

A Guided Tour of the Market Microstructure Approach to Exchange Rate Determination*

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Abstract

We propose a critical review of recent developments in exchange rate economics which have offered a novel approach to exchange rate determination. This new strand of research, the market microstructure approach to exchange rates, is motivated by some very stark empirical evidence, relating exchange rate dynamics to the imbalance in the sequence of purchases and sales of foreign currencies in the markets for foreign exchange. Through our review we outline the results this new strand of research has achieved alongside its open questions and future challenges.

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Introduction

In the 1980s an extensive body of empirical research on the models of exchange rate determination developed in the 1970s indicated how these were not able to explain exchange rate movements in the short-run. Typically, the coefficients of the regressors employed to explain exchange rate dynamics would present the wrong sign or would not be significantly different from zero, while the coefficient of multiple correlation would take extremely low values.¹ On the other hand, more recent empirical studies based on cointegration analysis suggest that the equilibrium relations provided by these models hold in the long-run.²

A popular explanation for the difficulty of these traditional models in explaining short-run exchange rate dynamics lies with the particular forward looking nature of currency values and with the impact that the arrivals of news on macro variables have on exchange rates. Indeed, when news reaches financial markets, conditioning market expectations of future values of exchange rate fundamentals, currency values immediately react anticipating the effect of these fundamental shifts. Since news is hard to observe, it is difficult to control for news effects on exchange rate dynamics and hence it is hard to conduct any meaningful analysis of traditional models of exchange rate determination.

With this background, a new strand of research has proposed a novel approach to exchange rate determination. Very recently researchers have gained access to detailed data on the transactions of individual traders in foreign exchange (FX) markets and have hence turned their attention to the study of such trading activity. Indeed, it has been suggested that moving from a macro to a micro perspective allows to bypass the analysis of the relation between fundamental variables and exchange rates. According to this approach the imbalance between buyer-initiated and seller-initiated trades in FX markets represents the transmission link between fundamental information and exchange rates, in that it conveys information on deeper determinants of exchange rates, which FX markets need to aggregate and impound in currency values.

In this survey we do not attempt to offer a comprehensive overview of what is generally referred as the *market microstructure approach* to exchange rates, we rather prefer to conduct a guided tour of the most interesting and promising contributions of this very recent strand of research.³ Moreover, we limit the boundaries of our survey as we concentrate on exchange rate determination. This means that we do not discuss contributions which apply the market microstructure approach to other international finance questions, such as the analysis of market performance, market design,

¹See *inter alia* Meese and Rogoff (1983), Backus (1984), Frankel (1993) and Frankel and Rose (1994).

²See Mark (1995) and McDonald and Taylor (1995).

³An extremely useful website containing up-to-date information on the market microstructure approach to exchange rates can be found at the following URL: <http://faculty.haas.berkeley.edu/lyons/wpothers.html>.

monetary union and alternative exchange rate regimes.

The survey is structured as follows. In Section 1 we briefly present the trading structure of FX markets. In the following Section, it is discussed some stark evidence showing a strong contemporaneous correlation between order flow and exchange rate variations. In Section 3, we discuss estimates of VAR models of order flow and exchange rate returns. In this way proper impulse response functions can be derived and short- and long-term effects of shocks can be studied, so as to outline possibly portfolio-balance and information effects of currency trades. In Section 4, the VAR approach is extended to consider the short- and long-term inter-relations between order flow, exchange rate returns and fundamentals. In the same Section we also examine the predicting power of order flow with respect to future fundamentals and exchange rates.

In Section 5, a simple structural model of exchange rate determination offers a theoretical underpinning for the empirical evidence pertaining to the relation between spot rates, fundamentals and order flow. Since order flow is often assigned an information content, in Section 6 empirical studies of the inter-relation between order flow, news arrivals and spot rates are examined. In Section 7 we discuss the role of central bank intervention in FX markets, since it corresponds to a very important component of order flow. A final Section concludes with some general remarks on the achievements and future challenges of this strand of research.

1 The Microstructure of Foreign Exchange Markets

Market microstructure theory is devoted to the study of the trading process in securities markets under explicit trading rules.⁴ According to this theory the organization and regulation of trading in securities markets have important implications for the process of price formation and more generally for all characteristics of these markets. However, this theory has been developed having in mind equity markets and therefore it is mainly oriented toward micro questions, such as institution design, regulation, and market performance.

The market microstructure approach to exchange rates is instead concerned with macro issues and is particularly interested in shedding some light on exchange rate determination. Thus, whereas the market microstructure approach to exchange rates borrows the economic concepts and the techniques of investigation developed within the traditional equity market microstructure theory, it applies them to different questions and employs different sets of data and variables.

Before we can examine the market microstructure approach to exchange rate determination, let

⁴See O'Hara (1995) for an introduction to market microstructure theory and Madhavan (2000) for an exposition of more recent developments.

us see in some detail the structure of FX markets. We should concentrate on four central aspects of this structure. Firstly, one should note that since these markets by their nature are dislocated in several financial centers, practically *no* rules can be imposed on their functioning and the activity of their participants. This means that their organization is not the result of the decisions of some authorities but the consequence of their *natural* evolution.

Secondly, one can easily classify the population of foreign exchange traders according to three different types of agents: FX dealers, brokers and customers. FX dealers, generally from the financial division of major commercial banks, trade among each others and with customers. These may be large corporations or financial institutions. Brokers are agents who do not trade on their own account. Instead, they help customers and/or FX dealers to complete their desired transactions.

Thirdly, transactions among these market participants can be either *direct* or can be *mediated* by a broker. Several estimations suggest that the inter-dealer market accounts for about 50 to 60 percent of the total volume of trading and that almost 50% of these transactions are carried out through a broker (BIS (2001,2004)).

Fourthly, in FX markets two different mechanisms of trading coexist: the *direct* (bilateral) market is *quote-driven* and *decentralized*, while the *indirect* (brokered) market is *order-driven* and *quasi-centralized*. As transactions can be completed at any time, markets for foreign exchange are also *continuous*. We will now try to explain briefly what we mean with this terminology, whilst for a more extensive analysis we refer to Lyons (2001) and Rime (2003).

The direct market operates like other *dealership* markets, such as the Nasdaq or the London Stock Exchange (LSE), where transactions are the result of private bilateral “meetings” between traders. In the past these meetings have generally been conducted on the phone. Nowadays, though, FX dealers employ electronic communication systems, such as the Reuters Dealing 3000 spot matching system.

In the direct market transactions are *quote-driven* because prices are fixed *before* quantities. In fact, clients contact single dealers, which “make the market” quoting bid and ask prices for any specific foreign currency they trade. These quotes specify at which prices dealers (*market makers*) will be ready to buy (bid) and to sell (ask) it. Then, clients can place orders to buy or sell the currency. Since quotes are valid for orders not exceeding some prefixed amount, the size of these transactions is limited, even though most market makers will accept very large orders.

The direct market is *decentralized* or fragmented in that transactions are completed through private bilateral deals among traders and *cannot* be observed by other market participants. On the contrary, in other securities markets, such as the NYSE, all transactions are centralized, because

trading is organized around a single market maker or according to an *open outcry system*. Moreover, there are other decentralized markets, notably the LSE, in which dealers are forced by institutional rules to communicate almost immediately information on their sequence of transactions to all other traders. These mechanisms of *consolidation* are absent in the direct FX market, that hence remains fragmented and *opaque*.

The indirect market is *order-driven*. Here prices and quantities are set *altogether*. Moreover, transactions are not the result of simple bilateral deals, but are mediated by brokers, that is agents who do not deal on their own but operate on account of clients charging a small transaction fee. Any broker keeps a *book* of *limit orders* placed by his/her clients. Limit orders placed with a broker are matched against other *market* and limit orders from other traders. A limit order specifies the amount of a particular currency a trader is willing to sell (buy) and the minimum (maximum) price he/she will accept. A market order indicates the intention to buy (sell) immediately a given quantity of the foreign currency at the existing *best* price.

In the past, the indirect market was operated on the phone. Traders would call a broker and ask for his *inside* spread on his/her *limit order book*. This means that the broker would quote the best buy and sell limit orders contained in his/her book and that the trader would then have the faculty to “hit” them, taking the other side of the outstanding orders. Nowadays the indirect market is dominated by *electronic* brokerage systems, such as EBS and Reuters Dealing 2000-2.

The trading platforms of these electronic brokerage systems share some common features with those of some centralized equity markets, such as the Paris Bourse or the SETS system in London. The platform’s subscribers are attached to a screen reporting the best outstanding buy and sell limit orders for a set of foreign currencies on an *electronic* limit order book. All other limit orders remain in the background and are used to up-date the information available to the subscribers when a transaction is completed or one of the best orders is withdrawn. At any time subscribers can hit the limit orders posted on the screen or add their owns.

Since these are centralized mechanisms of trading, the indirect market is *quasi-centralized*. However, given that the identities of traders which complete a transaction are kept *anonymous*, in that they are not published on the platform screen, the indirect market remains partially opaque.

2 The Explanatory Power of Order Flow

Traditional models of exchange rate determination are based on two fundamental principles: i) exchange rate determination is basically a macro phenomenon, in that exchange rate movements are uniquely determined by shifts in macro aggregates; and ii) exchange rates immediately react to shifts in macro aggregates. In other words, after a variation in the inflation rate or in the GDP growth a new equilibrium exchange rate is reached without any change in investors' portfolios.

