U.S. Exchange Rates and Currency Flows

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Abstract

After the Meese & Rogoff 1983-results, researchers have searched with torch for macroeconomic variables with predictive power on horizons shorter than 6 months. Recently several papers have showed that order flows influence exchange rates intradaily. Maybe order flow may be of importance also for lower frequencies than intraday, like the weekly frequency? In this paper I test a trading model where order flow may be informative due to the existence of private information, and where there are important macroeconomic public information as well. Using weekly data for spot and options trading in the U.S., the model is tested for five exchange rates against US Dollar. For three of the exchange rates, DEM/USD, GBP/USD and CHF/USD, I find that order flow is an important variable for explaining weekly changes in exchange rates, with correctly signed coefficients that are both statistically and economically significant.

Keywords: Foreign Exchange, International Macroeconomics, Microstructure
JEL Classification: G15; F31; F33

1 Introduction

In the last couple of years several papers have studied exchange rates intradaily, and found that the order flow is an important determinant of exchange rates intraday. Lyons (1995), Yao (1998) and Bjønnes and Rime (1999) have studied dealer response to order flow, while Evans (1998) and Payne (1999) have studied the importance of order flow on the whole market. Drawing on the theory of financial markets' microstructure, the authors

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have concluded that there exist private information in the foreign exchange market, and that order flow aggregates this information into prices.

The significance of these results becomes apparent when contrasted to the kind of result that we have been used to in exchange rate economics, since the seminal papers by Meese and Rogoff (1983a,b). Typically, the traditional macroeconomic models receive low support at the biannual frequency, and almost no support at the monthly frequency. de Vries (1994) states that the lack of effect of most macroeconomic variables is a stylized fact of exchange rate economics.

There may be several reasons for the lack of empirical support for the macroeconomic models. A questionnaire study of London-based foreign exchange analysts by Allen and Taylor (1989) showed considerable heterogeneity of expectations. Several recent survey studies confirm the view of agent heterogeneity.[1] The data in Bjønnes and Rime (2000) reveal that dealers expect other dealers to have different information than themselves.

Furthermore, in the traditional macroeconomic models exchange rates are determined by public macroeconomic information, while trading activities are completely irrelevant. As an example, consider the effect of trading in the flexible price monetary model, one of the traditional models. In this model price is determined by public information. Thus, trading as such has no effect on prices, since all available information will be impounded into prices prior to trading. In such a setting, trading will only occur to the extent that dealers require exchange, for well-known reasons, e.g. trade in goods or liquidity needs. Such trade will have no effect on prices, since it does not reveal any new information by assumption.

However, the huge trading volume of foreign exchange markets seems to be an important characteristic that one should try to take account of and build into models. Judging from the intra-day and survey evidence mentioned above, it might be that ignoring the possible existence of private information is the main shortcoming of the macroeconomic models for addressing shorter horizons. Maybe one should consider order flows as rele-

[1] Among these studies are Cheung and Wong (2000), Lui and Mole (1998), Menkhoff (1998), Cheung and Chinn (1999b,a) and Cheung et al. (2000).

vant variables also at lower frequencies, together with macroeconomic variables?

In this paper, I test a model for determining exchange rates that includes both public and private information variables on the weekly horizon. The model, based on a model by Evans and Lyons (1999), integrates public macroeconomic information in a microstructural trading model where, in equilibrium, the order flow aggregates private information. The model is tested for five exchange rates on four years of weekly data, from the beginning of July 1995 until the end of September 1999. The exchange rates are US Dollar (USD) against the Deutsche Mark (DEM), Japanese Yen (JPY), Pound Sterling (GBP), Canadian Dollar (CAD) and Swiss Franc (CHF). The key to this kind of analysis is a recent data set on weekly trading activity from the U.S market. The models receive considerable support, with significant and correctly signed effects from order flow.

In the theory of market microstructure of financial markets, one seeks to relax the assumptions of the traditional macroeconomic models: perfect information, homogeneous agents, and that the institutions for trading are non-consequential. Trading then becomes an important determinant of asset prices. Since the existence of private information results in trading when there are gains from trade, trading as such can be informative. Gains from trade may arise due to differentially motivated traders (like noise traders), and from dealers with different needs or attitudes towards risk. In markets with less than perfect transparency (observability), these different gains can not be separated from each other, and the flow may therefore contain some informative trade.

The foreign exchange market is characterized, among other things, by low transparency. Much of the trading in foreign exchange is not observe by all the participants. Dealers claim that there exist private information in the market, and that trading with customers is the most important source of private information (see Lyons, 1995; Yao, 1998; Bjønnes and Rime, 2000). Only the dealers in the specific bank observe the trades with customers. Within the interbank market, the dealers observe only a subset of the brokerage trades.

So how do we expect that order flow should influence exchange rates? Consider the models of Kyle (1985) and Glosten and Milgrom (1985). The price-setters, i.e. Market Makers, face other dealers that might have private information. When trading with potentially better informed players, the Market Makers adjust their beliefs about the uncertain asset value. In case of a buy order, they increase their expectations of the asset's value, and reduce it in case of a sell order. Effects of private information will therefore be related to an effect of currency trading on spot exchange rates.

This study utilizes a recent data set on currency trading by the "major players" in the U.S. currency market, collected by the U.S. Treasury. I have weekly observations from July of 1996 until September of 1999 on the volume of purchases and sales of spot transactions and changes in options positions. All measured in the foreign currency. As far as I know there are only three similar studies on foreign exchange markets. Wei and Kim (1997) were the first to use the present data set. Their approach was very different from the present, and they found no evidence that trading was informative about exchange rate changes. This paper is very close in spirit to Evans and Lyons (1999) and Rime (2000). Evans and Lyons (1999) develop a version of the model used in this paper and test it on daily data created from the real-time trading observations of Evans (1998). They find that order flow is more significant than change in interest differentials.

The advantage with the data set in this paper is that it covers four years of observations on the volume of trade. The series of Evans and Lyons (1999) cover observations for 79 days in 1996, and only on the net number of buy and sell orders and not the volume. The data in Rime (2000) are very similar to the present data set, with 3 years of weekly observations on aggregate currency trading by Norwegian banks. The trading observations are disaggregated on the three groups Foreigners, Norwegian Customers, and the Central Bank. Rime finds similar results as Evans and Lyons. Furthermore, the strongest effect is from the trading with customers, in line with the statements of dealers that customer trades are important private information.

The results in the present study are consistent with the results of Evans and Lyons. For three of the five exchange rates, order flow has a strong and correctly signed effect on price changes. The three exchange rates are DEM/USD, GBP/USD and CHF/USD. For these currencies I find that a sale of currency lead to a appreciation of the USD. What might be most surprising is the fact that order flow also has an effect over a week, implying that private information may live longer in foreign exchange markets than previously considered. The results are however in accordance with the results of Evans (1999) and Rime (2000).

The remainder of the paper is organized as follows: The model is presented in section 2. Section 3 presents the data. Results are presented and discussed in section 4, while section 5 concludes.

2 Model

The model, based on a model by Evans and Lyons (1999), captures important aspects of the foreign exchange market. Customer trading, which is the basic source of demand in foreign exchange, triggers interdealer trading. Dealers claim that customer trading is their main source of private information. During interdealer trading, dealers square their positions after the customer trade, and take a speculative position based on their private information in their customer trade. The following order flow from the interdealer trading leads to aggregation of information from the customer trades into prices. At the end of the day or week, most dealers want to go home with a zero position. Hence, the aggregate initial customer trading, interpreted as a portfolio shift, must be absorbed by the public after the interdealer trading. To be willing to absorb this, the public must be compensated by a risk premium, and the dealers speculate on its size during the interdealer trading. In addition, the initial portfolio shift by the customers may signal information on future currency return. In the model, the dealers will also speculate on basis of this signal and thus, aggregate order flow will be the variable signaling this private information to the rest of the market.

Consider an exchange economy with two assets, one risk free and one risky asset, represented by a currency.[2] There are N dealers, and a public sector (customers) that is distributed in the continuous interval $[0,1]$, so customers are more numerous than dealers and hence have a greater capacity for bearing risk (as a group). The horizon is infinite and timing within a period of the model is shown in figure 1. The information of each group will be clear from the below description of the timing. Dealers decide on prices in each round, $\{P_{i1,t}, P_{i2,t}, P_{i3,t}\}$, and the interdealer trade that takes place in round two, $T_{i2,t}$, while the public decide their demand in round three, $c_{3,t}$. The public trade in round 1 is stochastic (see below).

Both quoting and interbank trading must follow some rules. The following rules govern the quoting of prices, P (see Lyons, 1997):

P1. Quotes are given simultaneously, independently, and are required.

P2. All quotes are observable and available to all participants.

P3. Each quote is a single price at which the dealer agrees to buy and sell any amount.

Rule P1 ensures that prices cannot be conditioned on other dealers' prices, and that dealers cannot choose not to give quotes. When trades are initiated electronically in a multiple dealer market, this can potentially lead to simultaneous quotes, trades and both. Quoting and trading in the foreign exchange market is also extremely fast. Finally, not quoting would be a breach of the social norms for a Market Maker, and could be punished later by other dealers.[3] Examples of punishment might be not receiving trades from other dealers, and only obtaining wide spreads. Rule P2 states that there is costless search for quotes, which is true in the interbank market for normal trade sizes traded through the electronic broker systems. The foreign exchange market is extremely liquid with quotes and spread constant up to 10 mill USD, making rule P3 less restrictive than what might first be considered the case.

The following rules govern the interbank trading $T_{i2,t}$ of the dealers:

[2] The appendix contains a more detailed exposition of the solution of the model.

[3] The survey by Cheung and Chinn (1999b) shows that the "norms" of the market are considered important.

T1. Trading is simultaneous and independent

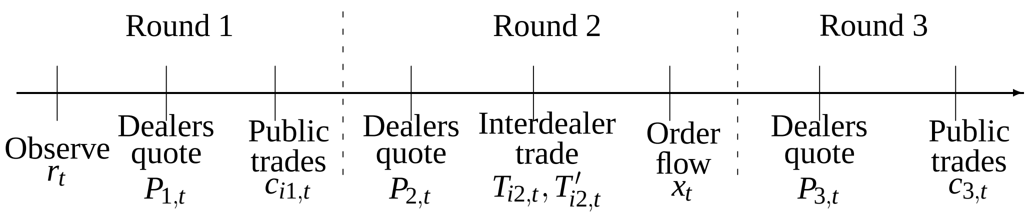
T2. Trading with multiple partners is feasible

T3. Trades are divided equally among dealers with the same quote, if someone wants to trade at the quote.[4]

T4. All dealers must end the period with a zero inventory of currency.

