Private or Public Information in Foreign Exchange Markets? An Empirical Analysis*

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Abstract

In macroeconomic models exchange rates are determined by public information. Trading activities are completely irrelevant. In general, these models have low explanatory power for short horizons, which might be due to the possible existence of private information. Dealers in the foreign exchange market consider the order flow from customers to be the most important source of private information. I test a microstructural trading model incorporating private information, including both order flow and macroeconomic variables. The results show that order flow is an important variable for explaining weekly changes in exchange rates, thereby indicating an important role for private information. The strongest effect comes from customer order flow, which highlights the fundamental role of customer demand.
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1 Introduction

In macroeconomic models of foreign exchange markets, exchange rates are determined by public information, while trading activities are completely irrelevant. In general these models have low explanatory power for horizons shorter than six months, which might be due to the possible existence of private information. Dealers in the market consider the order flow from customers to be the most important source of private information.

In this paper, I test a model for determining exchange rates including both public and private information variables. The model, based on a model by Evans and Lyons (1999), integrates public macroeconomic information in a microstructural trading model where,

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in equilibrium, the order flow aggregates private information. The model is tested for four exchange rates on 3 years of weekly data, from the beginning of 1996 and onwards (the Norwegian Krone (NOK) against US Dollar (USD), Deutsche Mark (DEM), Swedish Krona (SEK) and Pound Sterling (GBP)). The key to this kind of analysis is a recent data set on weekly order flow from the Norwegian market; hence my choice of the Norwegian Krone as the common currency and the weekly frequency. As will be shown below, the microstructure of the foreign exchange market and, in particular, the low transparency of trade, give both private information and macroeconomic information a role, even at the weekly horizon. The models receive considerable support, with significant and correctly signed effects from order flow. The regression fit, given by adjusted R^2, is 33% for NOK/DEM, which is high given the weekly frequency.

Until recently, the predominant way of analyzing exchange rates was to search for new possible macroeconomic variables that might explain the swings in exchange rates (Flood and Rose, 1995). The three mainstream macroeconomic models — the classical flexible price monetary model, the sticky price monetary model (the "overshooting model") and the portfolio balance model — rely solely on public macroeconomic information. However, these models have received little empirical support[1], in particular at a short horizon, as shown in the seminal papers by Meese and Rogoff (1983a,b), for example. Meese and Rogoff demonstrated that monthly and biennial forecasts based on macroeconomic information performed even worse than a random walk. Since the papers by Meese and Rogoff, there has been a huge amount of research on explaining the lack of support of the macro models, to little avail (for surveys, see Frankel and Rose, 1995; Taylor, 1995).[2] de Vries (1994) claims the lack of effect of most macroeconomic variables to be a stylized fact of exchange rate economics. The time has come to search for models of exchange rate determination outside the field of macroeconomics.

Empirical studies of other asset markets, such as the stock market, have also been plagued by lack of empirical support. This has led to the theory of market microstructure of financial markets, with a focus on market institutions, existence of private information, agent heterogeneity, and short-term phenomena. This approach seems well suited for the foreign exchange market. Phenomena such as huge trading volumes and high volatility that are difficult to explain within the macroeconomic approach, are addressed in this approach (see Lyons, 2000). To account for trading, there must be some heterogeneity among agents, and volatility draws the attention to speculation and private information.

The lack of empirical support for the macroeconomic models may be related to heterogeneous expectations (Frankel and Rose, 1995; Lewis, 1995) which, again, may be due to private information. 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.[3] The data in Bjønnes and Rime (2000a) reveal that dealers expect other dealers to have different information than themselves.

Empirically, the key problem is to identify variables that impound the existence of private information (and heterogeneous agents). In this paper, I will identify private information with order flow or currency trading. As an example of the effect of trading in the traditional models let us consider the flexible price monetary model. In this model,

[1] The state-of-the-art model of Obstfeld and Rogoff (1996), whose primary goal it is to provide the sticky-price approach with a dynamic microeconomic foundation, also relies on public information. It is still too early to give an empirical verdict of the Obstfeld and Rogoff model, though.

[2] Vikøren (1994), Langli (1993), and Bernhardsen (1998) test macroeconomic models for the Norwegian market and come up with similar results.

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

where only public information is important, trading 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.

It is important to note that order flow is fundamentally different from volume[4] or just "supply and demand". In financial markets, it can be determined who takes the initiative to a trade, thereby "signing" the trade. Therefore, it is also possible to determine buyer pressure or seller pressure, even in equilibrium (i.e. the direction of flow). Order flow, the signed flow of trades, serves the traditional role of affecting the price to balance supply and demand. In addition, changing beliefs may affect the price. In a market with private information, dealers utilize the additional information in the direction of the flow of trading (buyer pressure/seller pressure) to infer the motives for trade. Hence, buyer pressure leads dealers to infer that some agents have received positive private signals about asset value. Lyons (2000) offers an interesting discussion of what might constitute private information in foreign exchange markets.