The meagre explanatory power of these traditional models alongside the empirical evidence showing the importance of micro-structural aspects of the functioning of equity markets in explaining short-term movements in equity prices have induced many researchers to turn their attention toward the trading activity of market participants and *order flow* in FX markets.

Order flow is defined as the *net* of the buyer-initiated and seller-initiated orders in a securities market. It is the simplest measure of buying *pressure* and it is calculated from: i) the sequence of market orders reaching market makers in dealership markets; and ii) the sequence of market and limit orders which reach electronic trading platforms and cross with existing posted limit orders.⁵ Order flow may convey information on exchange rate fundamentals, which FX markets need to aggregate and impound in currency values.

Evans and Lyons (2002) consider a very simple model of exchange rate determination which makes use of the information contained in order flow. According to this model daily exchange rate variations are determined by changes in the interest rate differential, as suggested by traditional models, and *signed order flow*. Thus,

$$\Delta s_{t+1} = \beta_i \Delta(i_t^* - i_t) + \beta_z z_t, \quad (1)$$

where Δs_{t+1} is the first difference in the log of the foreign exchange price within day t , $s_{t+1} - s_t$, $\Delta(i_t^* - i_t)$ is the first difference in the interest rate differential, $(i_t^* - i_t) - (i_{t-1}^* - i_{t-1})$, and z_t is the difference between the number of buyer-initiated and seller-initiated trades in day t .⁶

To interpret this simple linear specification consider that a positive value for z_t implies that within day t the number of buy orders exceed that of sell ones. This means that a majority of traders has purchased the foreign currency during the day, indicating that they consider the

⁵Two distinct groups of traders operate on electronic trading platforms: “patient” or “passive” traders, which are willing to offer liquidity at given prices; and “impatient” or “active” traders which, in search of immediacy, hit outstanding limit orders and consume the liquidity offered by the former group. Impatient traders are interpreted as the initiators of transactions as their orders move prices and alter market conditions.

⁶Evans and Lyons write equation (1) differently, as the dependent variable in their model is the price of the *domestic* currency in terms of the foreign one. We follow the usual convention.

foreign currency undervalued. This imbalance might reflect all that news, in the form of macro announcements, data releases, etc., which reaches FX markets and induces traders to modify their evaluations of exchange rate returns and their portfolios of assets.

This interpretation is borrowed from equity market microstructure theory. Thus, Glosten and Milgrom (1985) and Kyle (1985) have developed market micro structure models in which trade innovations in equity markets contain information on future dividend announcements, which condition the fundamental values of equities and hence their equilibrium prices.⁷ Clearly, in the context of the market microstructure approach to exchange rates information on dividends is replaced by information on exchange rate fundamentals, such as interest rates, unemployment levels, GDP growth rates, and so on.

Evans and Lyons employ data pertaining to *all* bilateral transactions completed among FX dealers via the Reuters Dealing 2000-1 electronic trading system in the spot USD/DEM and USD/JPY markets between May 1st and August 31st 1996.⁸ Their data-set *indicates* for any transaction the exchange rate, which of the two counter-parties bought and sold and, more importantly, which initiated the transaction, allowing thus to define the corresponding direction (i.e. if a buy or a sell order) of trade. The data-set does *not* report either the transaction *size* or the counter-parties' identity.

Evans and Lyons consolidate their transaction data at the daily level and then estimate equation (1). They find that both for the USD/DEM and USD/JPY regressions a positive value for the order flow z_t induces an increase in the spot rate. Thus, in the case of the USD/DEM regression, Evans and Lyons estimate that in a day where DEM buy orders exceed DEM sell orders by 1000 the German currency appreciates by 2.1%. Given that the average trade size in the sample for the spot USD/DEM market is \$3.9 million, \$1 billion net purchases of the German currency increases its value by 0.54%. Assuming that the USD/DEM rate is 1.5, the value of the DEM augments by 0.8 pfenning (i.e. 0.08 DEM).

Both for the USD/DEM and USD/JPY regressions the coefficient of the interest rate differential is either not significant or does not contribute to the empirical fit of the regression. In particular, in the USD/DEM regression the coefficient of multiple correlation, R^2 , takes a value larger than 0.6 when the order flow variable is included and falls dramatically when it is excluded. A similar conclusion is drawn in the USD/JPY regression.⁹

⁷This thesis that trade innovations in equity markets may possess an information content was actually first put forward by Bagehot (1971).

⁸The Reuters Dealing 2000-1 system is the electronic platform for bilateral trading which pre-existed the recently introduced Reuters Dealing 3000 spot matching system.

⁹Other studies, notably Lyons (1995), Bionnes and Rime (2001,2005), Danielsson *et al.* (2002), Hau *et al.* (2002), Carpenter and Wang (2003), Berger *et al.* (2005) and Killen *et al.* (2005) have reported very similar results to

A legitimate criticism against the linear regression proposed by Evans and Lyons refers to the issue of simultaneity bias, which emerges if exchange rate movements cause order flow. In fact, in the case in which the exchange rate presents a *feedback* effect on order flow the OLS estimate of the coefficient β_z is biased. Suppose, in particular, that $z_t = z_{1,t} + z_{2,t}$, where

$$z_{2,t} = \gamma \Delta s_{t+1}, \quad \text{while} \quad \Delta s_{t+1} = \alpha z_{1,t} + \epsilon_t.$$

If we run the regression

$$\Delta s_{t+1} = \beta_z z_t + \eta_t,$$

the value of β_z is equal to

$$\beta_z = \frac{\alpha(1 + \gamma\alpha) + \gamma\phi}{(1 + \gamma\alpha)^2 + \gamma^2\phi}, \quad \text{where} \quad \phi = \frac{\sigma_\epsilon^2}{\sigma_{z,1}^2}.$$

Since $z_{2,t}$ is not directly observable, it is not possible to establish whether a positive value for the estimate of β_z corresponds to either $\alpha > 0$ (with $\gamma \geq 0$), so that order flow causes exchange rates to move (with or without a feedback effect on order flow), or $\alpha = 0$ and $\gamma > 0$, so that the estimated β_z assumes a positive value only because of a *positive* feedback effect of the exchange rate on order flow. Thus, in the presence of *positive* feedback trading rules ($\gamma > 0$) the results reported by Evans and Lyons are spurious and hence misleading.

3 Order Flow and Exchange Rate Returns

To take into account the possible feedback effects of exchange rate movements on order flow an alternative methodology can be employed. This is based on the study of a simple linear VAR model for trades and quote revisions originally proposed by Hasbrouck (1991) for the analysis of the NYSE.

Payne (2003) applies Hasbrouck's methodology to a transaction data-set which refers to the brokered section of the spot FX market. His study can then be considered a complement to that of Evans and Lyons, which instead analyzes the direct market. He considers all inter-dealer trades completed via the Reuters Dealing 2000-2 system in the spot USD/DEM market over the week between October 6th and October 10th 1997. While this period is rather short, his data-set

those of Evans and Lyons for other markets and periods. In particular, Bionnes and Rime and Killen *et al.* show that cumulative order flow and exchange rates are cointegrated. This suggests that the microstructure approach to exchange rate determination should not necessarily be confined to the analysis of short-run exchange rate dynamics. In Table 1 we present a synthesis of these and other empirical studies of FX market microstructure.

contains information over roughly 30,000 transactions, with a total volume of more than \$60 billion.

Differently from Evans and Lyons, Payne has access to information on the size of all transactions. This extra bit of information allows to measure more precisely the information content of order flow, as in the presence of asymmetric information rational expectations models of asset pricing show a clear dependence of trade size on information.¹⁰ Payne's empirical methodology is based on the following VAR model for exchange rate returns and trades

$$\begin{aligned} r_t &= \sum_{i=1}^p \alpha_i r_{t-i} + \sum_{i=0}^p \beta_{zi} z_{t-i} + \epsilon_{1,t}, \\ z_t &= \sum_{i=1}^p \gamma_i r_{t-i} + \sum_{i=1}^p \delta_{zi} z_{t-i} + \epsilon_{2,t}. \end{aligned}$$

In his study Payne does not consolidate transactions and hence the interval $(t, t + 1]$ does not refer to a given period of time, such as the day considered by Evans and Lyons. Indeed, Payne does not use calendar time, but an event time, where an event is any instance in which either the exchange rate best quotes (i.e. the best bid and ask prices) are revised or a transaction is completed on the Reuters Dealing 2000-2 system. In this way the interval $(t, t + 1]$ refers to the spell of time between two subsequent events.

In this simple VAR model z_t is now a *vector* containing trades information. This comprises: a signed trade indicator, which takes value 1 (-1) if an order to buy (sell) the US dollar is completed at time t and 0 if a quote revision takes place at time t triggered by the introduction or the cancellation of a limit order; a signed trade *size* variable, to analyze the effect of volume on exchange rates; a squared trade size variable, which is introduced to account for possible non linearities in the relation between price revisions and order flow.

Note that the return on the foreign currency, r_t , differs from the exchange rate variation, $s_t - s_{t-1}$, by the interest rate differential $i_{t-1}^* - i_{t-1}$. The difference is inconsequential at these very high frequencies, because over such short spells of time the period-by-period interest rate differential, $i_{t-1}^* - i_{t-1}$, is negligible. This component of the exchange rate return is hence ignored in the calculation of r_t .

