading hours (FX futures where possible) as our guide and find that these opening hours fit well with distinct increases in trading volume that occur before – and thus are unrelated to – news releases and standard fixings (and so are presumably related to the initial trading increase as local traders become active). We then convert these hours into New York time which is the universally accepted time zone for OTC FX transactions (i.e. the official end of the trading day is 5pm New York time, and FX option expiry is at 10am). Table 1 presents our assessment of these hours (note that the results presented below are not substantially affected by the precise choice of trading times).

We present three tests of the relationship between hourly returns and time of day, a simple test of significant excess returns, an excess returns test adjusted for time-varying volatility and a non-parametric sign test of returns.

1) **Simple test of significant excess returns**. We conduct two-sample t-tests for the acceptance of the null hypothesis of equality in means. These t-statistics refer to two-tail statistics on the difference

between a given intraday return mean over all the returns at the same intraday period. We perform the two-sample equal variance (homoscedastic) test.[5]

2) **Excess returns allowing for heteroscedasticity and autocorrelation**. A drawback of a simple test of excess returns is that it does not allow for the fact that the volatility of returns varies markedly over the trading day – with volatility usually concentrated in the morning sessions of each of the currencies in a given pair. It is also the case that simple tests may be biased in the presence of autocorrelation of returns. To help adjust for these effects we estimate a time of day returns model where volatility has a simple time-of-day structure and returns may be autocorrelated. We performed GARCH regressions as follows:

$$r_{t,i} = \sum_{h=1}^{24} \alpha_h . d_h + \sum_{k=1}^{k} \rho_h . r_{t,i-k} + \varepsilon_{t,i} \quad (1)$$

$$\sigma^2_{t,i} = \sum_{h=1}^{24} \omega_h d_h + \gamma \varepsilon^2_{t,i-1} + \lambda \sigma^2_{t,i-1} \quad (2)$$

Where r is the log change of the exchange rate from end hour i-1 to i on day t, d is a dummy variable equal to one at hour h and 0 otherwise, ε is the residual and α and ρ are estimated parameters, and *k* is chosen according to the Schwarz criterion. The conditional variance σ^2 of the error term is defined in equation 2 in which ω, γ and λ are parameters. This GARCH model accounts for three main statistical characteristics of the time series of intraday returns: autocorrelation, heteroscedasticity and non-Gaussian errors. We also experimented with some other specifications such as including a moving average term, but this did not materially change the results.

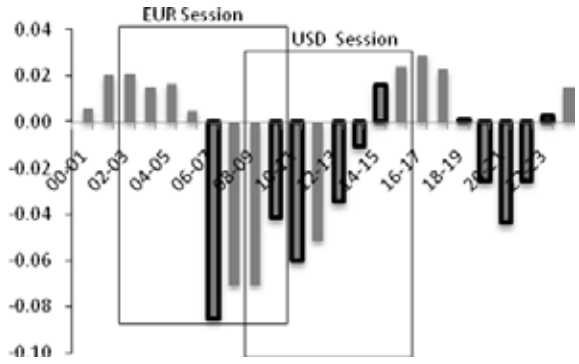
3) Sign test. As a simple non-parametric test of the properties of hourly returns we also assess the probability of observing positive returns in a given period and test the significance of that

[5] The homoscedastic t-test is a stricter test than the heteroscedastic case. In fact, the probability associated with a Student's t-test for equality in means has an upward bias and leads to a more likely rejection of the inequality hypothesis.

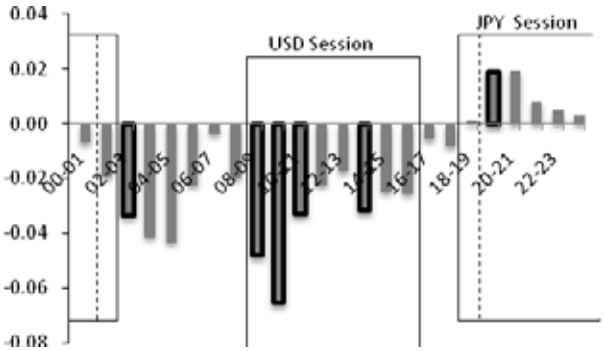
probability using a binomial distribution (we also conducted the Wilcoxon signed ranks test – results available from the authors).