For trading to create price effects, we need more than asymmetric information however, due to the famous no-trade result of Milgrom and Stokey (1982). In a fully transparent[5] competitive market with asymmetric information and no ex ante gains from trade that are common knowledge, all available information will be contained in the prices. Any attempt to trade will lead to revisions of expectations such that, in the end, the market price reflects all information and no trade takes place. The existence and importance of private information and trading are hence closely related to the transparency of the market.

Lately, the literature on the microstructure of financial markets has focused on situations where there are gains from trade, as is apparent from, for example, the existence of widespread trading and differences in buy (ask) and sell (bid) prices. Gains from trade may arise due to differentially motivated traders (like noise traders), dealers with different attitudes towards risk and in markets with less than perfect transparency (observability). In market microstructure theory, order flow is an important determinant of asset prices. Since the existence of private information will result in trading when there are gains from trade, trading as such can be informative.

In 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. From trading with potentially better informed players, the Market Makers adjust their beliefs about the uncertain asset value, increasing their expectations of the value of the asset in case of a buy order and reducing 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 approach has recently been applied to the foreign exchange market, indicating evidence of private information. With observations on dealers' intraday trading in the inter bank spot market, Lyons (1995), Yao (1998a) and Bjønnes and Rime (2000b) find evidence of an effect of trading flow on prices associated with private information.

One may ask how important this is for the overall market and at what time horizons. Due to the low transparency of foreign exchange markets, it might take quite some time before new private information is reflected in prices. Dealers claim that the most important source of information is trading with customers (see Lyons, 1995; Yao, 1998a; Bjønnes and Rime, 2000a), and that these trades are *only* observed by the dealer in the specific bank. Within the interbank market, only a subset of brokerage trades is observed by everyone.

[4]Volume is the sum of trades in absolute terms.

[5]By transparency of trade I mean the extent to which a trade becomes known in the market.

Studies considering the effect of private information on a wider part of the aggregate market have been constrained by the availability of observations on order flow. Evans (1998, 1999), Evans and Lyons (1999) and Payne (1999) address the overall market issue based on observations on market-wide trading on DEM/USD. Evans' paper covers all direct (bilateral) trading through the Reuters D2000-1 computer system over 79 days in 1996. He finds a strong correlation between price changes and order flow over the whole period. Payne studies all trades through the electronic brokerage system Reuters D2000-2 in one week, and finds a permanent effect on prices from trading. Evans and Lyons (1999) develop a version of the model used in this paper and test it on the same data as in Evans (1998). They find that order flow is more significant than change in interest differentials.

This study utilizes a recent data set on currency trading in the Norwegian currency market, collected by Norges Bank (the Central Bank of Norway). I have weekly observations from the beginning of 1996 until the spring of 1999 on the volume of purchases and sales of currency disaggregated on three groups; the Norwegian non-banking sector, foreigners, and Norges Bank. The only comparable data set is that of Evans and Lyons (1999). However, their series cover observations for 79 days in 1996, and observe the net number of buy and sell orders and not the volume.

The results are surprisingly strong. Order flow has a strong and correctly signed effect on price changes, where a buying pressure (positive flow) pushes prices upwards and a selling pressure pushes prices downwards. The effect on exchange rates from order flow is permanent, indicating that order flows carry important information. Changes in interest rate differentials are the single most important variable, while the most important flow variable seems to be the spot trading of Norwegian customers. This results is in line with the importance that dealers attach to customer trades, and that customer trades is the primary source of demand in the foreign exchange market. 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).

This paper considers a small-country currency, the NOK, yet the results are similar to those of Evans and Lyons for the major currencies. This may indicate that neither small currencies nor regional markets like the Norwegian differ a great deal from the global currency market dominated by exchange rates such as DEM/USD. It might be that the global character of the foreign exchange market makes the microstructure more or less similar across exchange rates and regions. The results may therefore be of interest both to the Euro-area and small countries. The effect from trading on weekly frequency also implies that microstructural effects are not "only intraday", but are important and should be taken into consideration also for longer horizons.

The remainder of the paper is organized as follows: In section 2, I discuss some important characteristics of currency markets. The model is presented in section 3. Section 4 presents the data. Results are presented and discussed in section 5, while section 6 concludes.

2 Currency markets

In this section, I will address important aspects of the microstructure of foreign exchange markets, both in general and for Norway in particular. The most important characteristics of currency markets are (*i*) the enormous trading volume, (*ii*) the distinction between customer trading and interbank trading, (*iii*) that trading between dealers accounts for a majority of the total volume, and (*iv*) the low transparency of trade. The focus will be on implications for transparency of trade.