Rule T1, that trading is simultaneous and independent, implies that trades received from other dealers, T'_{it}, is an unavoidable disturbance to dealer i's inventory, in line with the fact that Market Makers in foreign exchange cannot perfectly control their inventory. Rules T2 and T3 are more technical, and rule T3 can be relaxed. T4 captures that dealers have limits on their overnight positions.

Figure 1: Period t timing



r_t is the new public information on currency return arriving in the market in period t, $P_{\tau,t}$ is the price that the dealers give in trading round τ of period t, and $c_{i1,t}$ and $c_{3,t}$ are the public's trading at the prices in round 1 and 3. In round 2, dealer i trades $T_{i2,t}$ at other dealers' price, and receive a net of $T_{i2,t}{}'$ from other dealers. After trading in round 2, the net aggregate order flow x_t is revealed.

Before any trading takes place in period t, all agents observe the public information r_t, which is the period t increment to the fundamental value of the currency, $F_t = \sum_{\tau=1}^{t} r_\tau$. The increments to currency value, r_t, are $IID\left(0, \sigma_r^2\right)$ and r_1 is known. After observing the public information, dealers give quotes $P_{i1,t}$ to the public (i.e. the customers) who place their orders $c_{i1,t}$. This trading is modeled as exogenous shocks and these are considered as portfolio shifts on behalf of the public. In Evans and Lyons, these shocks are $IID\left(0, \sigma_c^2\right)$ and not related to currency value. Here, I consider the case when this trading is a signal

[4]When several dealers quote the same price, the volume at this price must be divided between the dealers. Such a split can be arranged in the following way: Dealers are placed in a circle. If several dealers quote the same price, dealer i trades with the next dealer to the left to i.

on increment in the next period in fundamental value,

$$c_{i1,t} = r_{t+1} + \eta_{it}, \tag{1}$$

where $\eta_{it} \sim IID\left(0, \sigma_c^2\right)$. The trading with customers in round 1 is only observable to the dealers involved in the trade, so that customer trades are private information to the dealers involved. Since trading in round 1 is stochastic, the public should be considered as divided into two groups, with one group trading in round 1 and the other in round 3. Each customer in round 1 is small, and does not regard his own trading in round 1 as informative about overall trading in round 3. The public will not speculate in round 3 prices based on their own round 1 trading.

In round 2, all dealers simultaneously give interbank trading quotes, and then trade with each other to get rid of the inventory risk associated with round 1 trading. In addition, they speculate on the price change in round 3 based on their private information, and hedge against interdealer trades. Their total demand in round 2 is

$$T_{i2,t} = c_{i1,t} + D_{i2,t} + E\left[T'_{i2,t} | \Omega^D_{i2,t}\right], \tag{2}$$

where $E\left[T'_{i2,t} | \Omega^D_{i2,t}\right]$ is hedging against the expected trade dealer i receives from other dealers in round 2, $D_{i2,t}$ is dealer i's speculative demand as a function of private information $c_{i1,t}$, and $c_{i1,t}$ is inventory control after customer trade. Expected trade received from other dealers is zero in equilibrium ($c_{i1,t}$ has expectation zero conditioned on public information only, and the elements of $c_{i1,t}$ are IID). Dealers learn about the overall portfolio shifts through the aggregate order flow, $x_t = \sum_i^N T_{i2,t}$, that they observe after the interdealer trading in round 2.

In round 3, all dealers once more trade with the public to get rid of the rest of their inventory risk. The initial portfolio shift has price effects (i) because the public must be compensated for taking the risk (assuming the shift is sufficiently large to matter), and (ii) because of the potential signal of future return when the initial trading $c_{i1,t}$ is correlated with future return. The dealers are willing to compensate the public for taking the risk, instead of bearing the risk themselves, because the public has a greater capacity of bearing risk. In addition, the dealers have overnight limits on their inventory. Public trading in round three is the result of optimization.

All agents, both dealers and the public, have identical negative exponential utility defined over terminal wealth. Since all shocks are *IID* and expected wealth in the infinite horizon equals present wealth, each period can be analyzed in isolation, and thus maximizing end-of-period wealth will also maximize the utility. Therefore, the utility that will be maximized is given by

$$U(W_{i3}) = -\exp(-\theta W_{i3,t}), \tag{3}$$

where $W_{i3,t}$ is end-of-period wealth in period t, and θ is the coefficient of absolute risk aversion.

2.1 Equilibrium

For the derivation of the specific equilibrium, I refer the reader to the appendix. The equilibrium shares the same structure, notwithstanding if $c_{i1,t}$ is correlated with future fundamental return or not. The equilibrium prices are

$$P_{1,t} = P_{2,t} = P_{3,t-1} + r_t - \pi x_{t-1}, \tag{4}$$

$$P_{3,t} = P_{2,t} + \lambda x_t,\ \lambda > 0, \tag{5}$$

where x_t is aggregate order flow[5] in the inter dealer trading in round 2, and λ a parameter that will be determined below. In round 1, all information is public when prices are set; hence all dealers set the same prices only adding the increment to currency value that was not included in the price already, here represented by $r_t - \pi x_{t-1}$. Equilibrium (no-arbitrage), and full transparency of prices, ensures that all dealers also set the same price in round 2. If the prices in round 2 are to be equal, these can only be conditioned on

[5] In Evans and Lyons, the period t order flow is denoted by Δx_t, and x_t is cumulative order flow up to time t.

public information, and therefore the round 2 price must equal the round 1 price. Setting a price different from the others would reveal information and attract all supply/demand. Instead, dealers utilize their private information in forming their speculative demand in round 2. Interdealer trade is only observed by the parts participating in the transaction.

Equilibrium trade by dealer i is given by

$$T_{i2,t} = c_{i1,t} + D_{i2,t}\left(c_{i1,t}\right) = \alpha c_{i1,t}, \alpha > 1, \tag{6}$$

where the second equality follows from the dealers' optimal speculative demand, derived in the appendix, and α is a constant in the dealers' trading strategy.

The important issue is the price in round 3. In round 3, dealers trade with the public to reduce their inventory and thereby share the risk with the public. This is normal in foreign exchange markets, where dealers usually go home with a zero position. Dealers know that the total supply the public must absorb equals the negative of the sum of the portfolio shifts in round 1, $-\sum_i^N c_{i1,t}$. Given the trading strategy above, the order flow in round 2, $x_t = \sum_i^N T_{i2,t} = \alpha \sum_i^N c_{i1,t}$, is a sufficient statistic of $\sum_i^N c_{i1,t}$. Hence, the dealers must quote a price $P_{3,t}$ such that

$$-\frac{1}{\alpha} x_t = c_{3,t} = \gamma\left(E\left[P_{3,t+1} | \Omega_{3,t}^P\right] - P_{3,t}\right)$$

where the second equality is the public demand from maximizing their utility, $\Omega_{3,t}^P$ is the information set of the public, and γ equals $\left(\theta Var\left[P_{3,t+1} | \Omega_{3,t}^P\right]\right)^{-1}$. Solving for $P_{3,t}$ gives

$$P_{3,t} = E\left[P_{3,t+1} | \Omega_{3,t}^P\right] + \rho x_t, \ \rho = 1/\left(\alpha\gamma\right) > 0. \tag{7}$$

In addition to their expectations, the public must be compensated for bearing the additional risk, so the risk premium is given by ρx_t.

Inserting for the expectation in (7), we get

$$P_{3,t} = P_{2t} + \pi x_t + \rho x_t = P_{2t} + \lambda x_t \tag{8}$$

$$P_{3,t} = \sum_{\tau=1}^{t} (r_\tau + \rho x_\tau) + \pi x_t \tag{9}$$

where $\pi = \phi/\alpha$ and ϕ is the parameter on new information in the public's conditional expectation ($\phi \in (0,1)$). The price in round 3 equals the expected fundamental value for the next period ($F_t + \pi x_t$) plus the accumulated risk premium related to the accumulated risk the public have absorbed ($\sum_\tau^t \rho x_\tau$). From (4) and (8), the change in price equals the adjusted increment, an element for the expected return in the next period, and the additional compensation for taking additional risk:

$$\Delta P_{3,t} = r_t - \pi x_{t-1} + \pi x_t + \rho x_t \tag{10}$$

If round 1 public trading is uncorrelated with future return, the two terms in the middle disappear,

$$\Delta P_{3,t} = r_t + \rho x_t. \tag{11}$$

This is the equation tested by Evans and Lyons. By rewriting (10), it can empirically coincide with the above equation. To see this, insert for x_{t-1}. After observing r_t, the noise from the flow in the previous period can be aggregated,

$$\pi x_{t-1} = \frac{\phi}{\alpha}\alpha \sum_{i=1}^{N} c_{i1,t-1} = \phi N r_t + \sum_{i=1}^{N} \phi \eta_{it-1},$$

where I use (1) to insert for $c_{i1,t-1}$. Inserting this in equation (10) gives

$$\Delta P_{3,t} = (1 - N\phi)\, r_t + \lambda x_t + \tilde{\eta}_t, \tag{12}$$

where $\tilde{\eta}_t = \sum_i \phi \eta_{it-1}$. This term is uncorrelated with r_t by definition. It is uncorrelatd with x_t since $x_t = \alpha \sum_i c_{i1,t}$, which are all *IID*. Therefore, r_t and x_t are weakly exogenous with respect to $(1-N\phi)$ and λ. The term $\tilde{\eta}_t$ is unobservable for the econometrician, and will hence be captured by the error term in the econometric implementation.