Figure 1: Cumulative returns over an average day 1997-2007 (New York time)

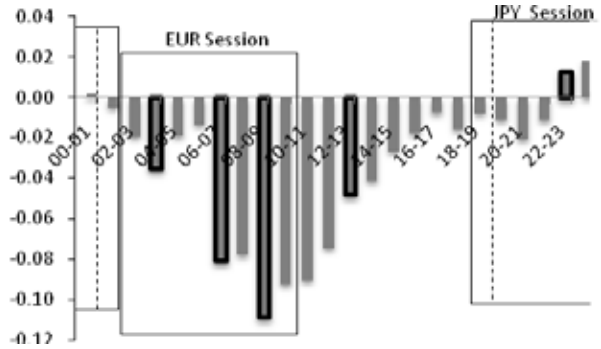
EUR/USD (base currency EUR)



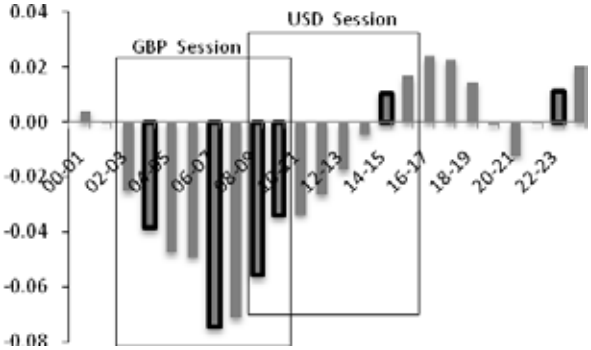
USD/JPY (base currency USD)



EUR/JPY (base currency EUR)

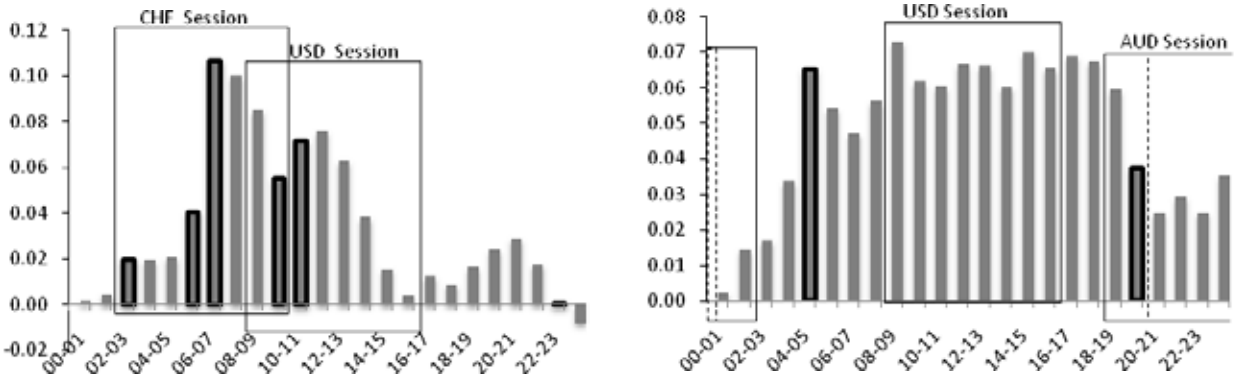


GBP/USD (base currency GBP)



USD/CHF(base currency USD)

AUD/USD (base currency AUD)



Average annualised log returns cumulated over a trading day. Columns in bold indicate hourly return is significantly different from zero at the 5% level (based on simple t-test described above).