Globally, the average daily turnover in April 1998 was USD 1.5 trillion; increasing from USD 820 billion in 1992 and USD 1.2 trillion in 1995 (BIS, 1998). The spot market share is about 40% of the market, while the interbank-share of spot trading is slightly above 80% as reported in table 1. Trading in DEM/USD accounts for almost half (49%) of all global spot trading. Small currencies, like the NOK, constitute 30% altogether, or 431 billion USD of the total volume of 1,442 billion USD.[6] It seems warranted to study this part of the foreign exchange market in order to complete the picture.

For the Norwegian currency market, the average daily turnover was almost 9 billion USD. This ranks Norway in twentieth place of the 43 countries in the latest BIS survey. The four largest regions (UK, US, Japan and Singapore) alone constitute 64% of the total market.

Table 1: The Norwegian currency market

	1992		1995		1998	
Total		5190		7577		8807
Spot total		1994		3434		2988
- Local dealers	390		354		161	
- Foreign dealers	1161	=1551	1745	=2099	2316	=2477
- Local financial customers	46		185		46	
- Foreign financial customers	124	=170	558	=743	29	=75
- Local customers	268		588		416	
- Foreign customers	5	=273	3	=591	19	=435
Swap total		3009		3911		5658
- Local dealers	921		458		517	
- Foreign dealers	1538	=2459	2104	=2562	4343	=4860
- Local financial customers	53		95		132	
- Foreign financial customers	300	=353	526	=621	110	=242
- Local customers	192		496		534	
- Foreign customers	4	=196	232	=728	22	=556
Forward total		187		231		194
Interbank share	(78 %—89 %)		(62 %—81 %)		(83 %—88 %)	
- Spot	(78 %—86 %)		(61 %—83 %)		(83 %—85 %)	
Cross border share		61 %		69 %		78 %
- Spot		65 %		67 %		79 %

Source: BIS (1993, 1996, 1998). Average daily volumes. All numbers in million USD.

Trading in the foreign exchange market occurs in two separate sub markets; first, customers trading with a bank, and second, the interbank market where banks trade with each other. Although customer orders only account for about 20% of the total volume, they are important for they generate the majority of trading profits for most foreign exchange dealers, (Yao, 1998b). Trading with customers is also regarded as an important source of private information.[7] This information is private since only the dealers in the specific bank have knowledge of each trade. Trading with customers entirely lacks transparency; i.e. the rest of the market does not know the customer trading of a bank. This may be of significance since the low transparency of trade enables a dealer to utilize the private

[6]These numbers are taken from table B-4 in BIS (1998), and equal the sum of USD and DEM towards "OtherEMS" and all other currency pairs not specified in the table. DEM/USD and JPY/USD were the by far most traded exchange rates in 1998. USD/GBP and CHF/USD followed these two.

[7]A customer is a non-banking firm, for instance a multinational company. Customers typically place rather large orders to the customer-relations part of a foreign exchange department, which communicates/trades the orders to the interbank spot-dealers that execute them in the interbank market. In this respect, large commercial banks with large customer order flows, such as Chase, have a competitive advantage over smaller banks (Cheung and Chinn, 1999b).

information over a long time span, and also makes other dealers take the possible existence of private information into account when trading. Customer trades provide the dealers with a signal of whether the market will be buyer or seller dominated within a certain time horizon. It may also provide signals on market sentiment or beliefs about future return.

The interbank market is a decentralized multiple dealer market. The trading options available to dealers in the interbank market can be illustrated in a 2×2 matrix as in figure 1. Direct trading is usually done through the Reuters D2000-1, a system for bilateral communication over a computer-network. In direct trading, Market Makers are expected to give quotes on request in the same way as a NYSE specialist. Direct trading is the preferred channel when the volume traded is either of an unusual size (like 525,000) or very large. Since orders on the D2000-1 system are often large (often executed shortly after the receipt of a customer order), and because the identity of the initiator of the trade is revealed to the Market Maker, direct trading is regarded as the most informative trading channel. The data of Evans and Lyons are from the direct trading system D2000-1, the importance of which has decreased somewhat since 1996.

Figure 1: Interbank trading options

	Incoming trade (Nonaggressor)	Outgoing trade (Aggressor)
Direct	Give quotes when requested	Trade at other dealers' quotes
Indirect (broker)	Give quote(s) to a broker (limit order)	Trade at quotes given by a broker (market order)

A Market Maker gives quotes (buy and sell prices) on request from other dealers. The dealer that takes the initiative and asks for quotes is called the "aggressor". Direct trading is bilateral trade over the D2000-1 computer system or the telephone. Indirect trading is trading through a broker, either a traditional "voice" broker (radio network) or electronic brokers D2000-2 and EBS.

Indirect trading takes place through a broker, either a traditional voice-broker or an electronic broker system.[8] A Market Maker may give quotes to brokers. The dealer decides whether to give two-way quotes (bid and ask) or only one-way quotes (bid or ask). Brokers are mainly used for smaller trades between USD 1 and 10 million. In contrast to direct trading, the identity of the counterpart is not revealed in indirect trading. In fact, in a single order, there can be several counterparties. There is also another important distinction between direct and indirect trades, namely as concerns timing. In an incoming direct trade, the dealer does not decide when to trade. In an incoming *in*direct trade there is a timing decision, since the dealer decides when to place quotes to brokers.