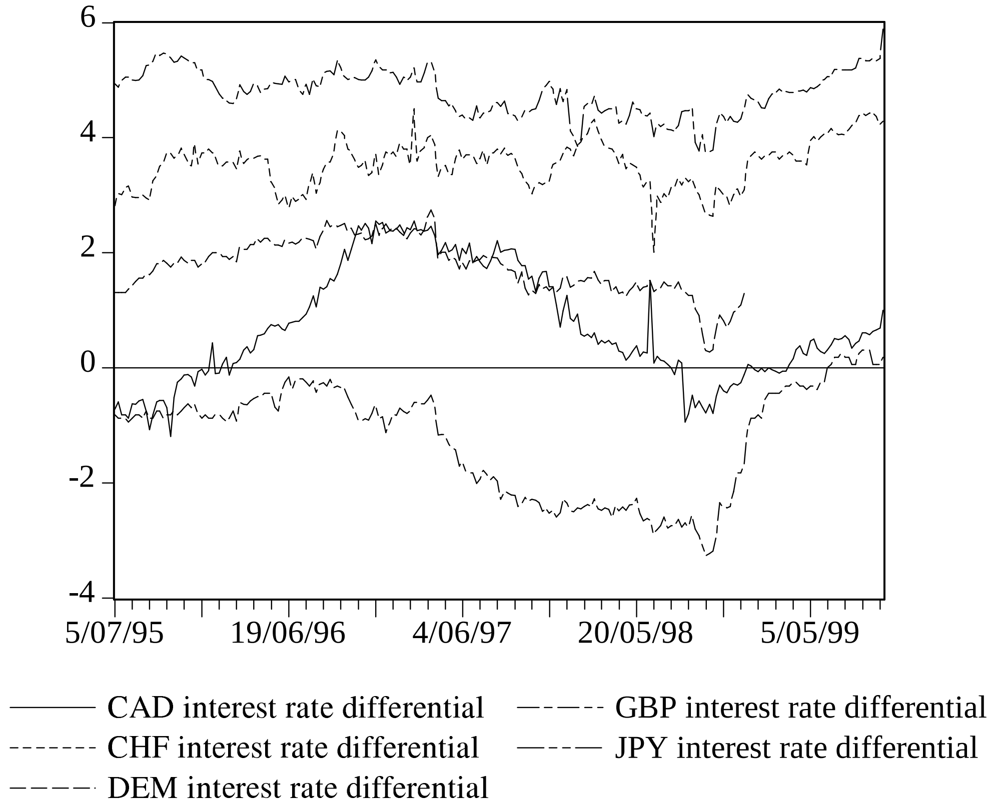
An example may clarify the model: For simplicity, imagine that all dealers are initially holding their preferred inventory of currency. In round 1, dealer 1 receives a buy order from a customer of 100 units of currency ($c_{11,t} = 100$). Dealer 1 is now short compared to his preferred position, and in round 2 he wants to cover the position. In addition, he speculates that there will be a buying pressure later on in round 3, and buys 120 $(\alpha = 1.2)$ in round 2 from the rest of the interbank market ("dealer 2"). Market order flow, x_t, is 120. Dealer 2 wants to become square in trading with the public in round 3, and hence wishes to buy 120 from the customers. Dealer 1, having a speculative position of 20, wants to sell 20. The net flow that the public must absorb is -100 ($= -c_{11,t} = -x_t/1.2$), in other words, they must be induced to sell 100. The public, holding their preferred inventory, must be compensated to carry the risk of holding 100 units of currency less. The price is bid up by $\lambda \cdot 120$, so that the public is willing to sell. Dealers accept this because it is less than what other dealers would have charged for taking the risk, since the public as a group has a greater capacity for bearing risk.

3 Data

The public information set consists of weekly observations on the interest rates for the six countries USA, Germany, Japan, Great Britain, Canada and Switzerland. In some regressions I will also use stock market indexes from the five countries. Figure 2 plots the interest rates. The GBP interest rate is the top graph, while the JPY interest rate is the bottom graph. The CAD, DEM and CHF interest rates are in the middle, in that sequence from above.

The exchange rates are quoted at the end of the week. If there is no observations available at the Friday, I use the observations from the following Monday. Exchange rates are the USD against the DEM, the JPY, the GBP, the CAD and the CHF. These six currencies are among the seven most traded currencies globally (the French Franc is no. 6,

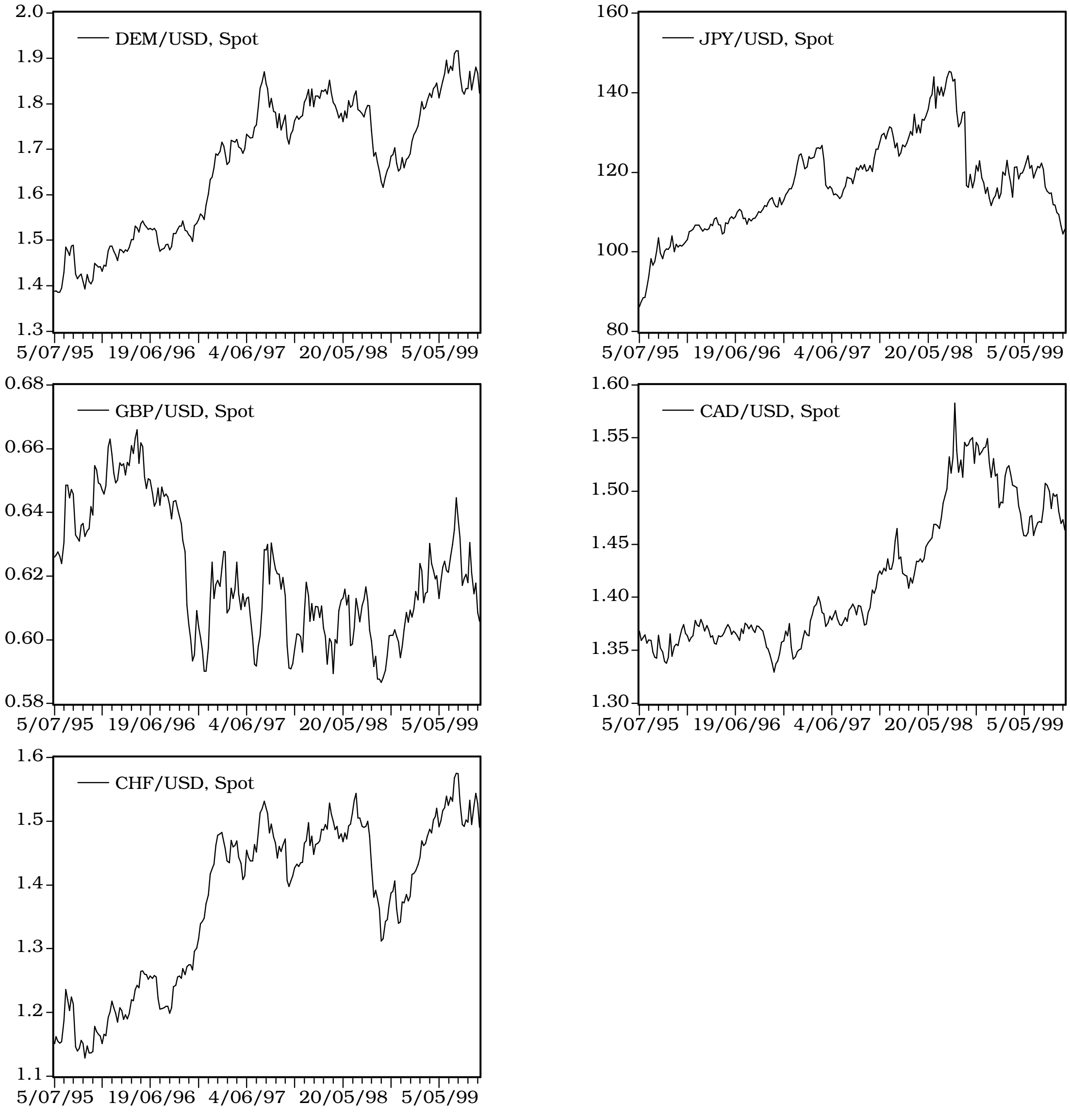
Figure 2: 3-month interest rate differential



The graphs are $\left(i_t^{USD} - i_t^{*}\right)$, where $*$ indicate the foreign interest rate. The 3-month interest rates are interest rates from the so-called "EuroDollar" market, and are provided by Norges Bank. The labels refer to the ending point of the series, so that the upper most series is the GBP interest rate etc. The DEM interest rate ends in 1998 due to the introduction of Euro in 1999.

before CAD). Similarly, the five exchange rates are among the six most traded exchange rates (BIS, 1998).

Figure 3: Spot Exchange Rates



Source: Norges Bank (Central Bank of Norway). The weekly exchange rates are end-of-week rates. If no Friday rates are available, I use the rate from the following Monday.

Figure 3 plots the five exchange rates. We see that the USD depreciated against the DEM, JPY, GBP and CHF in the fall of 1998, during the Asian crises. Also, notice that the DEM and the CHF are highly correlated.

Table 1 summarizes the descriptive statistics for the four exchange rates from the beginning of July 1995 until September 1999. The GBP/USD and the CAD/USD are the two most stable exchange rates, with standard deviation being 3% and 5% of the mean, respectively. Standard deviation as percentage of mean is ca. 9 – 10% for the others.

Table 1: Summary statistics for exchange rates

	DEM/USD	JPY/USD	GBP/USD	CAD/USD	CHF/USD
Mean	1.66	116.90	0.62	1.42	1.37
Median	1.70	116.27	0.62	1.39	1.42
Maximum	1.92	145.32	0.67	1.58	1.57
Minimum	1.39	86.18	0.59	1.33	1.13
Std. Dev.	0.15	11.74	0.02	0.06	0.13
Observations	222	222	222	222	222

Summary statistics for end-of-week exchange rates, calculated over the period Jul. 5. 1995 to Sep. 29. 1999.

3.1 Currency flows

Weekly observations on currency trading in Deutsche Mark (DEM), Japanese Yen (JPY), British Pound Sterling (GBP), Canadian Dollar (CAD) and Swiss Franc (CHF) by large market participants in the U.S. This represents the order flow in the theoretical model.

A major foreign exchange participant is one with more than $50 billion equivalent in foreign exchange contracts on the last business day of any quarter during the previous year (see Wei and Kim, 1997). There were 36 major participants in 1996 according to this definition, whereof 29 were commercial banks (Wei and Kim, 1997). In 1995, 20 banks covered 70% of the activity in the U.S, while in 1998 24 banks covered 75% of the activity, according to BIS (1998, 1996).