Figure 1 presents visual evidence that hourly FX returns do seem to follow significant time of day patterns, which, as predicted, show that local currencies tend to depreciate during their own trading hours. Table 2 tests the trading hours phenomenon more precisely by conducting our tests on opening-to-closing or opening-to-opening (for the cases when the opening session of one side of the currency pair occurs whilst the first market is still open – as in the case of EUR/USD)

Table 2: Statistical properties of trading session returns

	Trading session	Mid-quote return	Mid-quote return GARCH	Share positive	Trading return
EUR/USD	EUR session	-0.084**	-0.095**	0.44**	0.06
	USD session	0.100**	0.111**	0.53*	0.07
USD/JPY	JPY session	0.017**	0.029*	0.51	-0.13
	USD session	0.000	0.018	0.50	-0.05
EUR/JPY	EUR session	0.029**	0.041*	0.52	-0.05
	JPY session	-0.057**	-0.040*	0.48**	-0.42
GBP/USD	GBP session	-0.071**	-0.066**	0.45**	-0.12
	USD session	0.092**	0.126**	0.55**	-0.08
USD/CHF	CHF session	0.095**	0.108**	0.56**	-0.08
	USD session	-0.088**	-0.105**	0.48	-0.02
AUD/USD	AUD session	-0.028**	-0.038*	0.50	-0.51
	USD session	0.016**	0.023	0.52**	-0.50

Annualised log returns *,** indicate statistical significance at the 5% and 1% level respectively (t-test for mid quote return, F-test for GARCH and Binomial Test for share positive)

Starting with the simple mid-quote return, all returns are of the predicted sign and significant except USD/JPY in the USD session. After adjusting for autocorrelation and heteroscedasticity in returns, the

results are very similar though less significant with AUD/USD in the USD session becoming insignificant and a number of session returns becoming significant at the 5% level rather than the 1% level Finally, although not all the sign tests are individually conclusive the pattern of probabilities is consistent.

The final column of Table 2 shows the returns from a simple open-to-close/open-to-open trading strategy including transactions costs. Thus in this case we measure returns using bid and ask prices rather than the midquotes used in the rest of the table (recall that on EBS the quoted bid and ask prices are firm and thus could be transacted at normal size by the interdealer community) and go short the base currency in its own trading hours and long in the trading hours of the counter currency. As might be expected, most of these simple time-of-day trading strategies are not profitable when trading costs are included. However, the notable exception is EUR/USD where the significant intraday pattern combined with narrow spreads in this cross means that this basic strategy has been profitable on average with Sharpe Ratios of 1.3 and 0.9 respectively for the morning short and afternoon long. This result is even more surprising when one considers that we have made no allowance for bank holidays or other simple adjustments that could presumably improve returns[6] since we wish to minimise the possibility of data-mining biases.

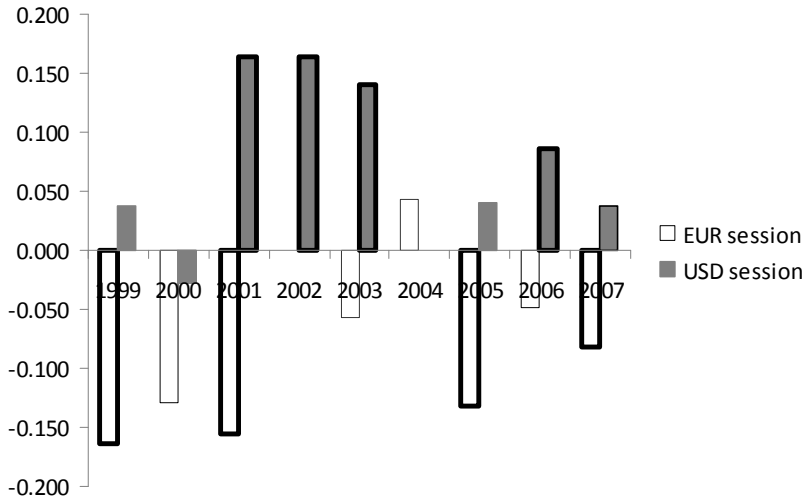
2.3 Stability through time

Since the time-of-day phenomenon was first documented some years ago (Cornett et al (1995)), it is possible that its impact has diminished more recently. Figure 2 shows the significance of the EUR/USD trading day effect through time by estimating average returns over the European and US trading sessions year by year. Interestingly, although the returns over each session individually show