The foreign exchange market is usually said to have low transparency. In foreign exchange, all customer trades and all direct trades are kept secret from everyone except the two parties. As for indirect trade, a small subset of the trades is communicated to the market, thereby giving the dealers a proxy of overall market activity.[9] Many stock exchanges, on the other hand, provide information on all trades, sometimes with a small time lag. Low transparency indicates that it may take longer before private information

[8]During the 1970s and most of the 1980s, traditional voice brokers were the dominant tool for trading. Voice brokers have lost much of their market share to electronic broker systems, because these offer tighter spreads and faster execution of trades. Since voice-brokers have no access to electronic brokers, there is also the problem of knowing what prices to compete against. Furthermore, their information advantage from seeing much flow has also decreased, thus making it even harder to give competitive quotes. In 1998, their market share of spot transactions in New York was only 24% compared to 47% in 1995. In the same period, electronic brokers have become very popular, with a market share of 31% in 1998 up from 10% in 1995 (FED NY, 1998). In London, electronic brokers are used in 25% of all spot transactions.

[9]Transparency of price, in contrast, is higher. At any price, there will be many transactions. Dealers observe only a few of these, but a majority of the prices traded at are observed through the electronic broking systems.

is reflected in prices.

While the major currencies (USD, EURO, JPY, GBP) are traded globally and constitute very liquid markets, “smaller” currencies like NOK and SEK are primarily traded through national centers and are less liquid (BIS, 1998). Trading in these national centers is also more concentrated than in the large financial centers like London, New York, Frankfurt and Tokyo (where the major currencies are traded in huge volumes). In Norway, four banks control 75% of the market, while in UK, US, Japan and Singapore, about 20 banks hold the same part of the market. Together with high concentration, there may also be higher transparency. Each of the dealers observes quite a large part of the market and may thereby also know more about the trading flow in which they do not participate. In regional markets, dealers may also have more knowledge of customer trades they have not received themselves, due to the small number of important customers and the possible predictability of their trading. On the other hand, given the market power of each bank, it may still be possible to take advantage of private information, even though transmission to the rest of the market might be faster. However, the “small” currencies are to a smaller extent traded through the new electronic brokers, meaning that less of the interbank order flow is communicated to the market compared to DEM/USD, where an increasing share of the spot trading is done through electronic brokers.

The importance of transparency may also be related to the motives for trading. There may be other reasons for trading in the major currencies than in the smaller currencies. Major currencies function as “vehicle” currencies (used as an intermediate in an exchange of two smaller currencies), and are also traded due to the fact that the most important commodities in the world are priced in these currencies. The smaller currencies, on the other hand, are typically more “regional” or country-specific. The NOK for example is supposedly very dependent on oil prices, giving the NOK a reputation as a “Petro-currency”, which is public information. However, the results in this paper indicate that the NOK is not a “Petro-currency.” Whether the trade in NOK-exchanges is more or less transparent than that in USD-exchanges is difficult to say.

3 Model

The model, based on a model by Evans and Lyons (1999), captures important aspects of the foreign exchange market. Customer trading triggers interdealer trading, and the order flow leads to aggregation of information into prices. During interdealer trading, dealers square their positions after the customer trade, and also take a speculative position. 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. In addition, the initial portfolio shift may signal information on future currency return. In the model, the dealers will also trade on basis of this signal and thus, 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.[10] There are N dealers, and a public sector (customers) that is distributed in the continuous interval $[0, 1]$; this captures the fact that customers are more numerous than dealers and hence have a greater capacity for bearing risk. The horizon is infinite and timing within a period of the model is shown in figure 2. The information of each group will be clear from the below description of the timing. Dealers decide on prices

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

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, $c_{3,t}$. Round 1, public trade, 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. Simultaneous quoting is consistent with the functioning of the interbank market: 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 implicit contract of being a Market Maker, and could be punished later by other dealers.[11] 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 to be the case.

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

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 this is a quote at which a transaction is desired.[12]

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

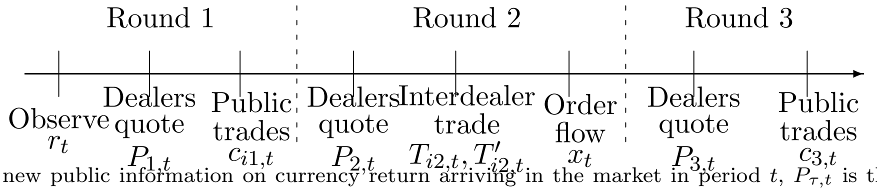
Rule T1, that trading is simultaneous and independent, implies that trades received from other dealers, T'_{it}, is an unavoidable disturbance to dealer i's inventory, in line with the fact that Market Makers in foreign exchange cannot perfectly control their inventory. Rules T2 and T3 are more technical,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

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 $IID\left(0, \sigma_c^2\right)$

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

[12] 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.