The observations on currency trading are collected by the U.S. Treasury. The Treasury began publishing these weekly time series in the quarterly Treasury Bulletin in September 1994, with observations beginning in January 1994. In this study, I use observations from the beginning of July 1995 until the end of September 1999, which makes a total of 222 weeks.[6] The series include the weekly net positions of currency options, and the weekly sale and purchase of spot, forwards and futures together, by the major foreign exchange market participants in the U.S. All series are measured in the foreign currency, so DEM

[6][SH: DÅRLIG SPRÅK?]Observations from January 1994 until July 1995 are only available in paper copies, which the author not yet has gotten hold off.

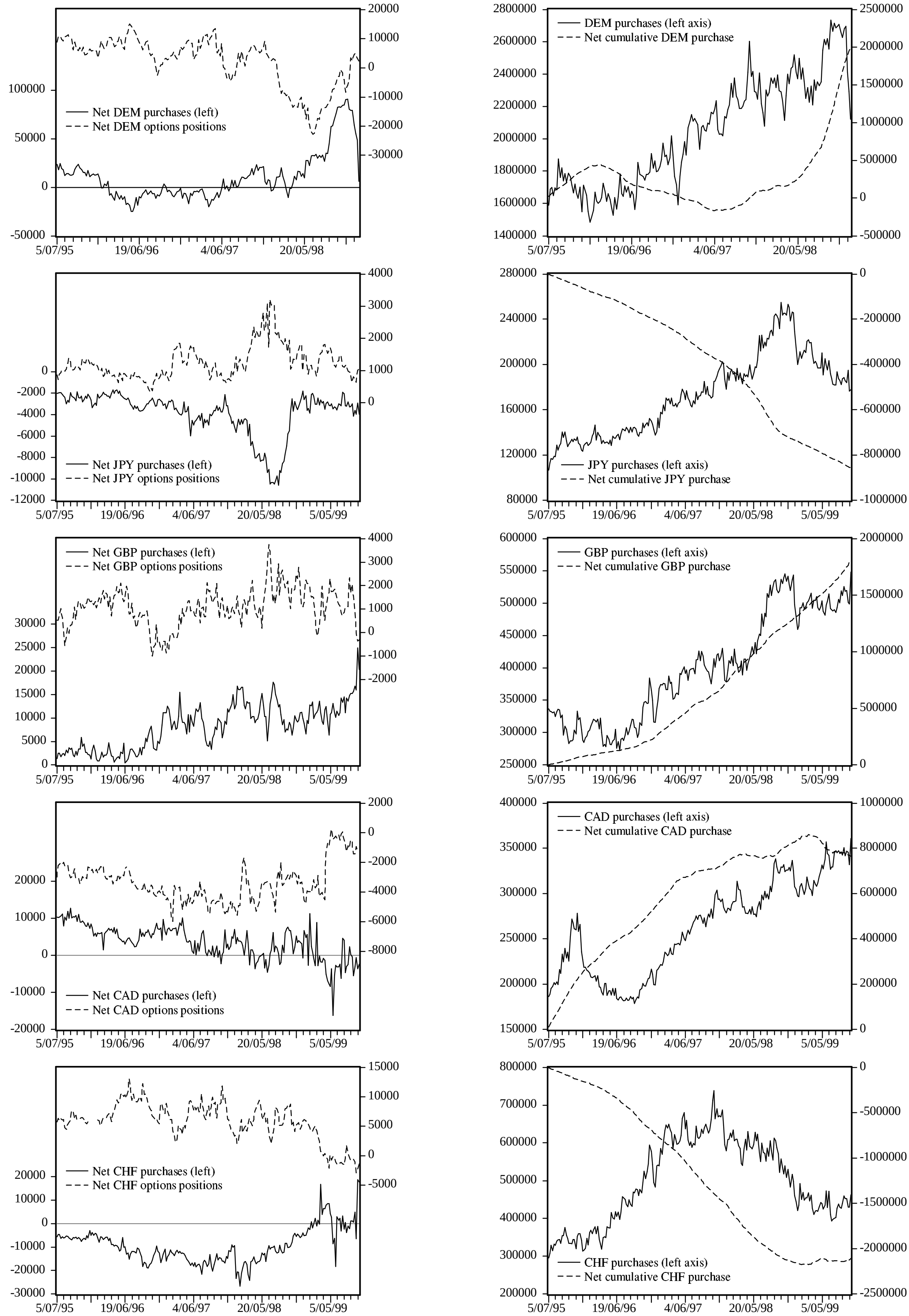
purchases are purchases of DEM by the major U.S. participants. The net option positions are measured as delta equivalent values. The delta equivalent equals the product of the first derivative of the option value with respect to the exchange rate, and the notional principal of the contract. The value of a call option (right to buy currency) is increasing in the price of the underlying currency. Hence, if a bank is long in call-options, they will have a positive net option position. If a bank is equally long in similar put and call options, the net position will be zero.

Figure 4 plot the weekly trading activity. There is one row for each currency, in the following order from the top: DEM, JPY, GBP, CAD, and CHF. In the left column, there are net purchases of currency, while the right column shows currency purchases on the left axis, and net cumulative purchases at the right axis. All flow variables are measured in millions of the foreign currency, except JPY flows which are measured in billions JPY. In the cumulative graphs, I have set the initial point to zero since I have no observations on initial positions. The Purchase and Net Purchase series includes spot, forwards and futures. These series contains trading with all counterparties, meaning it is not only interbank trading. The banks will report both the sales to a customer and the subsequent interbank trading to cover the customer transaction. From the graphs, it is clear that the net position of the banks is very small. Augmented Dickey-Fuller tests also show that all of the flow variables have unit roots, except the Net Options Position of CAD and CHF.

The model gives special attention to the sign of the trade, i.e. whether the initiator of the trade bought or sold currency. The reason is that a sale of currency by the initiating part may be taken as a signal that the currency is overvalued. Only knowing that one of the parts in a transaction sold currency is not enough information.

The data set in this study give no such indication of sign, and in the regressions I will include the observations as they are. The following conditional prediction can be made: *If* the U.S. banks are the main market makers in these currencies, then a net (unexpected) sale of the foreign currency should lead to an appreciation of the exchange rate, i.e. in-

Figure 4: Weekly order flows



There is one row for each currency, in the following order from the top: DEM, JPY, GBP, CAD, and CHF. In the left column there is net purchases of currency on the left axis, while the right axis show the Net Options Position. The right column shows currency purchases on the left axis, and net cumulative purchases at the right axis. All flow variables are measured in millions of the foreign currency, except JPY flows which are measured in billions JPY.

Table 2: Summary statistics for currency flows

		Mean	Median	Maximum	Minimum	Std. Dev.
DEM	Sale	2,022	2,071	2,652	434	339
	Purchase	1,711	2,064	2,734	441	354
	Net Options positions	2.02	4.76	14.96	-22.88	8.60
JPY	Sale	177	177	260	109	37
	Purchase	173	173	255	107	35
	Net Options positions	1.24	1.12	3.20	0.36	0.52
GBP	Sale	391	385	538	271	79
	Purchase	399	395	548	273	83
	Net Options Position	1.07	1.10	3.74	-1.00	0.81
CAD	Sale	259	271	363	172	55
	Purchase	263	273	361	178	52
	Net Options Position	-3.35	-3.45	0.24	-5.98	1.30
CHF	Sale	507	495	754	301	115
	Purchase	497	483	738	295	111
	Net Options Positions	5.77	6.15	13.11	-2.95	3.27

Summary statistics for the flow variables. The summary statistics for DEM trading is calculated on the sample ending in 31. Dec. 1998. Trading in DEM fell dramatically in 1999 due to the introduction of the Euro. All other statistics calculated based on the whole sample. All flows except JPY trading is measured in billions of foreign currency. Flows in JPY are measured in trillions JPY.

crease the value of the currency. In the data, a net sale by the U.S. banks would in this case mean that most of the initiators bought currency. The reason might be that they believed the currency to be undervalued. *If*, on the other hand, the U.S banks are not very particular active in market making, then it would mean that they are the ones that take initiative to trades. Then a net sale of foreign currency should lead a depreciation of the currency.

What can be said about this issue? Since the U.S. market is the only active major market during most of the trading-day in the U.S., the major players involved in this data set are also the major players of the global market during U.S. daytime. These banks are then probably also the main market makers. On the other hand, since the European market is the largest currency market, U.S. banks tend to try to do most of their trading between 8 and 11 in the morning, while the European market still is active. With this in mind, there is no particular reason to believe that the U.S. banks mainly do market making. In the European market, most banks both serve as market makers and trade at other quotes. The exception being banks in London, which has a word for doing more market making than others do.

4 Results

The model is tested on the weekly frequency. Evans and Lyons tested the model on the daily frequency. Effects from order flow need not be restricted to the intra-day or daily frequency, however. Evans (1999), going from the intra day to a weekly horizon, show that order flow can be important also at the weekly horizon. Furthermore, the testable implication of the model, the third round of trading and pricing, is equally applicable at the weekly frequency as the daily. In the third round of the model, the dealers trade with the public to share risk. Within a week, it is likely that dealers share the risk by trading with each other in different time zones, since the foreign exchange market is a 24-hour open market. When the Europe market is closing, dealers trade with US dealers to get rid of the inventory risk. Trading with the public to share risk may be a more important alternative at the end of week, since most regional markets are less active during weekends.

If one believes that the periods in the model should be strictly interpreted as days, I can still test the model with weekly data on order flow. My approach would be equivalent to taking the 7th-difference in price as the dependent variable instead of the first difference, using the 7 day cumulative sum of order flow as a regressor, and testing the equation by only choosing end of week observations.

The theoretical model puts few restrictions on how public information variables enter the public information component r_t. Evans and Lyons (1999) chooses the *change* in the interest differential. This is a fairly natural implementation, since r_t is the increment in return in each period. I follow Evans and Lyons and use change in the interest differential, $\Delta\left(i_t^{\mathrm{USD}} - i_t^*\right)$ with an * indicating the foreign interest rate.