[6] Bank holiday effects seem quite powerful in practice. For example, the dollar has appreciated against the euro (or DM) over the July 4 Federal holiday on 15 of the last 20 occasions. This is presumably due to the absence of US-based order flow on that day (see Ranaldo (2009) for further analysis).

considerable variation, the difference in returns between the two sessions remains remarkably stable. Only in 2004 do we find marginally higher returns in the EUR session than in the USD session in almost all other years the gap between returns is both significant and of the expected sign. We find similar stability over time for the other currency pairs.

Figure 2: Trading day effect over time (EUR/USD)



Average annualised log return for each year. Solid borders indicate returns significantly different from zero at 5% level using standard t-test.

3 Time of day effects and order flow

In section 2, we saw that all the currencies in our sample displayed a significant tendency to depreciate in local trading hours and that, in the case of EUR/USD, this tendency could be exploited to generate trading profits. In this section, we explore the relationship of this effect to order flow.

3.1 Time of day effects in FX order flow

Table 3 repeats the time-of-day analysis of Table 2, but this time for order flow (number of buy orders minus number of sell orders on EBS). Throughout the table we see a tendency for local currency selling to occur in local trading hours although the effect is not always significant (perhaps reflecting the

incomplete coverage of our order flow data). The one exception is AUD/USD where both the low market share of EBS coupled with AUD buying by larger Asian trading centres such as Tokyo and Singapore (that are, anecdotally, more likely to use EBS) mean there is more AUD buying recorded on EBS in the AUD session than in the USD session. Generally, however, we tend to see a strong relationship between average hourly order flow and average hourly returns (Figure 3).

Table 3: Statistical properties of trading session order flow

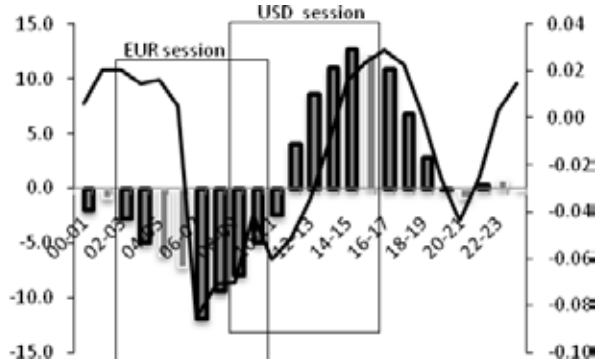
	Time period	Order flow	Order flow GARCH	Share positive	Residual returns
EUR/USD	EUR session	-2.190**	-1.415**	0.457**	0.0098
	USD session	2.284**	3.950**	0.522**	0.0004
USD/JPY	JPY session	0.374	0.222	0.505	0.0003
	USD session	-0.278*	-0.164	0.496	0.0003
EUR/JPY	EUR session	0.065	0.020	0.487*	-0.0006
	JPY session	0.308**	0.450*	0.520**	0.0001
GBP/USD	GBP session	-0.264**	-0.284**	0.483**	-0.0001
	USD session	0.132**	0.213**	0.509*	0.0004
USD/CHF	CHF session	1.461**	1.500**	0.530**	-0.0002
	USD session	0.329	1.254*	0.496	-0.0005
AUD/USD	AUD session	0.016	0.449*	0.502	-0.0002
	USD session	-0.500*	-0.271	0.598	0.0000