Figure 2: 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.

and not related to currency value. Here, I consider the case when this trading is a signal 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; i.e. this trading is not transparent to others 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 round 3 price change 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, $x_t = \sum_i^N T_{i2,t}$, 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 have a greater capacity of bearing risk due to their being more numerous than the dealers.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

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

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

3.1 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[13] 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, ensure 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 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. This risk premium coefficient is a constant, but increases with uncertainty about future prices, and with risk aversion (see appendix).

Inserting for the expectation in (7), we get

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

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

[13] 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.

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. After observing r_t, the aggregate 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 and with x_t, since $x_t = \alpha \sum_i c_{i1,t}$ which are all IID, i.e. 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.

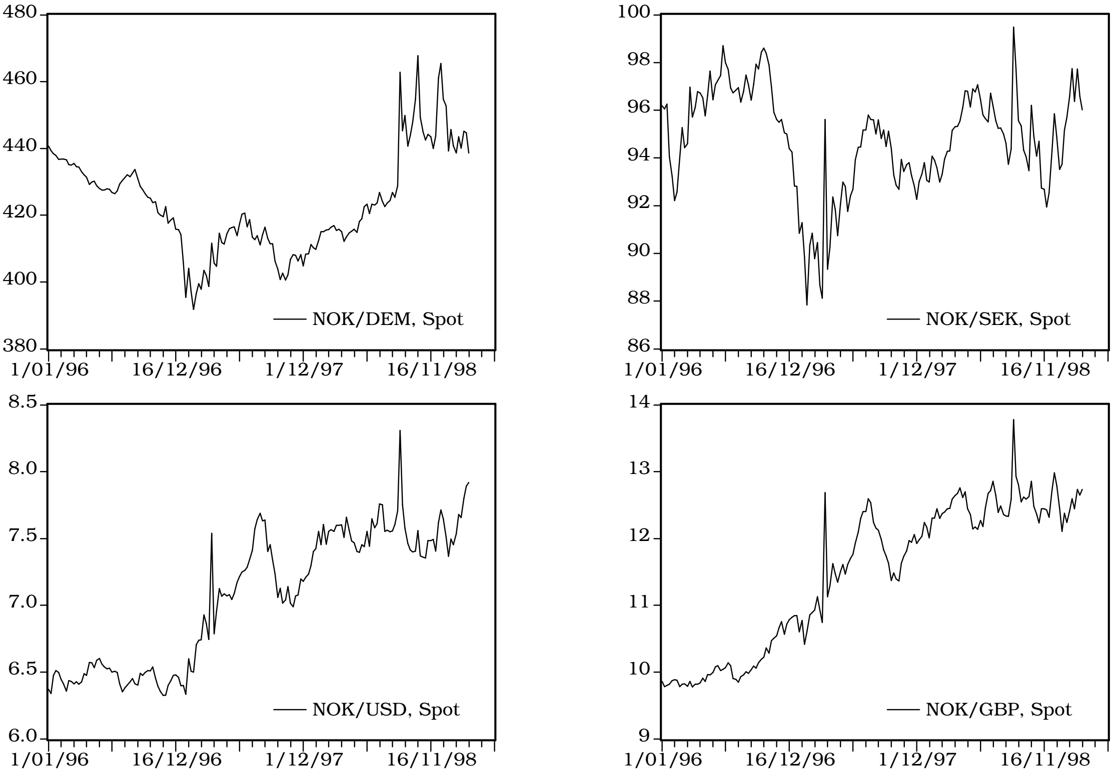
An example may clarify the model: For simplicity, imagine that all dealers are initially holding their preferred inventory of currency. In round 1, dealer 1 receives a buy order from a customer of 100 units of currency ($c_{11,t} = 100$). Dealer 1 is now short compared to his preferred position, and 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 have a greater capacity for bearing risk.

4 Data

The data set consists of two parts. First, weekly observations on currency trading in the Norwegian currency market represent the order flow in the theoretical model. Second, the public information set consists of weekly observations on the interest rates for the five countries Norway, USA, Germany, Sweden and Great Britain, and given Norway's dependence on oil revenue, I also include oil prices and information about tax payments from the oil industry in the public information set. These tax payments are paid in NOK, while the revenues are in USD and thus, they are quantitatively important in the

Norwegian market. As exchange rates I use the NOK against the DEM, the SEK, the USD and the GBP.

Figure 3: Spot Exchange Rates



Source: Norges Bank (Central Bank of Norway). The weekly exchange rates are end-of-week rates. If no Friday quotes are available, I use the quote from the following Monday. The NOK/USD and NOK/GBP exchange rates are more volatile than the NOK/DEM and NOK/SEK rates. Standard deviation i percentage of the mean are 7% and 9% for NOK/USD and NOK/GBP respectively, against 3.5% and 2.3% in the case of NOK/DEM and NOK/SEK.