In the VAR specification the *contemporaneous* realization of z_t enters into the regression for the exchange rate return. The opposite is not true, in that in the regression for z_t only lag values of the exchange rate return, r_t , are considered. Payne claims that at these very high frequencies transactions logically *anticipate* quote revisions and hence he does not allow the opposite causality.

¹⁰In this respect, within market microstructure theory see the seminal contribution by Kyle (1985).

This assumption, alongside with that that the innovation terms, $\epsilon_{1,t}$ and $\epsilon_{2,t}$, are uncorrelated, permits identifying the VAR model.¹¹

According to Payne's interpretation of the VAR model the innovation term $\epsilon_{1,t}$ corresponds to quote revisions induced by the arrival of public information, associated with macro announcements and the like. The innovation term $\epsilon_{2,t}$ refers instead to unpredictable trading activity, possibly associated with private information. From the vector moving-average (VMA) representation of the VAR model Payne is able to derive the impulse-response functions associated with news releases and trade innovations respectively. Payne suggests that the long-run response of exchange rates to trade innovations can be considered a measure of the information content of order flow.

The long-run response of exchange rates to trade innovations allows to measure the information content of order flow, but does not permit assessing its contribution to the total volatility of exchange rates. However, under the hypothesis that exchange rates can be decomposed in a random walk and a stationary process, Payne is able to separate the component of the total volatility of the exchange rate which pertains to public information from that which is due to trade innovations. Then, the importance of private information-based trades in determining exchange rate movements can be measured via the ratio between these two components.

Employing only the signed trade *indicator* among the transaction characteristics, z_t , Payne finds that in the exchange rate equation the coefficient of multiple correlation, R^2 , is equal to 0.25 and that the sum of the coefficients β_{zi} is positive and significantly different from zero, suggesting that order flow has a positive impact on exchange rates. From the VMA representation he finds that the total impact of a US dollar buy order on the USD/DEM rate is equal to 0.005%, i.e. that a purchase of the American currency brings about roughly a 1 basis point increase in its value, while from the variance decomposition Payne finds that more than 40% of the exchange rate variability must be attributed to unpredictable trading activity.

One should also notice that signed trade *size* and *squared* trade size when introduced among the transaction characteristics are not significant. A possible explanation of this finding rests with the very small variability observed in the trade size variable. However, it is rather worrying for an information-based argument to find no relation between trade size and price impact. Possibly, this is due to the strategic behavior of sophisticated informed traders, who may decide to split their large trades, so that the link between information content and trade size is broken.¹²

¹¹In a recent paper Danielsson and Love (2004) allow for *contemporaneous* feedback trading. In fact, differently from Payne's study, in their VAR specification order flow also depends on the *current* exchange rate return. Using instrumental variables to estimate their VAR specification on EUR/USD data, Danielsson and Love derive impulse response functions of spot rates to trade innovations which take account of contemporaneous feedback trading. Their analysis indicates an even stronger price impact of order flow than that outlined by Payne.

¹²An extensive literature on the strategic behavior of sophisticated informed traders exists within market mi-

In synthesis, Payne concludes that even when we take into account the possibility of feedback trading signed order flow is *still* a key determinant of short-term exchange rate dynamics.

4 Fundamentals, Order Flow and Exchange Rates

Froot and Ramadorai (2005) examine the relation which exists between order flow, exchange rate returns and fundamentals. With respect to the studies of Evans and Lyons (2002) and Payne (2003) there are two major differences in their approach.

Firstly, they employ a data-set of more than 6 million FX transactions obtained from State Street Corporation, a very large global asset custodian. This data-set contains records of end-user trades, consisting of all foreign exchange transactions for 111 currencies by more than 10,000 mutual funds over the period between January 1st 1994 and February 9th 2001. Clearly, this is different from previous studies where inter-dealer trades are considered. Secondly, they try to examine the long-run effects of international flows on exchange rates and their relation to fundamentals.

As a starting point Froot and Ramadorai repeat the analysis of Evans and Lyons considering the following regression

$$r_{t+1,j}(h) = \alpha + \beta_{z,j}^h z_{t,j}(h) + \epsilon_{t,j}^h,$$

where $r_{t+1,j}(h)$ is the h -period cumulative return on currency j over the interval $(t-h+1, t+1]$, $r_{t+1,j}(h) = \sum_{i=0}^{h-1} r_{t+1-i,j}$, and $z_{t,j}(h)$ is the corresponding cumulate for the signed order flow size, $z_{t,j}(h) = \sum_{i=0}^{h-1} z_{t-i,j}$.

Because of the lack of enough observations, Froot and Ramadorai do not consider simple bilateral rates. Rather, $r_{t+1,j}(h)$ represents the return on currency j against a *basket* of major currencies, while $z_{t,j}(h)$ is the corresponding value in US dollars of all currency j (*net*) inflows from the countries in the basket during the interval $(t-h+1, t+1]$. This hides a weakness of Froot and Ramadorai's methodology. Indeed, while their data-set is very broad cross-sectionally, it is also very shallow in the major currencies, given that the observed trades account for less than 5 percent of all transactions in these bigger markets. In other words, their study relies too much on information obtained from smaller and less important markets, while at the same time information derived from bigger markets is also quite inaccurate.

The coefficients $\beta_{z,j}^h$'s estimated by Froot and Ramadorai indicate that even over very long time horizons international inflows and exchange rate returns are positively correlated. For most currencies the values of these coefficients are significantly larger than zero and relatively stable

crostructure theory. See in particular Easley and O'Hara (1987).

across various time horizons. On average the values of the $\beta_{z_j}^h$'s indicate that a \$100 million dollar inflow results in a appreciation of 11.5 basis points (i.e. 0.115%) of the corresponding currency.

The correlation coefficients between signed order flow size and exchange rate returns, $\rho(r_{t+1,j}(h), z_{t,j}(h))$, reported by Froot and Ramadorai also present some very interesting regularities. These coefficients take positive values with maxima reaching values ranging from 0.3 to 0.6. In addition, they tend *first* to increase with the time horizon, h , between the 1-day and the 20 day horizon and *then* to decrease as horizons pass beyond 20-60 days.

Froot and Ramadorai suggest that these results do not show a stable causal relation from international flows to exchange rates, as the impact of signed order flow size on exchange rate returns is transitory. They conjecture that the positive correlation observed over short horizons between order flow and exchange rate returns is not related to fundamentals but is the consequence of trend chasing activity on the part of some investors.

To verify their conjecture Froot and Ramadorai examine a VAR model of exchange rate returns, fundamentals and order flow. Their VAR specification is *de facto* an extension of the formulation proposed by Payne, as it includes interest rate differentials and inflation differentials alongside order flow and exchange rate returns,

$$x_t = \Gamma x_{t-1} + \epsilon_t \quad \text{where} \quad x_t = (r_{t+1}, z_t, i_t - i_t^*, \pi_t - \pi_t^*)'.$$

Because of the limited number of observations a unique VAR specification is estimated for all currencies. This means that all observations are stacked together in a single series. Then, to take account of the differences in the volume of trading across FX markets, a standardization of the signed order flow size, z_t , is employed. In fact, single currency j trades, $z_{t,j}$, are normalized by dividing all purchases/sales of assets denominated in currency j by their standard deviation for the entire period. However, one should notice an important limitation of such a procedure, since this normalization does not allow to capture possible differences in liquidity and information conditions among different currencies.

Since Froot and Ramadorai concentrate on the short- and long-run interaction between order flow, fundamentals and returns, the impulse-response functions associated with this VAR specification play a paramount role in their analysis. Indeed, from these impulse-response functions it is possible to calculate the short- and long-run covariances between order flow and returns. This exercise proposes very interesting results.

Froot and Ramadorai find that the *contemporaneous* covariance between order flow and exchange rate returns is as expected larger than zero. In addition, the covariance between *current* order

flow and short-term *future* exchange rate returns is also positive. This indicates that order flow *positively* anticipates short-term (1-month ahead) movements in exchange rates. Anyhow, over longer horizons this anticipation effect changes sign, as the co-movement between *current* order flow and long-term *future* exchange rate returns (more than 1-month ahead) is negative.

Froot and Ramadorai's results also show that the covariance between short-term *future* cumulative innovations in order flow and *current* exchange rate returns is positive. This indicates that some investors employ positive feedback trading rules over short horizons. On the contrary, the covariance between long-term *future* cumulative innovations in order flow and *current* exchange rate returns is strongly negative. In brief, these results seem to indicate that some investors employ positive feedback trading rules over short-term horizons, accumulating speculative positions which they eventually unwind in the long-run. Consequently they appear to follow negative feedback trading rules over long horizons.

Froot and Ramadorai find *insignificant* values for the covariance between *overall* exchange rate returns (i.e. the sum of *contemporaneous*, short-term and long-term *future* exchange rate returns) and: i) *contemporaneous* order flow; ii) short-term *future* innovations in order flow; and iii) long-term *future* innovations in order flow. In synthesis, Froot and Ramadorai conclude that: i) there is no permanent link between order flow and exchange rates; and ii) the positive impact of order flow on exchange rate is a *transitory* phenomenon *not* necessarily related to fundamental information.