It is important to note that only *unexpected* order flows should influence the price, as the expected order flow should already be captured in the price. In the model, all order flow is unexpected, but this will not be the case in reality. I will test two versions of the theoretical model. In the first, I estimate the expected flow with an ARIMAX-model, while in the second I use the flow from the previous week as a proxy for the expected flow. The two formulations are,

$$\Delta P_t = \alpha + \beta_1 \Delta\left(i_t^{\text{USD}} - i_t^*\right) + \beta_2[\text{SpotPurchase}_t - \widehat{\text{SpotPurchase}_t}] + \beta_3[\text{SpotSale}_t - \widehat{\text{SpotSale}_t}] + \beta_4[\text{OptionsPos}_t - \widehat{\text{OptionsPos}_t}] + u_t \quad (13)$$

and

$$\Delta P_t = \alpha + \beta_1 \Delta\left(i_t^{\text{USD}} - i_t^*\right) + \beta_2 \Delta\text{SpotPurchase}_t + \beta_3 \Delta\text{SpotSale}_t + \beta_4 \Delta\text{OptionsPosition}_t + u_t \quad (14)$$

All regressions use the change in the log of nominal exchange rates for DEM/USD, JPY/USD, GBP/USD, CAD/USD and CHF/USD as a dependent variable. Using the change in levels, as in the theoretical model, instead of change in logs does not affect the results. Results are shown in table 3 to 7.

Table 3: Change in log exchange rates

	DEM/USD	JPY/USD	GBP/USD	CAD/USD	CHF/USD
Constant	0.001174	0.000857	-0.000215	0.000430	0.001103
	(1.33)	(0.63)	(-0.32)	(0.92)	(1.22)
$\Delta\left(i_t^{\text{USD}} - i_t^*\right)$	-0.000570	-0.000072	0.012163	-0.010821	-0.012625
	(-0.07)	(-0.01)	**(2.46)	***(-5.05)	**(-2.15)
Net Unexpected Spot sale	0.000512	0.000776	0.001025	-0.000004	0.000635
	***(2.99)	(0.30)	***(2.72)	(-0.02)	***(4.61)
Unexpected Options position	-0.001189	-0.015945	-0.004097	0.000208	-0.004095
	***(-2.87)	**(-2.49)	***(-2.72)	(0.23)	***(-5.19)
Adjusted R^2	0.06	0.02	0.07	0.09	0.14
Durbin-Watson stat	1.95	2.05	1.93	2.17	1.93

Estimated by GMM. t-values are in parenthesis, and ***, ** and * indicates significance at the 1%, 5% and 10%-level respectively. The net unexpected flow of spot sale equals "Spot sale$-\widehat{\text{Spot sale}}-$(Spot purchase$-\widehat{\text{Spot purchase}}$)", where $\widehat{\text{Spot sale}}$ is the expected value from a ARIMA regression on past values of the flow variables. The other unexpected flow variables are defined in similar way. All flow coefficients multiplied by 10^3. This means that the coefficients measure the effect of a 1 billion flow, except for JPY/USD where the coefficient measure the effect of a 1 trillion flow.

From table 3 we get the general picture from all the regressions. Net unexpected spot sale is significant for DEM/USD, GBP/USD and CHF/USD, while Unexpected Options positions is significant for JPY/USD as well as the exchange rates already mentioned. The coefficients on both flow variables are measured as the effect of a 1 billion flow. The coefficients on Net Unexpected Spot sale are positive. Since the flow variables are measured in the foreign currency, this means that an unexpected net sale of DEM, CHF or GBP by the major U.S. banks (i.e. an unexpected purchase of USD) appreciates the USD against the currency in question. The model would predict that the foreign currency should depreciate when the U.S. banks take the initiative to trade and sell currency. In this perspective, the U.S. banks rather trade at other banks quotes than to act as market makers. This can only be part of an equilibrium if somebody else is being market makers. If the U.S. banks do most of their trading while the European market is active, this might very well be the case.

The coefficient on the unexpected sale in the DEM/USD regression is 0.0005, which means that a unexpected sale pressure of 1 billion DEM increases the DEM/USD exchange rate with 0.05%. This is economically significant since the weekly change in DEM/USD is about 0.1%. The average absolute value of the net unexpected sale flow is 4 billion DEM.

The effect from increased options positions are negative and significant for DEM/USD, JPY/USD, GBP/USD and CHF/USD. If the U.S. banks unexpectedly increase their positions of call options (rights to buy currency), this is signal that they expect the currency to be more valuable than the current price/strike price. This will then subsequently lead to an appreciation of the currency. The effect is analogous to a unexpected spot purchase pressure for the currency.

In table 8 and 9 in the appendix we run the regression without the option variables. The unexpected spot flow remains significant, and the coefficients are only slightly less in value.

In table 4 I also include two stock indexes in each regression as well. The Standard & Poor 500 is included in all regressions, while the other indexes; the Frankfurt-index (Commerzbank) from Germany; the Nikkei 225 index from Tokyo, Japan; the FT-SE 100 from London, UK; the Toronto TSE-300 from Canada; and the SPI General Index from Zurich, Switzerland, are only included in their respective regressions. The stock indexes are included to see if the flow variables remain significant even when more public

Table 4: Change in log exchange rate

	DEM/USD	JPY/USD	GBP/USD	CAD/USD	CHF/USD
Constant	0.000532	0.000338	-0.000405	0.000475	0.000147
	(0.63)	(0.25)	(-0.62)	(1.04)	(0.17)
$\Delta\left(i_t^{\mathrm{USD}} - i_t^*\right)$	-0.006937	-0.000061	0.011449	-0.008387	-0.010030
	(-0.95)	(-0.01)	**(2.37)	***(-3.98)	*(-1.86)
Net Unexpected Spot sale	0.000301	0.000892	0.001004	0.000022	0.000593
	*(1.81)	(0.34)	***(2.72)	(0.13)	***(4.51)
Unexpected Options position	-0.000852	-0.015715	-0.003547	-0.000117	-0.003855
	**(-2.17)	**(-2.44)	**(-2.39)	(-0.14)	***(-5.14)
Δlog(S&P 500)	-0.025293	0.135970	-0.035722	0.048483	0.079779
	(-0.48)	*(1.97)	(-0.93)	(1.52)	*(1.75)
Δlog(Foreign SE)	0.183566	0.022209	0.130430	-0.141974	0.151557
	***(4.32)	(0.44)	***(3.37)	***(-4.21)	***(3.03)
Adjusted R^2	0.18	0.03	0.11	0.17	0.26
Durbin-Watson stat	2.06	2.05	1.99	2.22	1.99

Estimated by GMM. t-values are in parenthesis, and ***, ** and * indicates significance at the 1%, 5% and 10%-level respectively. The net unexpected flow of spot sale equals "Spot sale$-\widehat{\text{Spot sale}}-(\text{Spot purchase}-\widehat{\text{Spot purchase}})$", where $\widehat{\text{Spot sale}}$ is the expected value from a ARIMA regression on past values of the flow variables. The other unexpected flow variables are defined in similar way. All flow coefficients multiplied by 10^3. This means that the coefficients measure the effect of a 1 billion flow, except for JPY/USD where the coefficient measure the effect of a 1 trillion flow.

information that may be related to exchange rate return are included in the regressions. The table shows that the flow still is significant, although only at the 10% level for the DEM/USD. From the table we see that it is primarily the foreign stock index return that have explanatory power for the exchange rates, and that the coefficients have different signs. The effect is positive for the DEM/USD, GBP/USD and the CHF/USD, while it is negative for CAD/USD.

Changes in interest differentials have negative and significant coefficients for CAD/USD and CHF/USD, and positive for GBP/USD. The negative coefficients are a bit counter-intuitive. When the US interest rate increase relative to the foreign interest rate, the USD depreciates (the exchange rate decreases, so the foreign currency appreciates). From figure 2 and 3 we see that the USD has appreciated against the CHF and CAD over the sample, and at the same time the interest differential has remained stable (CHF) or fallen (CAD). Hence, it may be that the negative coefficient is due to long term trends not captured here. The lack of significance for the two other exchange rates may be due to that interest differentials are not very good indicators of new information since many interest changes are anticipated by the market.

In this paper the main focus is on the flow variables, and as the tables in the appendix show, the coefficients of the flow variables are not affected by using the lagged change in interest differentials as an instrument.

Table 5: Change in log exchange rate

	DEM/USD	JPY/USD	GBP/USD	CAD/USD	CHF/USD
Constant	0.001217	0.000806	-0.000228	0.000397	0.001086
	(1.37)	(0.64)	(-0.34)	(0.84)	(1.19)
$\Delta\left(i_t^{\mathrm{USD}} - i_t^*\right)$	-0.001132	0.002767	0.012355	-0.011050	-0.012950
	(-0.15)	(0.24)	**(2.47)	***(-5.12)	**(-2.30)
Net Unexpected Spot sale	0.000520	-0.000337	0.001020	0.000017	0.000675
	***(3.02)	(-0.12)	***(2.69)	(0.10)	***(4.02)
Unexpected Options position	-0.001113	-0.017617	-0.004199	0.000169	-0.004134
	***(-2.66)	**(-2.17)	***(-2.74)	(0.19)	***(-5.22)
Net Unexp. Spot sale, lagged	0.000241	0.008430	0.000117	-0.000064	0.000105
	(1.39)	***(2.63)	(0.30)	(-0.36)	(0.42)
Unexp. Options position, lagged	0.000000	-0.001362	0.000406	-0.001465	-0.000962
	(0.00)	(-0.25)	(0.27)	(-1.61)	(-1.47)
Adjusted R^2	0.06	0.06	0.06	0.10	0.14
Durbin-Watson stat	1.98	2.06	1.93	2.19	1.93

Estimated by GMM. t-values are in parenthesis, and ***, ** and * indicates significance at the 1%, 5% and 10%-level respectively. The net unexpected flow of spot sale equals "Spot sale$-\widehat{\text{Spot sale}}-\left(\text{Spot purchase}-\widehat{\text{Spot purchase}}\right)$", where $\widehat{\text{Spot sale}}$ is the expected value from a ARIMA regression on past values of the flow variables. The other unexpected flow variables are defined in similar way. All flow coefficients multiplied by 10^3. This means that the coefficients measure the effect of a 1 billion flow, except for JPY/USD where the coefficient measure the effect of a 1 trillion flow.

In the regressions in table 3 and 4 the flow variables have a permanent effect on exchange rates, in line with the presumption that they aggregate new information. This can however be tested, which is done in table 5. If the flow variables do not provide new information, the effect should not be permanent. The effect could then either be countered or disappear when lagged flows are included in the regressions. For the DEM/USD, GBP/USD and CHF/USD, the exchange rates with significant coefficients on the flow variables above, the lagged flow is insignificant while the current flows remain significant and with the same value on the coefficients. In case of JPY/USD, the current flow is insignificant, as before, but the lagged flow is significant.