Average hourly order flow in number of trades *,** indicate statistical significance at the 5% and 1% level respectively. The statistical tests used are as follows: Column 3 - T-test for assessing the difference in order flow averages (during country working hours versus the entire population) Column 4 - Wald test to assess if coefficients related to the dummy variables for each session are different from zero (from GARCH regression as described above). Column 5: Sign tests based on cumulative Bernoulli distribution. Column 6: t-test of residual seasonality of regression of returns on order flow

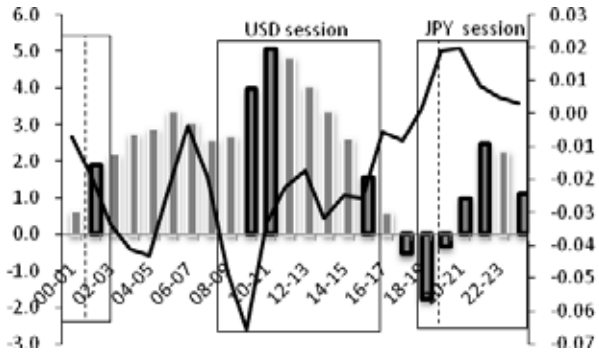
This result suggests that it is the timing of trades that is largely responsible for the intraday pattern in returns. A plausible explanation for this pattern of order flow (which we discuss further below) is that international investment funds tend to conduct currency trades in their own trading hours and that since they tend to receive net inflows of domestic currency (since they tend to grow over time) this implies a bias against the local currency in domestic trading hours. Additionally, Cornett et al (1995) highlight currency of invoicing effects that lead importers to be net demanders of foreign currency rather than exporters, as imports are more commonly invoiced in foreign currency. Once again the tendency of these trades to be conducted in local trading hours gives the pattern we observe here.

Figure 3: Cumulative order flow and returns on an average day (New York time)