Froot and Ramadorai also analyze the short-run and long-run covariances between: i) exchange rate returns and interest rate differentials; and ii) order flow and interest rate differentials. Their results partially vindicates order flow. In fact, they suggest that *current* exchange rate returns are positively correlated with short-term *future* changes in interest rates, while *current* order flow is *positively correlated* with short-term *future* changes in interest rates. Thus, we can differ from the conclusions of Froot and Ramadorai and suggest that order flow is at least related to some short-term fundamental information.

Furthermore, it could be argued that the sort of FX transactions Froot and Ramadorai employ refers to a specific subset of end-user transactions in FX markets and hence does not capture all the information content of order flow. In this respect it is worth noticing that several studies, notably Carpenter and Wang (2003), Marsh and O'Rourke (2004) and Evans and Lyons (2005a), have explored the information content of disaggregated order flow in FX markets.

Evans and Lyons, employing daily data on the transactions of Citibank with its customers between January 1993 and June 1999, claim that different classes of end-user transaction flows possess a different explanatory power for short-term exchange rate dynamics. Marsh and O'Rourke, investigating daily data on the customer transactions of Royal Bank of Scotland between August

2002 and June 2004, find that the probability of informed trading is larger for financial customers. Carpenter and Wang, using tick-by-tick data on the customer transactions of a large Australian FX dealer between May and July 2002, conclude that financial end-user order flow presents a larger impact on spot rates.

These studies appear to contradict the conclusions of Froot and Ramadorai, as they indicate that end-user order flow actually presents an information content. Though, such information content may not necessarily be linked to interest rate shifts, but rather to other macro and financial variables, such as GDP, money supply and dividends.¹³

Thus, Evans and Lyons find that end-user order flow Granger causes macro variables, such as money growth, output growth and inflation, at the monthly (for money and inflation) and quarterly (for output) horizon both in the US and Germany. Linear regressions of the innovation in these macro variables over lags of the disaggregated end-user transaction flows indicate that: i) order flow explains a substantial part of future movements in these macro variables over horizons ranging between 1 month and two quarters; and ii) such forecasting power is stronger over the longer horizons. Specifically, over the two-quarter horizon the coefficient of multiple correlation in these regressions takes values in the 0.20-0.50 range.

In brief, these results suggest that order flow might anticipate future exchange rate movements. Evans and Lyons (2005b) present compelling evidence of such forecasting power. This is based on the comparison of short-term exchange rate forecasts obtained from several alternative linear models against those derived from a random walk.

Evans and Lyons employ their Citibank transaction data to derive from several alternative linear models proper *ex-ante* exchange rate forecasts over horizons ranging from 1 day to 1 month. To obtain these forecasts Evans and Lyons split their data in two sub-samples of roughly the same length. The former, from January 1993 to February 1996, allows to estimate the parameters of the various alternative forecasting models they consider. The latter, from March 1996 to June 1999, is instead employed to derive the corresponding ex-ante forecasts.

In comparing the forecasts obtained from alternative models, beside the traditional mean square error (MSE) statistic, Evans and Lyons employ a test based on the *projection* statistic. This statistic

¹³Hau and Rey (2004, 2005) and Dunne *et al.* (2005) consider models in which exchange rate dynamics is linked to equity returns and portfolio flows. In particular, in Hau and Rey's model dividend innovations condition the portfolio holdings of international investors and hence affect capital flows and exchange returns. According to their portfolio rebalancing effect equity returns and exchange rate returns should be negatively correlated, while international portfolio flows and exchange rate returns should be positively correlated. In fact, risk-averse investors prefer to reduce their exposure to foreign exchange risk in the face of an appreciation of a foreign equity market. Their outflow of funds from the foreign equity market then leads to a depreciation of the corresponding foreign currency.

is calculated as the estimated coefficient, β_h , in the following linear regression

$$\widehat{\Delta s_{t+h}|t} = \beta_{0,h} + \beta_h (s_{t+h} - s_t) + \epsilon_{t+h}, \quad \text{with } h = 1 \text{ day, 2 days, } \dots, 1 \text{ month,}$$

where $\widehat{\Delta s_{t+h}|t}$ indicates the forecast of the exchange rate variation over the interval $(t, t+h]$ obtained from a specific forecasting model with data *available* at time t . A test of significance for the projection statistic, β_h , represents a check of the forecasting power of the model, as in the case of no forecastability this coefficient would not be significantly different from zero. In addition, the magnitude of the coefficient β_h can be taken as a measure of the forecasting performance of the model, as it estimates the contribution of the model forecasts to the variance of future exchange rate variations.

The MSE statistic indicates that the exchange rate forecasts based on end-user order flow are more precise than those derived from a random walk. However, the increase in the accuracy of these forecasts appears to be significant only over the longer horizons. In contrast, the projection statistic suggests that order flow possesses a significant forecasting power over all horizons and that the corresponding forecasts can explain up to 16% of the variance of future exchange rate variations. These are quite dramatic results, particularly in view of the negative conclusions drawn from analogous studies conducted for more traditional macro-based forecasting models.

5 Heterogeneous Information, Order Flow and Exchange Rates

Bacchetta and van Wincoop (2005) have offered a possible rationale for the empirical evidence outlined by Evans and Lyons, Payne, Froot and Ramadorai and others. Their basic idea is that in FX markets if risk averse traders i) possess heterogeneous beliefs over exchange rate fundamentals and ii) observe imperfectly correlated signals on fundamentals, portfolio shifts will have a *persistent* and *large* impact on exchange rates. This is due to: i) a *portfolio-balance* effect, when investors need to be compensated for any extra risk they are forced to bear as a consequence of a purchase or a sale of foreign currencies, and; ii) an *information-based* effect, when, in the face of the opaque structure of FX markets, investors confuse an appreciation (depreciation) of the exchange rate due to portfolio shifts with that induced by fundamental information.

When such confusion concerns fundamental information that becomes public in the *distant* future, the impact of order flow on exchange rates is *magnified* by the *infinite regress* of investors' individual beliefs. In fact, if investors receive private signals on fundamental variables, such as interest rates or monetary aggregates, whose realizations are not imminent but distant in the future, they will try to learn from prices and quantities they observe (i.e. exchange rates and order

flow) not only the fundamental value of foreign currencies, but also other investors' forecasts. This attempt to learn other investors' forecasts exacerbates the confusion between portfolio shifts and fundamental shocks, amplifying the impact of order flow on exchange rates.

The magnification effect is absent if private signals concern *imminent* shifts in fundamentals. This is because when private information is short-lived the knowledge of other investors' forecasts is redundant and hence the confusion between portfolio shifts and fundamental shocks subdues. More precisely, when private signals concern next period realizations of fundamental variables investors know that very soon they will all share the same fundamental information. If they are aware that changes to the fundamental variables to which their private signals pertain will become of public domain in the near future, investors realize that they will not be able to exploit any information they can extract from other investors' forecasts and hence will not seek to learn these forecasts.

We now briefly discuss Bacchetta and van Wincoop's market microstructure model of exchange rate determination. First we present a simplified analytical framework which represents their basic argument. We then discuss the properties of their model, analyzing the confusion between fundamental shocks and portfolio shifts and the magnification effect. Finally we present the empirical implications of this model in the face of the empirical evidence discussed in the previous Sections.¹⁴

5.1 A Simple Structural Model

According to this simplified framework presented by Breedon and Vitale (2004) in the market for foreign exchange a single foreign currency is traded for the currency of a large domestic economy. Trading in this market is organized according to a sequence of Walrasian auctions. When an auction is called agents simultaneously submit either market or limit orders for the foreign currency and then a clearing price (exchange rate) is established.¹⁵

¹⁴Bacchetta and van Wincoop's is not the unique attempt to formulate a market microstructure model of exchange rate determination. Recently, Evans and Lyons (2004) have proposed a very rich micro-founded model, which, combines a market microstructure component, based on the analytical framework originally proposed by Lyons (1997), with a general equilibrium set-up. However, whereas their model is more complex than the one we describe here, it contains similar features, such as heterogeneous beliefs and informative order flow, and produces fairly similar empirical implications.

¹⁵This Walrasian auction mechanism is typical of several rational expectations models of asset pricing, notably Grossman and Stiglitz (1980) and Hellwig (1980). The mechanism we propose differs from the very popular batch mechanism put forward by Kyle in his seminal contribution to market microstructure theory (Kyle (1985)). The former mechanism is better suited for the structure of FX markets. In fact, in Kyle's formulation risk-neutral market makers enforce a semi-strong form efficiency condition for the equilibrium price. This is problematic as it is well known that in FX markets investors are risk-averse. In addition, considering risk-neutral investors would wash away any portfolio-balance effects of order flow on currency values. The Walrasian auction mechanism is also consistent with the growing share of FX transactions which is now conducted through centralized electronic limit order books, such as the Reuters Dealing 2002 and EBS systems, and captures the lack of transparency of FX markets, in that all transactions are anonymous.