In table 6 and 7, I test the model with unexpected flow proxied by the change in the flow variables. I also include the sale of currency and purchase of currency as separate variables, instead of the net of the two, to see if they have different coefficients. This is also done in table 9 to 12 in the appendix, there with estimated expected flow as previous.

Table 6: Change in log exchange rate

	DEM/USD	JPY/USD	GBP/USD	CAD/USD	CHF/USD
Constant	0.001077	0.001053	-0.000224	0.000367	0.001047
	(1.24)	(0.76)	(-0.34)	(0.78)	(1.15)
$\Delta\left(i_t^{\mathrm{USD}} - i_t^*\right)$	0.000563	-0.000691	0.011844	-0.010948	-0.011353
	(0.07)	(-0.08)	**(2.42)	***(-5.08)	*(-1.93)
ΔSpot sale	0.000585	-0.001827	0.000948	0.000046	0.000548
	***(3.45)	(-0.63)	***(2.65)	(0.30)	***(4.98)
ΔSpot purchase	-0.000569	0.001496	-0.000855	-0.000048	-0.000577
	***(-3.40)	(0.47)	**(-2.40)	(-0.31)	***(-5.34)
ΔOptions Position	-0.001341	-0.011028	-0.004123	0.000296	-0.003853
	***(-3.36)	**(-2.13)	***(-2.91)	(0.34)	***(-4.92)
Adjusted R^2	0.08	0.03	0.07	0.09	0.13
Durbin-Watson stat	1.94	2.00	1.93	2.17	1.92

Estimated by GMM. t-values are in parenthesis, and ***, ** and * indicates significance at the 1%, 5% and 10%-level respectively. All flow coefficients multiplied by 10^3. This means that the coefficients measure the effect of a 1 billion flow, except for JPY/USD where the coefficient measure the effect of a 1 trillion flow.

Table 7: Change in log exchange rate

	DEM/USD	JPY/USD	GBP/USD	CAD/USD	CHF/USD
Constant	0.000350	0.000587	-0.000435	0.000434	0.000097
	(0.42)	(0.42)	(-0.67)	(0.95)	(0.12)
$\Delta\left(i_t^{\mathrm{USD}} - i_t^*\right)$	-0.004891	-0.000446	0.011176	-0.008469	-0.009393
	(-0.67)	(-0.05)	**(2.33)	***(-4.01)	*(-1.72)
ΔSpot sale	0.000390	-0.001760	0.000947	0.000074	0.000542
	**(2.36)	(-0.60)	***(2.72)	(0.50)	***(3.90)
ΔSpot purchase	-0.000372	0.001475	-0.000855	-0.000100	-0.000546
	**(-2.29)	(0.46)	**(-2.46)	(-0.67)	***(-4.00)
ΔOptions Position	-0.001042	-0.011105	-0.003603	-0.000002	-0.003659
	***(-2.75)	*(-1.96)	**(-2.58)	(0.00)	***(-4.96)
Δlog(S&P500)	0.005135	0.115676	-0.025627	0.050774	0.076109
	(0.09)	(1.56)	(-0.67)	(1.59)	*(1.69)
Δlog(Foreign SE)	0.167619	0.030445	0.127023	-0.145291	0.155296
	***(3.96)	(0.39)	***(3.30)	***(-4.31)	***(3.09)
Adjusted R^2	0.19	0.04	0.12	0.18	0.25
Durbin-Watson stat	2.05	2.00	2.00	2.21	1.98

Estimated by GMM. t-values are in parenthesis, and ***, ** and * indicates significance at the 1%, 5% and 10%-level respectively. All flow coefficients multiplied by 10^3. This means that the coefficients measure the effect of a 1 billion flow, except for JPY/USD where the coefficient measure the effect of a 1 trillion flow.

First we see that the flow variables enters significantly for the same exchange rate as above, and with similar absolute values on the coefficients as before. The coefficients on sale and purchase are also of opposite sign, as expected. Therefore, the results do not seem to be very sensitive to the formulation of the unexpected flow. Second, there seems to be no asymmetric response to the flow. The coefficients on the sale and purchase look very similar, which they also are in case of DEM/USD. For GBP/USD and CHF/USD however, it depends on which regression we use to test the coefficients. In the regression in table 6, the coefficients for CHF/USD are insignificantly different, while they are significantly different at the 10% level in case of GBP/USD using a Wald test.

It is important for the interpretation of order flow as valuable information that the effect from unexpected flow is permanent. In that case we also have a relationship between the level of the exchange rate and the cumulative unexpected flow, i.e. the exchange rate and the cumulative flow cointegrates. This is evident in the model from equation (9). In figure 5 the level of the exchange rates is plotted on the left axes, while cumulative unexpected sales of foreign currency is plotted on the right axes. The figure shows the three exchange rates with significant relationship between the change in rate and the flow The cumulative unexpected sale is calculated as the cumulative sum of the net unexpected sale from table 3.

From the figure it seems that the series cointegrate, and the cointegrating relationsships can be written as

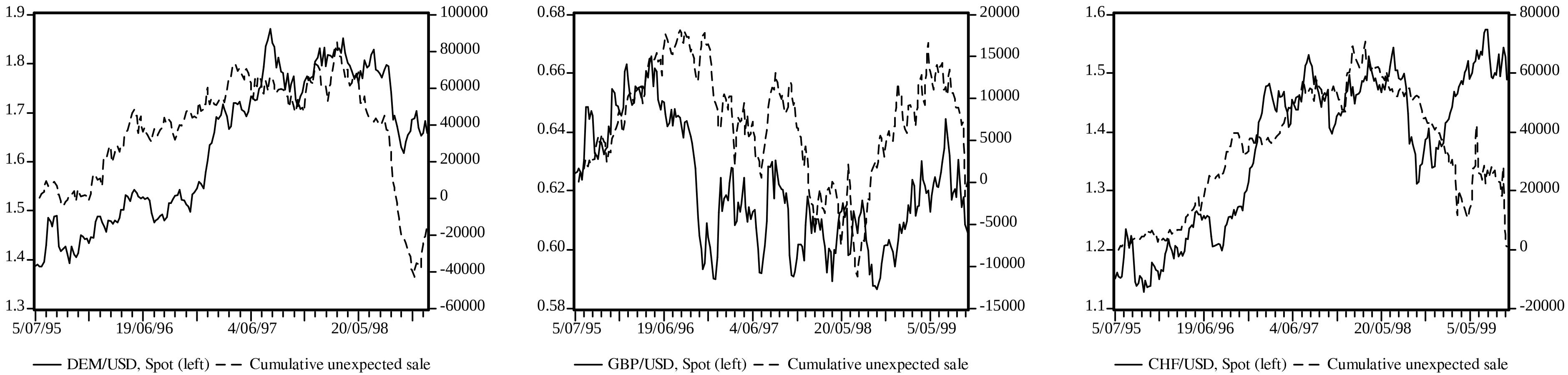
$$P_{\mathrm{DEM/USD}} = 1.53 + \underset{(1.95)}{0.0029} \cdot \mathrm{CumFlow}, \tag{15}$$

$$P_{\mathrm{GBP/USD}} = 0.60 + \underset{(2.35)}{0.0026} \cdot \mathrm{CumFlow}, \tag{16}$$

$$P_{\mathrm{CHF/USD}} = 1.12 + \underset{(6.98)}{0.0064} \cdot \mathrm{CumFlow}. \tag{17}$$

The coefficients are multiplied with 10^3 as in the table, so they measures the effect of the cumulative sum of unexepcted sales of 1 billion foreign currency. Below the slope-coefficients t-values are reported. The cointegration result confirm the results from above.

Figure 5: Exchange rates and cumulative unexpected sale of foreign currency



The graphs show the level of the exchange rates on the left axis, and the level of the cumulative unexpected spot sale of currency on the right axis.

5 Conclusion

Since the float of the major currencies in the 1970s, there have been enormous amounts of empirical research on exchange rates. This has provided us with insights on exchange rate behavior in the longer run. However, our knowledge of the functioning of the market at shorter horizons is still limited. Most research has been within the asset approach to foreign exchange. However, questionnaire surveys from the market indicate that assumptions like perfect information and homogenous agents that underlie the asset approach and other macroeconomic models of exchange rate determination are too restrictive.

In the theory of market microstructure, these assumptions are relaxed. One consequence is that order flow may be informative about exchange rate movements. Recently several papers have shown that order flow influences exchange rates, in contrast with the traditional macroeconomic models. This is important because trading activities obviously is an important characteristic of the foreign exchange market, and therefore should be part of theoretical models. The importance of order flow for exchange rate determination is also something market participants have highlighted.

In this paper I test a macroeconomic model where order flow is informative due to private information. The model is tested on four years of weekly data for U.S. exchange rates and currency flows. The exchange rates studied, the DEM/USD, JPY/USD, GBP/USD, CAD/USD and CHF/USD, are the most traded exchange rates globally. The weekly horizon is sufficiently long for fundamental macroeconomic variables having effect, while still much shorter than what one has been able to explain earlier. The weekly horizon is also short enough to potentially allow for private information.

For three of the exchange rates, the DEM/USD, GBP/USD and CHF/USD, the trading activities by major players in the U.S. market have a both economically and statistically significant effect on exchange rates. The results are robust to several formulations, both to what may constitute public macroeconomic information, and to how we should measure unexpected currency flows.

When U.S. banks buy currency, or rights to buy currency (call options), the currency appreciates. This is consistent with the view that U.S. banks do most of their trading while the European market still is active (8 am – 11 am), and that they during this trading primarily trade at other banks' quotes.

As an extra confirmation on the relationship between exchange rates and the order flow, I find that the level of the exchange rates and their respective cumulative order flow are positively cointegrated. The order flow has an permanent effect on the exchange rates.

The results confirm earlier results on the importance of order flow from intraday analysis (Payne, 1999; Evans, 1999), daily exchange rates (Evans and Lyons, 1999) and weekly exchange rates (Rime, 2000). That the order flows have effect even on the weekly horizon may be surprising, and indicate that microstructural effects are to be considered also on longer horizons than intraday. This may have implications for monetary policy actions in the foreign exchange market.