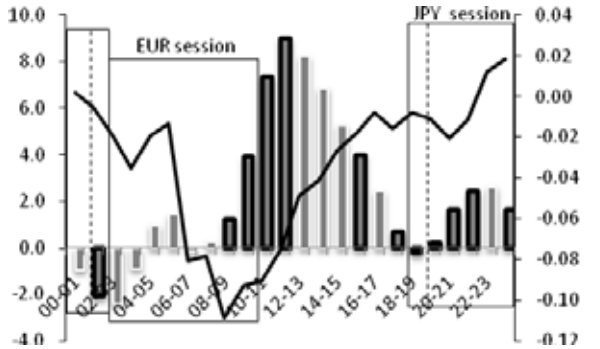
EUR/USD



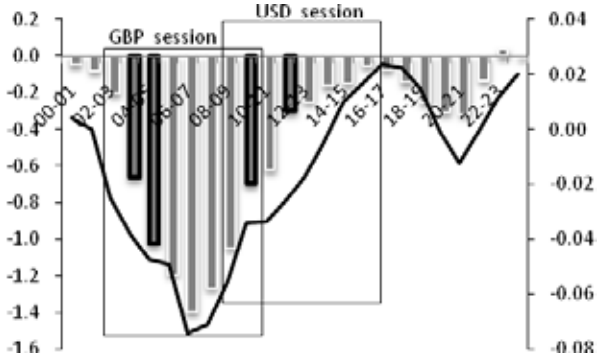
USD/JPY



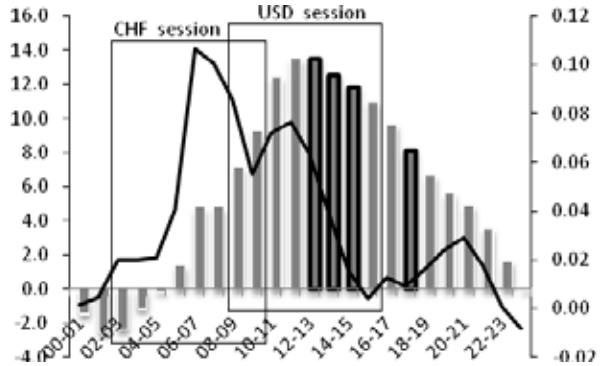
EUR/JPY



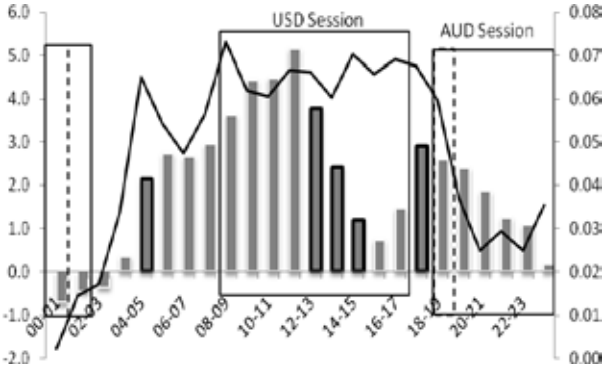
GBP/USD



USD/CHF



AUD/USD



Columns show cumulative order flow in number of trades (left-hand scale). Line shows cumulative annualised log returns (right-hand scale). Columns in bold indicate hourly order flow significantly different from zero at the 5% level based on t-test. Trading sessions as in Figure 1

3.2 The order flow returns relationship

As Figure 3 shows, both FX returns and order flow display a similar intraday pattern. In this section we conduct a simple test to see if pattern in order flow can explain the pattern in returns.

To do this we employ the simple model of order flow and returns, like the one proposed by Hasbrouck (1991), where returns are a function of contemporaneous order flow and lags of both order flow and returns. Although this kind of model has been criticised both for assuming that contemporaneous returns do not influence order flow and for not allowing for any cointegrating relationship between cumulative order flow and the asset price (see for example, Love and Payne (2008)), it is adequate for our purpose since we simply require a straightforward framework in which to analyse the intraday pattern of order flow and returns. As is standard in the literature (e.g. Chinn and Moore (2008)), we find a very strong contemporaneous relationship between order flow and returns with lagged effects generally far weaker and often insignificant (details available from the authors). The last column of table 3 shows the average cumulative residuals of our simple model over each trading session and tests if they display any residual intraday pattern. Tests confirm that they is no significant residual intraday pattern in returns for any currency pair after order flow is allowed for, suggesting that the intraday pattern in order flow is sufficient to explain the intraday pattern in returns.

4 Further evidence on order flow

Although order flow data from EBS give us an excellent coverage of the interbank market, the dataset we have gives us no information on the geographical location or identity of the counterparties. It is also unclear if order flow from this source has any correspondence with macroeconomic data on capital flows. In this section, we look at data from a single market maker and from detailed US capital flow data in order to address these limitations.

4.1 Data from a single market maker

We are lucky to have access to order flow data from BNP Paribas on both the geographical location and type of customer orders. Paribas have kindly supplied us with data on the size, sign and counterparty type and geographical location of all their customer trades over the period January 2005 to May 2007. Although not a key market maker, BNP Paribas is estimated to be one of the top 15 market makers (in terms of market share) for corporations, banks and real money accounts (with estimated market shares of 3.1%, 2.9% and 1.4% respectively), though not for leveraged funds (Euromoney FX poll 2008).

Table 4: Average order flow imbalance in local trading hours: BNP Paribas data

	EUR/USD	USD/JPY	EUR/JPY	GBP/USD	USD/CHF	AUD/USD
European-based order flow	-0.85		-0.30	-0.04	-0.28	
US-based order flow	0.01	-0.20*		0.03	-0.06	0.02
Asia/Australasia-based order flow		0.90*	0.07*			-0.06*

Average order flow imbalance in millions of dollars is for customers of a given geographic location in their own trading hours. * indicates that imbalance is statistically significant at the 5% level based on a difference in means test versus mean imbalance of aggregate order flow over whole trading day

Table 4 shows a more detailed analysis of order flow in different trading periods by different location of customer. Here we see the expected pattern whereby local customers tend to be net sellers of the local currency in local trading hours, though this effect is only statistically significant in a few cases. The strongest results are for USD/JPY, where both US and Asian imbalances are significant. This is slightly surprising given the mixed results we obtained for USD/JPY with EBS data. The only exception to the selling in local hours pattern is USD/CHF in European trading hours (which appears to be offset by net out-of-hours purchases by European customers for reasons we cannot explain).