In the market for foreign exchange two classes of traders coexist: rational investors and unsophisticated customers. Rational investors, such as FX dealers, managers of currency funds, hedge funds and other actively traded funds, are risk-averse agents who select optimal portfolios of domestic and foreign assets. They are supposed to be short-sighted in that their investment horizon is just one period long. This assumption is introduced for tractability but also captures a quite well known feature of the behavior of many professional traders in FX markets, which usually attempt to unwind their foreign exchange exposure by the end of any trading day.¹⁶

All rational investors share the same CARA utility function of their end-of-period wealth. At time t they can invest in three different assets: a domestic production technology, which depends on the amount of real balances possessed, domestic bonds that pay period-by-period interest rate i_t and foreign bonds that pay period-by-period interest rate i_t^* . Their optimal demand for foreign bonds (foreign currency) on the part of the population of rational investors is

$$d_t = \frac{1}{\gamma \sigma^2} \left(\bar{E}_t(s_{t+1}) - s_t + (i_t^* - i_t) \right),$$

where s_t is the log of the spot rate (i.e. the number of units of the domestic currency for one unit of the foreign one), $\bar{E}_t(s_{t+1})$ is the average of the conditional expectations for next period spot rate, s_{t+1} , on the part of all rational investors given the information they possess in t , σ^2 is the corresponding conditional variance and γ is their coefficient of absolute risk-aversion.

The unsophisticated customers provide all the supply of foreign currency. Thus, at time t the total demand for foreign currency on the part all rational investors is in equilibrium equal to the total amount of foreign currency supplied by their clients, x_t ,

$$d_t = x_t.$$

These customers comprise a population of noise and informed traders. The amount of foreign currency these customers supply changes over time in order to meet their liquidity needs and/or exploit their private information. If o_t represents the amount of foreign currency noise and informed traders collectively desire to sell at time t , the total supply of foreign currency changes according to the following expression

$$x_t = x_{t-1} + o_t.$$

Signed order flow, o_t , can be decomposed in the number of units of foreign currency traded

¹⁶Such behavior is documented by Lyons (1995) and Bionnes and Rime (2005).

respectively by the noise, b_t , and the informed customers, I_t ,¹⁷

$$o_t = b_t + I_t.$$

The population of noise customers may be interpreted as formed by the financial arms of industrial corporations and by other unsophisticated financial traders, whose portfolios of foreign assets are subject to persistent shifts. Such shifts may be associated with current account transactions or with capital movements, such as foreign direct and portfolio investment, which are not motivated by current movements in exchange rates.

At time t the amount of foreign currency offered for sale by the informed traders, I_t , is instead correlated with the innovation in a macro variable, f_t , which depends linearly on the interest rate differential, $i_t^* - i_t$, and which determines the equilibrium value of the foreign currency. Whilst this fundamental variable is observable, at time t all informed traders possess some private information on its *next* period innovation, ϵ_{t+1}^f . This assumption indicates that the informed traders collect information on future shifts in interest rates before these shifts become of public domain. In order to gain speculative profits they collectively place a market order equal to

$$I_t \equiv -\theta \epsilon_{t+1}^f,$$

where θ is a positive constant that measures the intensity of their trading activity.

Imposing equilibrium conditions for the domestic and foreign money markets and assuming that the purchasing power condition holds, it can be established that the following “present value” equilibrium condition applies to the spot rate

$$s_t = \frac{1}{1+\alpha} \sum_{k=0}^{\infty} \left(\frac{\alpha}{1+\alpha} \right)^k \left(\bar{E}_t^k(f_{t+k}) - \alpha \gamma \sigma^2 \bar{E}_t^k(x_{t+k}) \right), \quad (2)$$

where $\bar{E}_t^k(f_{t+k})$ is the order k average rational expectation across all rational investors of period $t+k$ fundamental variable, f_{t+k} , i.e. $\bar{E}_t^k(f_{t+k}) = \bar{E}_t \bar{E}_{t+1} \dots \bar{E}_{t+k-1}(f_{t+k})$. Similarly, $\bar{E}_t^k(x_{t+k})$ is the order k average rational expectation across all rational investors of period $t+k$ supply of foreign currency, x_{t+k} .

In their simplified version of Bacchetta and van Wincoop’s model, Breedon and Vitale assume that all rational investors: i) possess symmetric information; and ii) at time t can only receive signals over next period fundamental innovation, ϵ_{t+1}^f . These two assumptions allow to circumnavigate the

¹⁷Differently from the usual convention a positive o_t indicates a net sale of foreign currency. If instead o_t is negative, rational investors’ clients collectively place an order to purchase the foreign currency.

infinite regress problem Bacchetta and van Wincoop study and hence obtain simple closed form solutions for the exchange rate equation (2). In practice, this amounts to impose the conditions that $\bar{E}_t^k(f_{t+k}) = E(f_{t+k} | \Omega_t)$ and $\bar{E}_t^k(x_{t+k}) = E(x_{t+k} | \Omega_t)$, where Ω_t corresponds to the information set rational investors possess at time t . Thus, the order k average rational expectations of period $t+k$ fundamental variable, f_{t+k} , and supply of foreign currency, x_{t+k} , are simply equal to all rational investors' conditional expectations of these variables.

As rational investors can readily obtain from various official sources and publicly available data, such as newswire services, newsletters, monetary authorities' watchers and so on, information on macro variables which condition currency values, Breedon and Vitale also assume that at time t all rational investors observe the following common signal on the fundamental innovation

$$v_t = \epsilon_{t+1}^f + \epsilon_t^v.$$

Alongside this signal all rational investors can observe the flow of transactions that are completed in the market for foreign exchange. This is possible because in centralized platforms such as EBS and Reuters Dealing 2000-2, all transactions are immediately published on the system's computer screens. This means that in any period t all rational investors observe the signed order flow, o_t .

Then, under the assumption that the fundamental variable and the noise trading component of order flow follows independent AR(1) processes, Breedon and Vitale (2004) show that in a stationary equilibrium the variation in the exchange rate respects the following expression

$$\begin{aligned} s_t - s_{t-1} = & \lambda_{s,-1}(s_{t-1} - s_{t-2}) + \lambda_f(f_t - f_{t-1}) + \lambda_{f,-1}(f_{t-1} - f_{t-2}) + \lambda_x o_t + \\ & \lambda_{x,-1} o_{t-1} + \lambda_o(o_t - o_{t-1}) + \lambda_{o,-1}(o_{t-1} - o_{t-2}) + \lambda_v(v_t - v_{t-1}), \end{aligned} \quad (3)$$

where the coefficients λ 's depend on the parameters of the model.

5.2 Model Interpretation

Whereas explicit formulae for the coefficients λ 's are reported in Breedon and Vitale (2004), here we offer an economic interpretation of equation (3). We start from the coefficient λ_f whose sign turns out to be positive. This is because an increase in the fundamental variable, f_t , corresponds to a rise in the interest rate differential $i_t^* - i_t$ and hence in the excess return on the foreign currency. A similar result holds for the public signal, whose coefficient, λ_v , is also positive.

The coefficient λ_x is instead negative because an increase in the supply of foreign currency depresses its value via a portfolio-balance effect. Rational investors will be willing to hold a larger

quantity of the foreign currency only if they are compensated for the increased risk they bear. Thus, a larger x_t forces a depreciation of the foreign currency, as this corresponds to a larger excess return rational investors expect from holding foreign bonds.

The coefficient λ_o is negative, because of the aforementioned portfolio-balance effect and because order flow possesses an information content. When some customer orders are informative (i.e. for $\theta > 0$) an excess of sell orders might indicate an impending negative fundamental innovation ($\epsilon_{t+1}^f < 0$) which induces rational investors to expect a future exchange rate depreciation. Consequently, they will be willing to hold the same amount of the foreign currency only if a reduction in s_t re-establishes the expected excess return foreign bonds are required to yield.

Breedon and Vitale show that $|\lambda_o| > |\lambda_{o,-1}|$, so that the effect of order flow on exchange rates is *persistent*. Importantly, this result holds even when customer trades do not carry any information, i.e. when $\theta = 0$, suggesting that the impact of portfolio shifts on exchange rates is not transitory. Such conclusion contrasts with the generally held view that any transitory imbalance between buy and sell orders possesses only a short-lived effect on exchange rates if order flow does not carry any information.

5.3 Extensions and Empirical Implications

When, differently from the formulation we have presented here, rational investors observe correlated *but* different signals of the fundamental process, the impact of order flow on exchange rates is amplified. If any rational investor, i , observes a private signal on the fundamental innovation, $v_{t,i} = \epsilon_{t+1}^f + \epsilon_{t,i}^v$, other things being equal, the coefficient λ_x in the equilibrium equation (3) is *larger*, indicating that the impact of non-fundamental shocks, b_t , is *magnified*.

Bacchetta and van Wincoop show that the impact of these non fundamental shocks is *very large* if traders possess long-lived private information. This is the case if at time t either informed customers observe period $t + T$ fundamental innovation, ϵ_{t+T}^f (with $T > 1$), or rational investors observe private signals on the same shock, $v_{t,i} = \epsilon_{t+T}^f + \epsilon_{t,i}^v$. In both cases it is not possible to impose the simplifying assumption that $\bar{E}_t^k(f_{t+k}) = E_t(f_{t+k})$ and $\bar{E}_t^k(x_{t+k}) = E_t(x_{t+k})$ and as a consequence the impact of non fundamental shocks, b_t , on exchange rates is *greatly* magnified.

The empirical implications of Bacchetta and van Wincoop's model are very interesting. In particular, the fundamental shock, ϵ_{t+T}^f , presents a *persistent* effect on the value of the foreign currency. However, its initial impact is *smaller* than its total effect. In fact, when a positive innovation hits the fundamental variable, $\epsilon_{t+T}^f > 0$, because of the rational confusion between noise trading and fundamental shifts, rational investors need several observations of the exchange rate

to realize the extension of this innovation.