A Tables

Table 8: Change in log exchange rate

	DEM/USD	JPY/USD	USD/GBP	CAD/USD	CHF/USD
Constant	0.001110	0.000865	-0.000214	0.000390	0.001211
	(1.23)	(0.63)	(-0.32)	(0.84)	(1.23)
$\Delta\left(i_t^{\text{USD}} - i_t^*\right)$	-0.000203	-0.001660	0.012483	-0.010877	-0.014111
	(-0.03)	(-0.18)	**(2.49)	***(-5.10)	**(-2.51)
Unexpected Spot sale	0.000402	-0.001525	0.000761	0.000002	0.000347
	**(2.36)	(-0.61)	**(2.06)	(0.01)	**(2.09)
Adjusted R^2	0.02	-0.01	0.04	0.10	0.04
Durbin-Watson stat	1.99	2.11	1.97	2.18	1.83

Estimated by GMM. t-values are in parenthesis, and ***, ** and * indicates significance at the 1%, 5% and 10%-level respectively. The unexpected flow of spot sale equals "Spot sale$-\widehat{\text{Spot sale}}$", where $\widehat{\text{Spot sale}}$ is the expected value from a ARIMA regression on past values of the flow variables. The other unexpected flow variables are defined in similar way. All flow coefficients multiplied by 10^3. This means that the coefficients measure the effect of a 1 billion flow, except for JPY/USD where the coefficient measure the effect of a 1 trillion flow.

Table 9: Change in log exchange rate

	DEM/USD	JPY/USD	GBP/USD	CAD/USD	CHF/USD
Constant	0.000913	0.000863	0.000197	0.000313	0.001012
	(1.03)	(0.64)	(0.30)	(0.64)	(1.11)
$\Delta\left(i_t^{\text{USD}} - i_t^*\right)$, lagged	0.005332	-0.003305	-0.010134	0.006113	0.004965
	(0.69)	(-0.35)	**(-2.04)	***(2.66)	(1.42)
Unexpected Spot sale	0.000552	0.001452	-0.001079	-0.000059	0.000598
	***(3.06)	(0.56)	***(-2.84)	(-0.32)	***(4.72)
Unexpected Spot purchase	-0.000536	-0.002022	0.000976	0.000067	-0.000662
	***(-3.02)	(-0.76)	**(2.59)	(0.35)	***(-5.09)
Unexpected Options Position	-0.001174	-0.014682	0.004503	0.000040	-0.004136
	***(-2.76)	**(-2.32)	***(2.98)	(0.04)	***(-5.18)
Adjusted R^2	0.06	0.04	0.07	0.02	0.12
Durbin-Watson stat	1.96	2.03	1.92	2.12	1.94

Estimated by GMM. t-values are in parenthesis, and ***, ** and * indicates significance at the 1%, 5% and 10%-level respectively. The unexpected flow of spot sale equals "Spot sale$-\widehat{\text{Spot sale}}$", where $\widehat{\text{Spot sale}}$ is the expected value from a ARIMA regression on past values of the flow variables. The other unexpected flow variables are defined in similar way. All flow coefficients multiplied by 10^3. This means that the coefficients measure the effect of a 1 billion flow, except for JPY/USD where the coefficient measure the effect of a 1 trillion flow.

Table 10: Change in log exchange rate

	DEM/USD	JPY/USD	GBP/USD	CAD/USD	CHF/USD
Constant	0.000906	0.000861	0.000194	0.000297	0.001083
	(1.00)	(0.64)	(0.29)	(0.61)	(1.08)
$\Delta\left(i_t^{\text{USD}} - i_t^*\right)$, lagged	0.009631	-0.002424	-0.010143	0.006109	0.007512
	(1.24)	(-0.25)	**(-2.01)	***(2.67)	*(1.85)
Unexpected Spot sale	-0.000634	-0.000777	-0.000057	0.000301	
	**(2.35)	(-0.26)	**(-2.09)	(-0.31)	**(2.18)
Unexpected Spot purchase	-0.000403	0.000021	0.000691	0.000065	-0.000358
	**(-2.31)	(0.01)	*(1.86)	(0.35)	**(-2.53)
Adjusted R^2	0.03	0.02	0.03	0.02	0.02
Durbin-Watson stat	2.01	2.07	1.97	2.12	1.84

Estimated by GMM. t-values are in parenthesis, and ***, ** and * indicates significance at the 1%, 5% and 10%-level respectively. The unexpected flow of spot sale equals "$\text{Spot sale} - \widehat{\text{Spot sale}}$", where $\widehat{\text{Spot sale}}$ is the expected value from a ARIMA regression on past values of the flow variables. The other unexpected flow variables are defined in similar way. All flow coefficients multiplied by 10^3. This means that the coefficients measure the effect of a 1 billion flow, except for JPY/USD where the coefficient measure the effect of a 1 trillion flow.

Table 11: Change in log exchange rate

	DEM/USD	JPY/USD	GBP/USD	CAD/USD	CHF/USD
Constant	0.000310	0.000420	-0.000429	0.000478	0.000171
	(0.36)	(0.31)	(-0.66)	(1.05)	(0.21)
$\Delta\left(i_t^{\text{USD}} - i_t^*\right)$,	-0.005378	-0.002633	0.011348	-0.008288	-0.009642
	(-0.74)	(-0.29)	**(2.37)	***(-3.91)	*(-1.74)
Unexpected Spot sale	0.000391	0.001478	0.001082	0.000012	0.000592
	**(2.26)	(0.57)	***(2.93)	(0.07)	***(4.15)
Unexpected Spot purchase	-0.000374	-0.002023	-0.000989	-0.000045	-0.000616
	**(-2.19)	(-0.77)	***(-2.70)	(-0.26)	***(-4.32)
Unexpected Options Position	-0.000958	-0.014548	-0.003825	-0.000139	-0.003853
	**(-2.42)	**(-2.28)	**(-2.58)	(-0.16)	***(-5.21)
Δlog(S&P500)	-0.002593	0.116183	-0.027059	0.047914	0.076985
	(-0.05)	*(1.69)	(-0.70)	(1.50)	*(1.70)
Δlog(Foreign SE)	0.174618	0.031853	0.127114	-0.142761	0.149864
	***(4.10)	(0.64)	***(3.30)	***(-4.22)	***(3.03)
Adjusted R^2	0.18	0.05	0.12	0.17	0.26
Durbin-Watson stat	2.06	2.03	2.00	2.22	1.99

Estimated by GMM. t-values are in parenthesis, and ***, ** and * indicates significance at the 1%, 5% and 10%-level respectively. The unexpected flow of spot sale equals "$\text{Spot sale} - \widehat{\text{Spot sale}}$", where $\widehat{\text{Spot sale}}$ is the expected value from a ARIMA regression on past values of the flow variables. The other unexpected flow variables are defined in similar way. All flow coefficients multiplied by 10^3. This means that the coefficients measure the effect of a 1 billion flow, except for JPY/USD where the coefficient measure the effect of a 1 trillion flow.

Table 12: Change in log exchange rate

	DEM/USD	JPY/USD	GBP/USD	CAD/USD	CHF/USD
Constant	0.001335	0.000806	-0.000243	0.000396	0.001106
	(1.49)	(0.61)	(-0.37)	(0.84)	(1.23)
$\Delta\left(i_t^{\text{USD}} - i_t^*\right)$,	0.000209	-0.000287	0.012303	-0.011032	-0.012092
	(0.03)	(-0.03)	**(2.48)	***(-5.07)	**(-1.97)
Unexpected Spot sale	0.000555	0.000416	0.001096	0.000015	0.000687
	***(3.10)	(0.16)	***(2.89)	(0.08)	***(4.41)
Unexpected Spot purchase	-0.000546	-0.000953	-0.001004	-0.000017	-0.000754
	***(-3.10)	(-0.36)	***(-2.66)	(-0.09)	***(-4.76)
Unexpected Options Position	-0.001132	-0.016528	-0.004692	0.000165	-0.004089
	***(-2.69)	**(-2.57)	***(-3.05)	(0.18)	***(-5.62)
Unexp. Spot sale, lagged	0.000123	0.008187	0.000029	-0.000066	0.000125
	(0.69)	***(3.12)	(0.07)	(-0.36)	(0.58)
Unexp. Spot purchase, lagged	-0.000145	-0.008234	-0.000096	0.000058	-0.000195
	(-0.82)	***(-3.09)	(-0.25)	(0.31)	(-0.90)
Unexp. Options Position, lagged	0.000090	-0.002693	0.000655	-0.001468	-0.001098
	(0.21)	(-0.43)	(0.43)	(-1.61)	*(-1.73)
Adjusted R^2	0.08	0.07	0.07	0.09	0.15
Durbin-Watson stat	1.96	2.03	1.91	2.19	1.94

Estimated by GMM. t-values are in parenthesis, and ***, ** and * indicates significance at the 1%, 5% and 10%-level respectively. The unexpected flow of spot sale equals "Spot sale$-\widehat{\text{Spot sale}}$", where $\widehat{\text{Spot sale}}$ is the expected value from a ARIMA regression on past values of the flow variables. The other unexpected flow variables are defined in similar way. All flow coefficients multiplied by 10^3. This means that the coefficients measure the effect of a 1 billion flow, except for JPY/USD where the coefficient measure the effect of a 1 trillion flow.

B Model solution

Each dealer chooses quotes and trading strategy by maximizing a negative exponential utility function defined over expected nominal terminal wealth.[7] The public decide on their round 3 demand by maximizing an identical utility function. The horizon is infinite. However, because returns are independent across periods, with an unchanging stochastic structure, the problem collapses into a series of independent trading problems, one for each period. Since all shocks are normally distributed, the conditional variances in each period do not depend on the realization of the shock and is constant across periods.

I choose the infinite horizon to circumvent the problem of accounting for the time left before the terminal period, which arises in a model with a finite horizon. In the final period, in a finite horizon model, the fundamental value will be revealed, and trading will only occur at this price. In the next-to-final period, everybody knows all elements of the fundamental value except the last; thus the final price should be associated with very little uncertainty. Yet, the price in this period might very well be different from the expected final period fundamental value, due to an accumulated risk premium. Hence, any risk premium in the next to final period should reflect this. The problem is that the solution in Evans and Lyons' model does allow this, since it does not take account of the remaining period of time. With an infinite horizon, each period will be equally far away from a "final" period, and we can use this trick to analyze each period in isolation. Notice that the expectation of wealth in the infinite horizon exactly equals wealth in the present period, and is thereby finite.