Further analysis by type of customer (available from the authors) shows that banks and investment funds have the strongest tendency to sell their own currency in local trading hours, while this effect is not observed in trades by corporations (though the sample of such trades is small). This suggests that

the time-of-day pattern in order flow is not restricted to currency of invoicing effects as implied by Cornett et al (1995).

4.2 Data from the Treasury International Capital System

Although the intra-day effect we have identified is clearly a microstructure phenomenon, it is interesting to see if we can find some correspondence between the results we have found here and macroeconomic capital flow data. Data from the US Treasury International Capital System (TIC) allow us to look in some detail at flows by geographic source and so make some general observations. We use the TIC data on equity flows (which are the most likely to involve an outright currency exposure) to check two propositions

1) Is it the case that US investors tend to be net purchasers of foreign equity and vice versa, as our Paribas data suggest?
2) Are the intra-day patterns we have identified correlated with measured flows at the macro level? More precisely, is the average intraday fall in the dollar in US hours over each month correlated with the recorded net purchase of foreign equity by US citizens over that month (and vice versa for flows into the US)?

Table 5: Evidence from US cross-border equity flow data

	EUR/USD	USD/JPY	GBP/USD	USD/CHF	AUD/USD
Average net purchases of US equity by foreigners (% of holdings, AR)	6.0%	1.9%	14.3%	3.1%	2.1%
Average net purchases of foreign equity by US (% of holdings, AR)	0.1%	6.3%	4.2%	0.3%	3.4%
Correlation of return in US time with US purchases	0.13$^{\psi}$	0.04	0.11	0.10	0.09
Correlation of return in foreign time with foreign purchases	0.18*	0.06	-0.03	0.07	0.18*

Average net purchases shows net purchases by country X of US equity (or US purchases of country X equity) as a percentage of estimated average holdings of US equity by country X (or holding of country X equity by the US) expressed at an annual rate.

Correlations show relationship between the average mid-quote intraday trading session return over the month with net foreign equity purchases that month. $^{\psi}$,* indicates significance at 10% and 5% level respectively. All flow and stock data from TIC

Table 5 summarises our results using TIC data. It confirms that local investors tend to be net purchasers of foreign equity, as we expected, and that the intraday pattern in returns is generally positively correlated with the scale of these net purchases (significantly so in the case of EUR/USD and AUD/USD) since the correlation shows that the average time of day effect is larger in months when net equity outflows are large.

5 Conclusion

Although the phenomenon we have outlined here is a relatively straightforward one and our empirical approach has been a deliberately simple one, our results have wide-ranging implications. First, we provide possibly the strongest evidence yet of the importance of order flow in driving FX returns through a mechanism not driven by asymmetric information. Thus our results give further support to the microstructure approach to FX in general and the importance of liquidity effects in particular. Second, as a description of intraday dynamics, our results have implications for portfolio management and the timing of FX trades as well as for the design of profitable intraday trading rules. Third, our results indicate the kind of mechanism through which FX dealers can make significant trading profits without any informational advantage and despite narrow quoted spreads (see for example, Mende and Menkhoff (2006)), in this case by intermediating between different trading sessions. Of course, we have left a number of important questions unanswered. For example, why do investors not time their trades more effectively, and could a more sophisticated trading rule increase the profitability of time-of-day trading strategies? We leave these questions to future research.

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