Bacchetta and van Wincoop show that under heterogeneous information: i) order flow variability accounts for a large share of exchange rate volatility over the short-run; ii) the amount of exchange rate volatility explained by fundamental variables augments over time; and iii) the exchange rate is a good *predictor* of future changes in fundamentals over short horizons.¹⁸

6 News, Order Flow and Exchange Rates

In the previous Sections we have seen that at least over the short-run order flow and exchange rates are strongly correlated. Via Bacchetta and van Wincoop's analytical framework we have seen that order flow can affect exchange rates through either a portfolio-balance effect, as investors need to be compensated for the risk they bear when they hold foreign currencies, or an information effect, if order flow conveys information on fundamental shifts which affect the value of currencies. In the second scenario order flow is related to news arrivals, i.e. to information on macro variables which FX traders obtain from various sources.

The analysis of the effects of news arrivals on spot rates dates back to the debate over the exchange rate disconnect puzzle stimulated in the early 1980s by Meese and Rogoff's influential work. Since then researchers have tried to verify whether macro variables influence exchange rates, studying the effects of macro announcements on exchange rates. Earlier contributions (Hardouvelis (1985), Ito and Roley (1987)), that concentrated on the analysis of *daily* data, have reaffirmed the role of fundamentals, showing that news arrivals on variables such as output, price levels, etc., do affect exchange rates. Recently researchers (Goodhart (1992), Andersen *et al.* (2003)) have studied the effects of news arrivals at *high frequencies*, also trying to explore the relation between news and order flow (Evans and Lyons (2003), Love and Payne (2003)).

Data on macro variables are continuously released by official and unofficial sources. According to the efficient markets paradigm prices reflect *all* available information, so that only the *unexpected* component of these macro announcements should affect exchange rates. Thus, let $A_{k,t}$ represent a macro announcement variable. This is equal to the announced value of a macro indicator k , such as US GDP or German unemployment level, in the interval $(t, t + 1]$ in which a public announcement is released and zero in any other interval. Let $E_{k,t}$ indicate the corresponding value expected by market participants at time t . According to the efficient markets paradigm only the unexpected component, $A_{k,t} - E_{k,t}$, of the announcement variable should influence exchange rates.

¹⁸As already mentioned, Evans and Lyons (2002,2005a,2005b), Payne (2003) and others offer some evidence in favor of the first two empirical implications. Engel and West (2005) provides some empirical support in favor of the predicting power of exchange rates with respect to future changes in fundamentals.

Andersen *et al.* (2003) have studied the effects on six major exchange rates (USD/CHF, USD/DEM, EUR/USD, GBP/USD and USD/JPY) of the unexpected components of announcements on 41 macro variables for the United States and Germany over the period between January 1992 and December 1998, employing Reuters data on exchange rate returns, r_{t+1} , observed at 5-minute intervals and MMS data on money managers' *expectations* of the 41 macro variables, $E_{k,t}$.

For any indicator, k , a *standardized* news variable is defined as follows

$$N_{k,t} \equiv \frac{A_{k,t} - E_{k,t}}{\sigma_k},$$

where σ_k is the sample standard deviation of the news variable $N_{k,t}$. The effect of these news variables on exchange rates is evaluated estimating a linear regression of the 5-minute return, r_{t+1} , on its own lags and on the contemporaneous and lagged values of the news variables $N_{k,t}$'s,

$$r_{t+1} = \alpha_0 + \sum_{i=1}^p \alpha_i r_{t+1-i} + \sum_{k=1}^K \theta_{k,j} N_{k,t-j} + \epsilon_t. \quad (4)$$

Andersen *et al.* find that both for US and German indicators the *unexpected* components of the macro announcements significantly *affect* exchange rates. Moreover, exchange rates react *quickly* to news shocks, with an immediate jump and very little movement thereafter. For example, a one standard deviation US payroll employment shock, $N_{e,t} = 1$, appreciates the US dollar against the German currency by 0.16%. Adding the announcement indicators, $A_{k,t}$'s, to the linear model (4) Andersen *et al.* find that the *expected* components of the macro announcements do *not* affect exchange rates.

Most of the econometric fit in equation (4) comes from the lagged values of the dependent variable and the contemporaneous news variables, $N_{k,t}$'s. This suggests that most of the effect of the news variables $N_{k,t}$ on the spot rate is felt within a 5-minute interval. Indeed, considering only the intervals of time for which some news is released (this amounts to a sub-sample of less than 0.2% of all observations), Anderson *et al.* find that the news variables present a strong explanatory power. This is documented by the following linear regression

$$r_{t+1} = \theta_k N_{k,t} + \epsilon_t, \quad \text{for } k = 1, \dots, 41, \quad (5)$$

where the sample is restricted to the intervals, $(t, t+1]$, in which an announcement on the macro variable k is observed. While the coefficients of multiple correlations are very small for all currency pairs in the case of equation (4), in the 41 estimations of equation (5), where only the event windows are considered, the coefficient of multiple correlation, R^2 , often takes values around 0.3 and at times

approaches 0.6.

Love and Payne (2003) extend the analysis of the effects of news arrivals on exchange rates by studying the interplay between order flow, spot rates and macro news. More precisely, they study: i) the effect of news arrivals on exchange rates and order flow *separately*; ii) the impact of order flow on exchange rates *around* announcement dates; and iii) the effect of news arrivals and order flow on exchange rates *simultaneously*.

They employ transaction data which consist of all spot inter-dealer trades completed via the Reuters Dealing 2000-2 system in the EUR/USD, EUR/GBP and GBP/USD markets over several months in 1999 and 2000. Exchange rate returns are sampled at the 1-minute frequency, so that several thousands observations are available for the three spot rates. Only the *direction* of individual trades is available, whilst no information on their size is accessible. We have already seen that this lack of information is inconsequential for the study of the effects of order flow on spot rates.

Their news data consist of announcements on several macro indicators for the three listed economic areas, alongside the corresponding market expectations collected by Standard and Poors. Since very few announcements per any macro indicator are available, for any economic area a *unique* macro news variable is obtained consolidating the data for the individual indicators. This is done in two stages: firstly, in the economic area C the news variable for the individual indicator k is standardized via the familiar formulation, $N_{k,t}^C \equiv (A_{k,t}^C - E_{k,t}^C)/\sigma_{k,C}$; secondly, this standardized news variable is *signed* according to its effect on the value of the currency of the area.

To give a sign to the news variable $N_{k,t}^C$ a simple linear regression of the return for currency C , r_{t+1}^C , on the news variable $N_{k,t}^C$ is estimated via OLS over the entire sample period. If the coefficient of this linear regression is positive (negative), positive unexpected shocks in the indicator k appreciate (depreciate) currency C . The news variable $N_{k,t}^C$ is then signed by pre-multiplying its value by the sign of this linear coefficient. Hence, for any economic area C a single news variable is obtained by aggregating (i.e. summing together) the *signed* standardized news variables, $N_t^C = \sum_{k=1}^K \text{sign}(N_{k,t}^C) N_{k,t}^C$.

As a preliminary analysis, Payne and Love study the impact of news arrivals on exchange rates and order flow *separately*. Returns and order flow are regressed on leads and lags of macro news variables. Conclusions of this exercise are that: i) even at this very high frequency (1-minute) news arrivals affect exchange rates; and ii) surprisingly, news arrivals *also* affect order flow, with both immediate and delayed effects.

Love and Payne also examine the possibility that news arrivals alter the impact of order flow on exchange rates. Thus, their analysis shows that around periods of news arrivals exchange rates are

more sensitive to order flow than during calmer times. Contemporaneously to the release of US (UK) news, order flow presents a significantly larger impact on the value of the US dollar (British pound). Finally, in order to test whether exchange rate response to news arrivals is mediated by order flow, the two authors estimate a simple bivariate VAR model for each spot rate,

$$\begin{bmatrix} r_{t+1}^C \\ z_t^C \end{bmatrix} = \begin{bmatrix} \alpha_r \\ \alpha_z \end{bmatrix} + \begin{bmatrix} \beta \\ 0 \end{bmatrix} z_t^C + \sum_{i=1}^p \Gamma_i \begin{bmatrix} r_{t+1-i}^C \\ z_{t-i}^C \end{bmatrix} + \sum_{j=1}^q \Theta_j N_{t-j} + \epsilon_t, \quad (6)$$

where z_t^C indicates order flow moving funds into currency C in the interval $(t, t+1]$, i.e. the difference between the number of buy and sell orders for currency C , while N_t is the vector of the news variables in the three economic areas, $N_t \equiv (N_t^{EU}, N_t^{UK}, N_t^{US})'$.

As in Payne (2003) this specification is identified assuming that while the contemporaneous value of the order flow variable, z_t^C , enters into the return equation the opposite is not true. This identification restriction is justified by the 1-minute frequency at which the variables are observed. As already mentioned, over such short periods of time a causal link from returns to flows is improbable.

Results from the estimation of this VAR specification indicate that, as seen elsewhere, the order flow variables, z_t^C 's, possess a large and highly significant positive impact on exchange rates. A net purchase of euros in the EUR/USD and EUR/GBP markets brings about a rise in the value of the euro. Similarly, a net purchase of US dollars in the EUR/USD and GBP/USD markets produces a rise in the value of the American currency.