Figure 3 plots the four exchange rates, which are quoted at the end of the week. Since December 1992, Norway has followed a floating exchange rate regime, but the Central Bank has been instructed to aim at keeping the exchange rate stable against the ECU/EURO. Table 2 summarizes the descriptive statistics for the four exchange rates from the beginning of 1996 until May 1999.

As shown in table 3, the exchange of these four foreign currencies into NOK represents the major part of NOK trading in Norway. Although the trade in DEM/USD is also substantial (as in the rest of the world), trading in NOK-crosses are the most important crosses in Norway. Besides, the trading volume in the major exchange rates, e.g. DEM/USD, in Norway is probably too small to influence DEM/USD rates and is most likely related to the use of the cross as a vehicle for trading in other currencies.[14] Trading in NOK/SEK is only reported for 1992, when the total daily volume was 42 million USD. Judging from the GBP trading in 1995 and 1998, probably all of the 21 million in the "Other"-column in 1992 are exchanges into NOK. This might indicate that the NOK/SEK currency cross is more traded in Norway than the NOK/GBP, which has been confirmed by dealers. This is as expected, bearing in mind the importance of trade between Sweden and Norway and the otherwise close relations between the two countries.

[14] Currencies that are primarily traded against USD.

Table 2: Summary statistics for exchange rates

	NOK/DEM	NOK/SEK	NOK/USD	NOK/GBP
Mean	423.62	94.76	7.07	11.47
Median	422.58	95.14	7.18	11.79
Maximum	467.73	99.49	8.31	13.78
Minimum	391.74	87.83	6.33	9.77
Std. Dev.	15.08	2.20	0.50	1.08
Observations	166	166	166	166

Summary statistics for end-of-week exchange rates, calculated over the period Jan. 1. 1996 to May 10. 1999.

Table 3: Main currency pairs traded in Norway

1992	DEM	GBP	NOK	Other	Total
USD	1033	182	1805	191	4198
DEM	–	42	365	30	1841
GBP		–	Na	21	245
NOK			–	176 (42)	2346
1995	DEM	GBP	NOK	Other EMS	Total
USD	1239	85	2310	1471	5499
DEM	–	45	900	679	3045
GBP		–	40	0	170
NOK			–	113	3480
1998	DEM	GBP	NOK	Other EMS	Total
USD	1798	203	4421	402	7320
DEM	–	279	656	177	3012
GBP		–	52	0	534
NOK			–	145	5350

Source: BIS (1993, 1996, 1998). Average daily volume. All numbers in million USD, including spot, outright forward and swap.

The table reports total trading, including spot, outright forward and swaps.[15] The reason for NOK/USD trading being so much larger than NOK/DEM is the dominant role of USD as part of swaps. In spot trading, NOK/DEM is the most traded exchange rate.

In the next section, I describe flow variables in some detail, while the public information components of the data set are discussed later.

4.1 Currency flows

The novel part of the data set employed consists of weekly reports of aggregate currency trading in the Norwegian currency market. These data are collected by Norges Bank, from the largest banks in Norway operating in the foreign exchange markets, and are made public three weeks after the week they are collected. The series begin in the first week of 1996, with the last observations from week 20 in 1999, a total of 176 weeks of observations.

According to Norges Bank, the reports cover at least 90% of the Norwegian market. Although NOK-exchanges are certainly made outside of Norway, the series included most likely cover a majority of NOK-exchanges, given the regional nature of the NOK. The series are divided into the main counterparties of the Norwegian banks, namely (A) the Central bank, (B) foreigners, and (C) Norwegian non-bank customers. The numbers are

[15] A swap transaction is a transaction where the two parties exchange currencies spot today, and also sign a forward agreement to reverse the transaction in the future. An outright forward is an agreement to exchange currencies more than two days later, at an agreed forward rate.

Table 4: Currency flows in the Norwegian foreign exchange market

Flow variable, x_t	Average	Std. dev	Avg.$\|x_t\|$
A. Net sale from the central bank to Norwegian banks	0,81	2,44	1,22
- A1. CB Spot	0,81	2,49	1,25
- A2. CB Forward	0,00	0,53	0,06
Counterparties:			
B. Norwegian banks' net sale to foreigners	-0,27	6,50	4,78
- B1. Foreigners' Spot	-0,17	4,70	3,20
- B2. Foreigners' Forward	-0,10	5,50	3,95
C. Norwegian banks' net sale to non-bank Norwegians	-0,70	7,06	5,28
- C1. Norwegian customers Spot	-0,23	6,81	5,22
- C2. Norwegian customers Forward	-0,19	3,69	2,69
- C3. Change in net FX liabilities towards customers	-0,28	3,12	2,40
D. Miscellaneous	0,16	3,12	2,35
- D1. Banks' income loss in currency towards foreigners	0,05	0,04	0,05
- D2. Rate losses towards foreigners	0,04	1,21	0,67
- D3. Rate loss and other corrections	0,04	2,36	1,72
- D4. Increase in banks' total inventory of currency	0,02	2,30	1,69
Specification of B1: Foreigners' spot trading			
- Change net NOK-deposits	0,01	3,81	2,60
- VPS-registered stocks	0,04	0,72	0,50
- VPS bonds	-0,23	1,20	0,81
- VPS certificates	-0,00	2,10	0,84
Increase in banks' spot inventory towards foreigners *	-0,50	5,62	4,45