The problem solved by the dealers is the following:

$$\max_{\left\{P_{i1,t},P_{i2,t},P_{i3,t},T_{i2,t}\right\}} E\left[-\exp\left(-\theta W_{i3,t}\right)|\Omega^D_{i\tau,t}\right] \tag{B.1}$$

[7] The model is based on Evans and Lyons (1999), who use several features from Lyons (1997). I use infinite horizon instead of finite horizon, and consider a more general shock structure.

subject to

$$
\begin{aligned}
W_{i3,t} &= W_{i0,t} + c_{i1t}P_{i1t} + T'_{i2,t}P_{i2} + I_{i2t}P_{i3} - T_{i2t}P'_{i2t} \\
&= W_{i0,t} + c_{i1t}\left(P_{i1t} - P'_{i2t}\right) + \left(D_{i2,t} + E\left[T'_{i2,t}|\Omega^D_{i2,t}\right]\right)\left(P_{i3t} - P_{i2t}\right) \\
&\quad + T'_{i2t}\left(P_{i3t} - P_{i2t}\right).
\end{aligned} \tag{B.2}
$$

Initial wealth in period t is given by $W_{i0,t}$. $P_{i\tau,t}$ denotes dealer i's quote in round τ of period t, $T_{i2,t}$ is dealer i's trading in round 2 of period t, and $'$ denotes a quote or trade received from other dealers by dealer i. Dealer i's inventory of currency after trading in round τ is given by $I_{i\tau,t}$.

The outgoing interdealer trade of dealer i in round 2 can be divided into three components:

$$
\begin{aligned}
T_{i2t} &= D_{i2t} - I_{i1t} + E\left[T'_{i2t}|\Omega^D_{i2t}\right] &\text{(B.3)}\\
&= D_{i2t} + c_{i1t} + E\left[T'_{i2t}|\Omega^D_{i2t}\right], &\text{(B.4)}
\end{aligned}
$$

where $D_{i2,t}$ is speculative demand, inventory after trading in round 1 is $-c_{i1,t}$, and $E\left[T'_{i2t}|\Omega^D_{i2t}\right]$ is a hedge against incoming orders from other dealers. In equilibrium, this expectation equals zero, since $E\left[c_{i1,t}|\Omega_{1t}\right] = E\left[r_{t+1} + \eta_{it}|\Omega_{1t}\right] = 0$ and $c_{i1,t}$ is *IID*.

The information sets are as follows, where superscript D and superscript P mean dealer and public respectively:

$$
\begin{aligned}
\Omega^D_{i1,t} &= \left\{\{r_\ell\}^t_{\ell=1}, \{x_\ell\}^t_{\ell=1}\right\} = \Omega^P_{1,t} = \Omega_{1,t} \\
\Omega^D_{i2,t} &= \left\{\Omega^D_{i1,t}, c_{i1,t}\right\} \\
\Omega^D_{i3,t} &= \left\{\Omega^D_{i2,t}, x_t\right\} \\
\Omega^P_{3,t} &= \left\{\Omega_{1,t}, x_t\right\}
\end{aligned}
$$

B.1 Equilibrium prices

Equilibrium prices are given by

$$
\begin{aligned}
P_{1,t} &= P_{3,t-1} + r_t - \pi x_{t-1} = P_{2t},\ \forall i &\text{(B.5)}\\
P_{i3t} &= P_{2t} + \lambda x_t. &\text{(B.6)}
\end{aligned}
$$

Observability of all prices and no-arbitrage require that all dealers give equal quotes in each round. For the quotes to be equal, they can only be conditioned on public information. Equilibrium prices are then pinned down by demand and supply:

$$
E\left[c_{i1,t} + D_{i2,t}\left(P_{1,t}\right)|\Omega_{1,t}\right] = 0 \tag{B.7}
$$

$$
E\left[\sum_{i=1}^N \left[c_{i1,t} + D_{i2,t}\left(P_{2,t}\right)\right]|\Omega_{1,t}\right] = 0 \tag{B.8}
$$

$$
E\left[\sum_{i=1}^N c_{i1,t} + c_{3,t}\left(P_{3,t}\right)|\Omega^P_{3,t}\right] = 0. \tag{B.9}
$$

Round 1 price P_{1t} ensures that the public willingly hold all the currency they held at the end of the previous period, and that dealers are willing to absorb their trading, i.e. in expectation of there being zero net-supply from the public. Since $P_{3,t-1}$ contains an expectation about r_t, we need to adjust for this part when the market observes the realization of r_t; hence we extract $\pi x_{t-1}$from r_t. The price in round 2 can only be conditioned on public information and must therefore equal the price in round 1.

From T4, dealers must end each period with zero inventory and the round 3 price must satisfy

$$c_{3t}\left(P_{3,t}\right)=-\sum_{i=1}^{N}c_{i1t}. \tag{B.10}$$

The conjectured trading strategy of dealers equal

$$T_{i2,t}=\alpha c_{i1,t}. \tag{B.11}$$

We can now write the sum on the right-hand-side of (B.10) in terms of observed interbank order flow:

$$\begin{aligned} x_t &= \sum_{i}^{N}T_{i2,t}=\alpha\sum_{i}^{N}c_{i1,t} \\ \sum_{i}^{N}c_{i1,t} &= \frac{1}{\alpha}x_t. \end{aligned} \tag{B.12}$$

Customers' optimal demand follows

$$c_{3t}=\gamma\left(E\left[P_{3,t+1}|\Omega_{3,t}^{P}\right]-P_{3t}\right)=-\frac{1}{\alpha}x_t,$$

where $\gamma^{-1}=\theta var\left[P_{3,t+1}|\Omega_{3,t}^{P}\right]$ and the second equality comes from the amount the dealers want the public to absorb. The market-clearing price in round 3 then becomes

$$P_{3t}=E\left[P_{3,t+1}|\Omega_{3,t}^{P}\right]+\frac{1}{\gamma\alpha}x_t.$$

Since the flow is informative about the increment in the next period, this will be part of the expectation. The round 3 price becomes

$$P_{3t}=P_{2,t}+\left(\pi+\frac{1}{\gamma\alpha}\right)x_t=P_{2t}+\lambda x_t,$$

where $\pi=\phi/\alpha$ and $\phi=\sigma_r^2/\left(\sigma_r^2+\sigma_c^2\right)$ is the updating parameter. The price in round 3 equals the price in round 2, which induces the public to maintain their inventory, and adds an information adjustment element and a new risk premium. By subsequently inserting for lagged price, we get

$$P_{3,t}=\sum_{\ell=1}^{t}\left(r_\ell+\frac{1}{\gamma\alpha}x_\ell\right)+\pi x_t=F_t+\frac{1}{\gamma\alpha}\sum_{\ell=1}^{t}x_\ell+\pi x_t.$$

The price in round 3 contains all public information up to period t and the necessary risk premium for the public to hold the currency from previous periods. In addition, they infer information about the increment in the next period from the flow and update their beliefs accordingly. Finally, they demand a risk compensation to absorb the new additional flow.

The testable equation is

$$\Delta P_{3,t}=r_t+\pi x_{t-1}+\pi x_t+\rho x_t,\ \rho=1/\gamma\alpha,\ \pi=\phi/\alpha. \tag{B.13}$$

The first two terms are related to the new information in public news, the third is a signal on the return of the next period, while the last term picks up the new risk premium.

B.2 Trading strategy

The trading strategy is given by

$$T_{i2,t} = \alpha c_{i1t}. \tag{B.14}$$

The problem the dealers must solve is the following:

$$\max_{D_{i2,t}} E\left[-\exp\left(-\theta W_{i3,t}\right)|\Omega^D_{i2,t}\right],$$

subject to

$$\begin{aligned} W_{i3,t} &= W_{i0,t} + c_{i1t}\left(P_{i1t} - P'_{i2t}\right) + \left(D_{i2,t} + E\left[T'_{i2,t}|\Omega^D_{i2,t}\right]\right)\left(P_{i3t} - P_{i2t}\right) \\ &\quad + T'_{i2t}\left(P_{i3t} - P_{i2t}\right). \end{aligned}$$

This utility function has the convenient property of maximizing its expectation, when variables are normally distributed, i.e. that $W \sim N\left(\mu, \sigma^2\right)$, is equivalent to maximizing[8]

$$E\left[-\theta W_{i3}|\Omega^D_{i2,t}\right] - Var\left[-\theta W_{i3}|\Omega^D_{i2,t}\right]/2.$$

In this case, this allows me to write the problem as

$$\max_{D_{i2t}} D_{i2t}\left(E\left[P_{3t}|\Omega^D_{i2,t}\right] - P_{2t}\right) - D^2_{i2t}\frac{\theta}{2}\sigma^2,$$

where $\sigma^2 = \text{var}\left[E\left[P_{3t}|\Omega^D_{i2,t}\right] - P_2|\Omega^D_{i2,t}\right]$. From above, we know that

$$E\left[P_{3t}|\Omega^D_{i2,t}\right] - P_{2,t} = E\left[\lambda x_t|\Omega^D_{i2,t}\right] = \lambda T_{i2t} = \lambda\left(D_{i2t} + c_{i1t}\right).$$

Hence, I can write the problem as

$$\max_{D_{i2t}} D_{i2t}\lambda\left(D_{i2t} + c_{i1t}\right) - D^2_{i2t}\frac{\theta}{2}\sigma^2.$$

The first-order condition is

$$2\lambda D_{i2t} + c_{i1t} - \theta\sigma^2 D_{i2t} = 0, \tag{B.15}$$

which implies a speculative demand of

$$D_{i2t} = \left(\frac{1}{\theta\sigma^2 - 2\lambda}\right)c_{i1t}.$$

Trading then becomes

$$T_{i2} = D_{i2t} + c_{i1t} = \left(\frac{1}{\theta\sigma^2 - 2\lambda} + 1\right)c_{i1t} = \alpha c_{i1t}. \tag{B.16}$$

The second-order condition,

$$2\lambda - \theta\sigma^2 < 0 \Rightarrow \theta\sigma^2 - 2\lambda > 0, \tag{B.17}$$

ensures that $\alpha > 1$.

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[8] If W is $N\left(\mu, \sigma^2\right)$, then $E\left[\exp\left(W\right)\right] = \exp\left(\mu - \sigma^2/2\right)$.

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