News arrivals also have a significant impact on exchange rates and order flow. A positive news shock in the euro area ($N_t^{EU} > 0$) appreciates the euro against the US dollar and generates positive order flow from the United States and the United Kingdom. Likewise, a positive value for N_t^{US} appreciates the US dollar against the euro and the British pound and generates positive order flow from Euro-land and the United Kingdom. Interestingly, news arrivals in one area also condition the performance of the market between the other two currencies. A positive news shock in the US ($N_t^{US} > 0$) brings about an outflow from Euro-land toward the United Kingdom and a corresponding depreciation of the euro against the British pound.

Since news arrivals provoke order flow and this on its turn moves exchange rates, news shocks condition the values of currencies both via a *direct* channel, as exchange rates immediately adjust after an informative shock, and via an *indirect* channel, as exchange rates react to imbalances between buy and sell orders.

Studying the impulse response functions of the VAR model Love and Payne are able to separate

these two components of the impact of news shocks on exchange rates. Calculating the cumulative return generated by a positive news shock in area C under the restriction that order flow is not affected by news, i.e. by introducing zeros in the second row of all the matrices of coefficients Θ_j in equation (6), Love and Payne isolate the direct component. Subtracting the direct component from the cumulative return generated by a positive news shock in area C under no restriction they pin down the indirect component.

Results of this decomposition show that, according to the currency pairs examined, between 30 and 60 percent of the simultaneous impact of news shocks on exchange rates is mediated by order flow. Love and Payne conclude that nearly 50% of public information simultaneously released to all market participants is impounded into exchange rates via order flow. This implies that efficient markets paradigm, according to which public information should be immediately transferred into prices with *no role* for trading, is violated.

A difficulty with the analysis of Love and Payne is that their methodology is prone to a circularity issue. In fact, the direction of news is defined on the basis of the effect of macro announcements on exchange rates. $N_{k,t}^C$ is positively (negatively) signed if an unexpected positive macro announcement ($A_{k,t}^C > 0$) augments (reduces) the value of currency C . The effect of news arrivals on the *first* moment of order flow and exchange rates is then investigated. Since Love and Payne use the same sample of observations to sign the variables $N_{k,t}^C$ and to study their effects on exchange rates, their results are *biased* in favor of a positive effect of news arrivals on returns.

The contradictory results of the empirical analysis of traditional models of exchange rate determination make it hard to sign news. For example, an unexpected rise in the growth rate of monetary aggregates in one country can lead either to a depreciation of the domestic currency, if this process brings about inflation and devaluation expectations, or to its appreciation, if, in the presence of a central bank reaction function, nominal interest rates are set to rise. In other words, any empirical study of the effects of news on exchange rates and order flow is plagued by the issue of the *indeterminacy* of the direction of news.

In the face of these difficulties one could just concentrate on the effects of news arrivals on the *second* moments of exchange rates and order flow. That is the route followed by Evans and Lyons (2003). In their study they employ data on all bilateral transactions between FX dealers via the Reuters Dealing 2000-1 system in the spot USD/DEM and USD/JPY markets between May 1st and August 31st 1996 and data on macro announcements for US and German indicators derived from Reuters' newswire services. From these sources they construct daily observations for signed order flow, z_t , the exchange rate variation, Δs_{t+1} , and the number of news releases, A_t .

Evans and Lyons study the effects of news arrivals on the volatility of exchange rates and of

order flow, considering the following simple linear model of exchange rate determination

$$\Delta s_{t+1} = \alpha z_{1,t} + N_{C,t} + \epsilon_t, \quad \text{where}$$

$$z_t = z_{1,t} + z_{2,t}, \quad \text{with} \quad z_{2,t} = \gamma \Delta s_{t+1}, \quad \text{and} \quad z_{1,t} = N_{P,t} + \eta_t.$$

Here order flow can be both informative, $z_{1,t}$, and induced by exchange rate movements, $z_{2,t}$, as consequence of feedback trading. Moreover, exchange rate movements can be the consequence of public information, $N_{C,t}$, or of private information contained in order flow, $N_{P,t}$.

Notice that Evans and Lyons propose a different role for public information from that advocated by Love and Payne, in that they suggest that public information does not affect order flow and it is immediately incorporated in currency values. Only the private component of information alters exchange rates via order flow. Their notion of private information is also different from the usual one, as FX traders do not share a common model of exchange rate determination and give different interpretations to macro announcements. Hence, a general consensus on the implications of an unexpected shock to a macro variable can be obtained only via trading. Thus, $N_{C,t}$ refers to the common knowledge component of news while $N_{P,t}$ subsumes all the rest.

Evans and Lyons do not attempt to identify $N_{C,t}$ and $N_{P,t}$. Rather, they simply assume that the corresponding variances, $\sigma_{C,t}^2$ and $\sigma_{P,t}^2$, are increasing in the pace of news arrivals,

$$\sigma_C^2 = \sigma_C \cdot A_t, \quad \sigma_P^2 = \sigma_P \cdot A_t.$$

Using GMM estimators they find that news arrivals significantly increase the volume of trading. The arrival of news also augments the volatility of exchange rates via both a (direct) public information channel and an (indirect) order flow one. In line with the results of Love and Payne, Evans and Lyons calculate that roughly 70% of daily exchange rate variance due to news arrivals is via order flow and 30% is via the direct effect. In addition, they find that exchange rate movements have a *negative* feedback effect on order flow. Note that this clearly contradicts the thesis of Froot and Ramadorai on the short-term trend chasing activity of some FX traders.

We now turn to the intervention activity of central banks in FX markets, as this is an important component of order flow.

7 Central Bank Intervention in Foreign Exchange Markets

Central banks routinely buy and sell currencies in spot FX markets with the intention of conditioning currency values. We denote this trading activity as *foreign exchange (FX) intervention*.¹⁹ However, notice that we intend *sterilized* FX intervention, in that when central banks buy and sell currencies, the consequent change in the money supply is usually *offset* through an immediate open market operation. In effect, FX intervention represents an independent instrument of policy-making as long as it does not change the money supply, since otherwise it would be a different and less convenient way of implementing the monetary policy.

FX intervention may alter currency values via the portfolio-balance effect, for it modifies the ratio between domestic and foreign assets held by the private sector. A purchase (sale) of foreign currencies by the central bank, which reduces (augments) the ratio between domestic and foreign assets held by the private sector, induces a depreciation (appreciation) of the national currency, in that investors require a greater risk-premium to hold a larger quantity of this currency.

Early studies, such as Frankel (1982), Frankel and Engle (1984), Jurgensen (1983), Loopesko (1984), Neumann (1984) and Rogoff (1984), indicated that FX intervention had a very *small*, if any, effect on exchange rates, suggesting that either domestic and foreign assets are perfect substitutes or that the effect of FX intervention on risk-premia is minuscule. Other studies based on more recent and accurate data, notably Dominguez and Frankel (1993a) and Gosh (1992), concluded that FX intervention presents a *significant* short-term impact on exchange rates and influences risk-premia.

An alternative channel through which FX intervention may alter exchange rates has been popularized by Mussa (1981). According to his *signalling* hypothesis, operations in FX markets by a central bank may signal changes in future monetary policy. As a consequence, FX intervention affects market expectations on currency fundamentals and hence exchange rates. In other words, order flow in FX markets “carries” fundamental information and condition exchange rates. This is because some informed agents, central banks, trade on their superior information and consequently alter currency values.

Several studies, such as Dominguez and Frankel (1993b,1993c), Klein and Rosengren (1991), Dominguez (1992), Watanabe (1992), Lewis (1993), Kaminsky and Lewis (1996) and Catte *et al.* (1994), have attempted to assess the signalling role of FX intervention. Their conclusions support Mussa’s hypothesis, as they conclude that FX intervention is related to the monetary policy and

¹⁹Here we present the bulk of the empirical research on FX intervention. For a more detailed coverage of this strand of research see the surveys of Edison (1993) and Sarno and Taylor (2001).

that it conditions investors' expectations.

All cited authors in their studies have considered either daily or monthly observations of FX intervention. Payne and Vitale (2003) instead employ transaction data on the intervention operations of the Swiss National Bank (SNB) and conduct an event study of the effects of FX intervention on exchange rates at high frequency.²⁰ Their data-set consists of all *customer* and *intervention* operations, time-stamped to the minute, conducted by the SNB in the USD/CHF market and are recorded for the period covering 1986 to 1995.²¹ The data-set also contains tick-by-tick indicative exchange rate quotes on the USD/CHF rate over the same period.

Payne and Vitale consider simple linear regressions of the 15 minute percentage return, r_{t+1} , on the USD/CHF rate on leads and lags of a signed intervention operation indicator, I_t , and a signed customer operation indicator, C_t ,

$$\begin{aligned} r_{t+1} &= \alpha + \sum_{j=8}^{-8} \beta_j I_{t+j} + \gamma_1 r_t + \gamma_2 r_{t-1} + \epsilon_t, \\ r_{t+1} &= \alpha + \sum_{j=8}^{-8} \beta_j C_{t+j} + \gamma_1 r_t + \gamma_2 r_{t-1} + \epsilon_t. \end{aligned}$$

Here I_t (C_t) is +1 in any 15 minute interval where the SNB purchased dollars, within an intervention (customer) operation, -1 in intervals when the SNB sold dollars and zero otherwise.