Source: Central Bank of Norway. Weekly trading. All numbers in billion NOK. Positive flow indicates that the Norwegian banks are selling currency, and negative flow indicates that they are buying. Bold group-letters indicate the groups used in the econometric analysis.
* Equals -(A1+B1+C1+D1+D2).

not directly comparable to those in table 1. Table 4 shows the flow variables reported together with their average, their standard deviation and the average of absolute values.

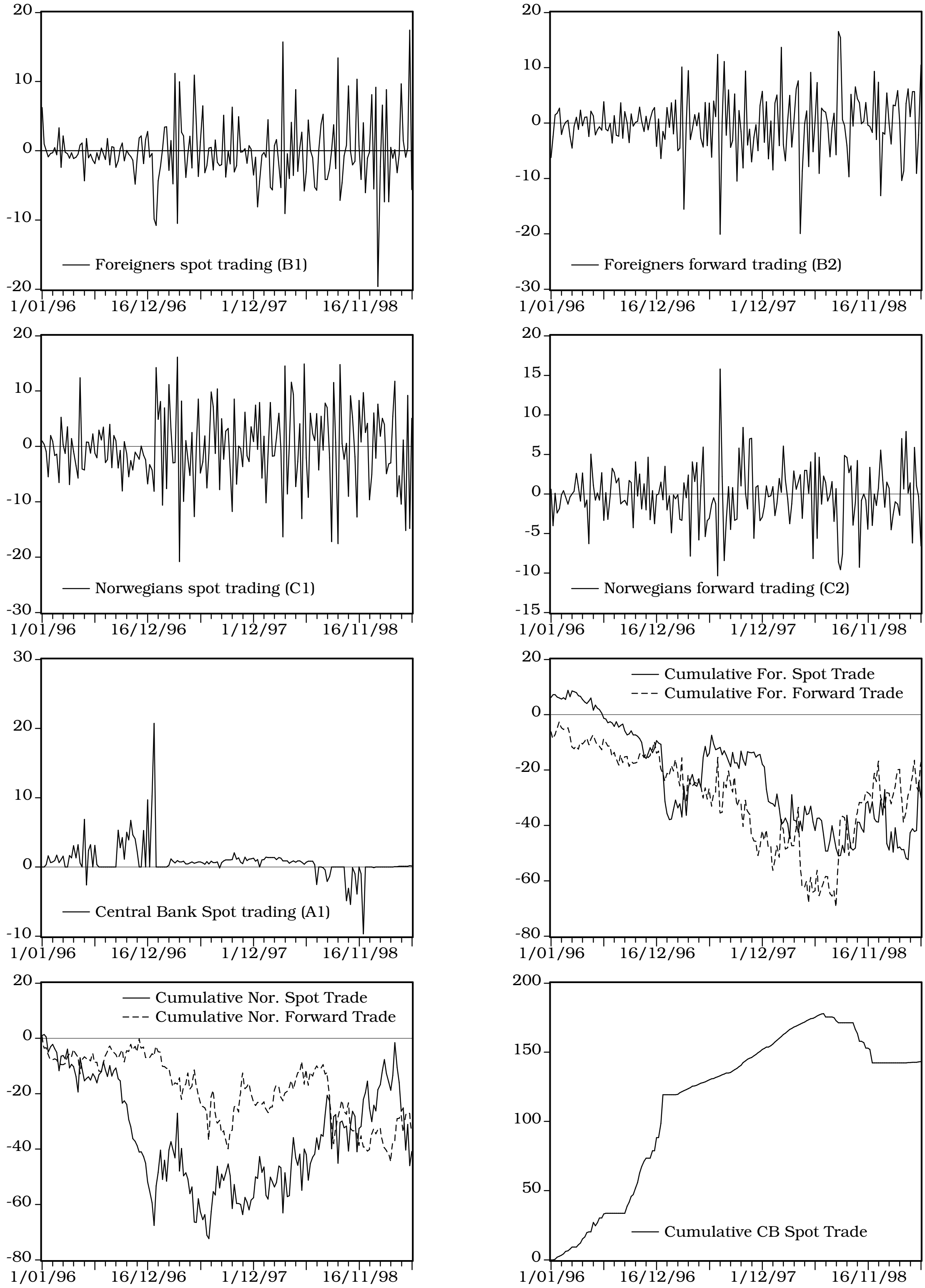
A positive flow indicates that the Norwegian banks are selling currency, and a negative flow that they are buying. The spot numbers consist of both pure spot transactions and spot transactions as part of a swap transaction. The C3-group contains changes related to customers transforming their NOK-deposits into e.g. USD-deposits, without any trading necessarily taking place. Groups D1 and D2 are related to the gains and losses for the bank by holding an open spot inventory overnight. D1 are related to the interest rate loss on an open spot inventory, and D2 to the possible appreciation/depreciation of the exchange rate.