Payne and Vitale's results indicate that interventions have a *significant* impact on exchange rate levels. On the contrary, customer trades do not alter exchange rates, as at no point is the cumulative effect of a customer trade on the USD/CHF rate significantly different from zero. These results suggest that the exchange rate reaction to the SNB intervention activity is not the consequence of the portfolio-balance effect. Rather, it is evidence that intervention operations carry information.

As a further check of the signalling hypothesis, Payne and Vitale assess the relevance of the *size* of intervention in the relationship between intervention size and the USD/CHF return, inserting among the regressors of the percentage return, r_{t+1} , leads and lags of the signed intervention *quantity*, z_t .

Results for this regression show that the size of the intervention operation is important. In fact, the coefficient on contemporaneous intervention is significantly positive, so that the larger the magnitude of intervention, the larger its immediate impact on the exchange rate. More precisely,

²⁰Dominguez (2003) has also offered a high frequency study of FX intervention. However, she does not have access to actual transaction data and makes use of newswire reports of central bank activity in FX markets.

²¹The distinction between *customer* and *intervention* operations is crucial: whilst the former are triggered by the need of the Swiss government for foreign currency, the latter are aimed at influencing the value of the Swiss franc.

the estimated impact on the exchange rate of an intervention purchase of \$50 million by the SNB (nearly 30 basis points) is *very* large. This impact is an order of magnitude larger than the lower bound estimated by Evans and Lyons (2000) for the impact of central bank intervention in the USD/DEM market (5 basis points for operations of \$100 million).

To investigate the *persistence* of these effects Payne and Vitale also examine the results from regressions of *temporally aggregated exchange rate return* data on *aggregated intervention activity*. These regressions indicate that the effect of SNB intervention operations is significant, even though the quantitative impact of these operations *falls* with the time horizon. In brief, at least over the short-run, the signalling hypothesis seems confirmed. Intervention operations in FX markets represent an *expensive* instrument of policymaking. Because of their potential cost, they can be employed by monetary authorities to credibly convey information to market participants and hence condition market sentiment and currency values. Moreover, since large operations are potentially more expensive they have a bigger impact on exchange rate returns than small ones.

Concluding Remarks

Like a guide presenting a collection of paintings in a gallery we have offered a tour of the recent market microstructure approach to exchange rate determination. Thus, in lieu of a complete overview of a large and growing body of research, we have tried to isolate its most important and innovative contributions, focusing our attention on some key studies.

Market microstructure studies of exchange rate determination report widespread evidence that signed order flow is strongly positively correlated with short-term exchange rate movements. Even when taking into account possible feedback effects from exchange rates to trade innovations, order flow presents a significant explanatory power for short-term exchange rate dynamics.

This explanatory power can be associated with two different channels of transmission, due respectively to portfolio-balance and information effects. How important these two channels of transmission are remains an open question. Some researchers suggest that the contemporaneous correlation observed between order flow and exchange rate variations is not the consequence of a stable causal link from order flow to exchange rates, but rather the effect of the transitory impact of portfolio shifts. Others instead claim that order flow presents an information content, as it anticipates innovations in some fundamental variables and future movements in exchange rates.

In our opinion, a pressing challenge for this strand of research is represented by the estimation of a proper market microstructure model of exchange rate determination. This model should deal

with the issue of simultaneity in the determination of exchange rates and order flow, while disentangling the portfolio-balance and information effects of the latter on the former. The estimation of such a model would shed further light on the dispute over the portfolio-balance and information effects of order flow on exchange rates and help dissipating the general skepticism that the market microstructure approach to exchange rate determination has met among several international finance scholars.

An even more important challenge pertains to the forecasting power of order flow. In fact, the existing evidence put forward in its favor mostly concerns end-user transaction flows and is limited to few studies based on one or two data-sets. It can be argued that the forecasting power of order flow should be corroborated by more complementary studies. In addition, it is worth noticing that end-user transactions amount to proprietary order flow, which cannot be widely observed and whose potential forecasting power would in any case be of minimal practical use. In the end, more work is required before it can be legitimately argued that an answer to the elusive quest for valid exchange rate forecasts has been found.

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Table 1: Synthesis of empirical studies of FX market microstructure.

Study	Data	Spot Rates	Main Results
Andersen <i>et al.</i> (2003)	Reuters FFXF 03/01/92 - 30/12/98 5-minute obs.	EUR/USD, USD/DEM USD/JPY, GBP/USD USD/CHF	News announcements have a large and immediate impact on spot rates. News releases generates R^2 5-40% on announcement periods' returns.
Berger <i>et al.</i> (2005)	Reuters D2000-2 01/01/99 - 29/02/04 1-minute obs.	EUR/USD, USD/JPY	Order flow generates R^2 30-50% for intra-daily and daily returns. Order flow Granger causes returns at 1-minute frequency.
Biønnes and Rime (2005)	Four Scandinavian dealers' trades 02/03/98- 06/03/98 tick-by-tick obs.	USD/DEM, DEM/CHF USD/NOK, DEM/NOK DEM/SEK, DEM/DKK	Order flow and spot rates are cointegrated. 50/80% of spreads explained by private information. Half-lives of dealers' inventories range between 1 and 15 minutes.
Carpenter and Wang (2003)	Australian dealer's trades 01/05/02 - 03/07/02 tick-by-tick obs.	EUR/USD, USD/AUS	Order flow generates R^2 10-24% on tick-by-tick rates. Financial end-user order flow presents a significantly larger impact on returns.
Danielsson and Love (2004)	Reuters D2000-2 01/12/99 - 24/07/00 1- and 5-minute obs.	EUR/USD, GBP/USD EUR/GBP	Contemporaneous feedback trading is significant at high frequencies. IRF of trade imbalance more than twice with contemporaneous feedback trading.
Danielsson <i>et al.</i> (2002)	Reuters D2000-2 28/09/99 - 24/07/00 5-minute obs.	EUR/USD, USD/JPY GBP/USD, EUR/GBP	Order flow generates R^2 10-50% on intra-daily rates. In-sample forecasts of spot rates based on order flow outperform those of the random walk.
Evans and Lyons (2002)	Reuters D2000-1 01/05/96 - 31/08/96 daily obs.	USD/DEM, USD/JPY	Order flow generates R^2 40-60% on daily rates. \$1 billion trade imbalance increases USD/DEM by 0.5%.
Evans and Lyons (2003)	Reuters D2000-1 01/05/96 - 31/08/96 5-minute obs.	USD/DEM	News releases increase order flow and exchange rate volatility at daily and intra-daily frequency. The impact of news releases on spot rates via order flow is 2/3 of the total.
Evans and Lyons (2005a)	Citibank dealer's customer trades 01/01/93 - 30/06/99 daily obs.	EUR/USD	Customer order flow forecasts future macro variables over horizons ranging from 1 month to 2 quarters. Different explanatory power of different end-user order flows for daily to monthly returns.
Evans and Lyons (2005b)	Citibank dealer's customer trades 01/01/93 - 30/06/99 daily obs.	EUR/USD	Micro-based out-of-sample forecasting models out-perform traditional macro models and the random walk. Micro-based forecasts explain 16% of monthly exchange rate volatility.

Table 1: Synthesis of empirical studies of FX market microstructure. (cont.ed)

Study	Data	Spot Rates	Main Results
Froot and Ramadorai (2005)	State Street Co int. portfolio flows 01/01/94 - 09/02/99 daily obs.	111 rates from 19 countries	International portfolio flows are strongly positively correlated with contemporaneous returns. No long- run co-movement between flows and spot rates.
Hau <i>et al.</i> (2002)	EBS 01/01/98 - 31/12/99 monthly obs.	USD/DEM, EUR/USD USD/JPY, USD/CHF JPY/DEM, EUR/JPY DEM/CHF, EUR/CHF	Pooled order flow generates R^2 36% on pooled monthly rates. Impact of order flow on spot rates is larger in the post-euro period.
Killen <i>et al.</i> (2005)	EBS 01/01/98 - 31/12/98 daily obs.	DEM/FF	Cumulate order flow and spot rate cointegrated over flexible regime period. DEM1 billion trade imbalance increases DEM/FF by 3 pips.
Love and Payne (2003)	Reuters D2000-2 28/09/99 - 24/07/00 1-minute obs.	EUR/USD, GBP/USD EUR/GBP	Impact of order flow on spot rates doubles around news releases. Over half of the impact on spot rates of news releases is via order flow.
Lyons (1995)	NY bank dealer's and broker's trades 03/08/92 - 07/08/92 tick-by-tick obs.	USD/DEM	Trade innovations have strong information and inventory-control effects. \$10 million trade imba- lance increases USD/DEM by 1 pip.
Marsh and O'Rourke (2004)	RBS customer trades 01/08/02 - 29/06/04 daily obs.	EUR/USD, USD/JPY GBP/USD, EUR/JPY EUR/GBP, GBP/JPY	Customer order flow generates R^2 5-27% on daily rates. Financial order flow presents larger PINs.
Payne (2003)	Reuters D2000-2 06/10/97 - 10/10/97 tick-by-tick obs.	USD/DEM	60% of spreads explained by private information. 40% of spot rate variability is due to trade imbalance.

Notes: 1 pip corresponds to the fourth digit employed to quote exchange rates. IRF stands for impulse-response function. PIN stands for probability of information trading.