Figure 4 plot the cumulative order flow and the per period order flow. From the graphs of per period trading it may seem that the activity in the market increased somewhat after the beginning of 1997. The jump in CB spot trading in early 1997 is related to the appreciation pressure on NOK in this period. The central bank had to buy currency from the Norwegian banks. In the cumulative graphs I have set the initial point to zero since I have no observations on initial positions.

An important question is who takes the initiative in these transactions. The model above gives special attention to the signing of the order flow according to whether the initiator is buying (positive flow) or selling (negative flow). There are reasons to believe that a majority of these trades are not initiated by Norwegian banks.

In the relationship between banks and customers, banks provide the service of access to the interbank market. Hence, trading between banks and customers only occurs when customers demand these services, and therefore takes the initiative to the trade. According

Figure 4: Weekly trading flows



The first five graphs, going from left to right, show period flow. The last three graphs show cumulative flow. A positive flow mean that a sector is buying currency, i.e. selling NOK. From the period graphs there seems to be an increased trading activity after the beginning of 1997. The cumulative graphs indicate that the Central Bank has accumulated currency in the process of establishing the Petroleum Fund, and that Norwegian banks has accumulated currency towards the foreigners and Norwegian customers, i.e. the foreigners and Norwegian customers have decumulated their stocks of currency towards Norwegian banks.

to table 1, most of these customer trades are with Norwegian customers.[16]

The low share of foreigner customer trading reported in table 1 indicates that the major part of the foreigners' group (group B) above is interbank trading. Since a majority of trading in Norway is with NOK on one side, with a Norwegian bank as one of the parties, it may suggest that Norwegian banks have an information advantage in NOK-trading. Hence, foreign banks are most likely not interested in trading when Norwegian banks take the initiative, and will give a wide spread to protect themselves against private information. Therefore, most interbank trading with foreign banks is most likely initiated by foreigners. The data from Bjønnes and Rime (2000b) support this. According to these data, all of the NOK/USD trades and 63–65% of the NOK/DEM trades are initiated outside the bank. In value terms, 70% of all NOK/DEM trades are not initiated by the bank.

The initiative in transactions with the Central Bank is not obvious and has, most likely, varied over the last decade. While Norway had a fixed exchange rate regime, prior to December 1992, the interventions from the Central Bank were of the passive kind absorbing any volume offered by the banks. In these cases, the banks were the initiators. In the last few years, the Central Bank's activity in the market has been of two kinds. First, the Central Bank has bought currency as part of the efforts to build up the Petroleum Fund of the Norwegian Government. These transactions, being similar in nature to those of the customers, are initiated by the Central Bank. Second, the Central Bank has actively intervened on the market. Active interventions in a floating regime, opposed to passive interventions in a fixed regime, are initiated by the Central Bank.

Assuming that Norwegian banks do not initiate a majority of the trades, net buying of NOK by foreigners or Norwegian customers (a negative "B"- or "C"-flow) would, according to the model, lead to an appreciation of the NOK. If interventions were successful, the purchase of NOK would appreciate the NOK.

Compared to the data set of Evans and Lyons (1999), not knowing the direction of the flow, that is, which party is the initiator, is a drawback. However, given the special structure of the Norwegian currency market, this need not be a major problem, as the discussion above suggests. The daily frequency of their data set is probably better suited to pick up short-term variations than weekly frequency, but the weekly frequency covers a longer time span. An advantage of the present data is that they include trading volume, while the data of Evans and Lyons only observe the *number* of buyer and seller-initiated trades.

In the empirical implementation, I will use the spot trading of all three groups, Central Banks, foreigners and Norwegian non-bank customers, as a measure of currency flow. In addition, I also use the forward trading of foreigners and Norwegian non-bank customers.[17] I choose these variables because they are the result of actual trading. Furthermore, it creates a flow that better matches the complete market.The other currency variables are not directly related to trading. Some of those other variables also contain an element of exchange rate variation, and are therefore endogenous variables. The correlations between the different flow variables, and the variables that contain an element of exchange rate variation (D2 in particular) are reported in table 5. Note that the correlations between spot trading of foreigners and Norwegians on the one hand and the endogenous variables D1, D2 and D3 on the other are small. In the case of foreigners' forward trading, the correlations are higher. The possibility of the flow variables being endogenous is further

[16] Positions that banks do not want to hold are sold on in the interbank market, either by directly taking contact or by changing quotes to induce trade in the preferred direction. See section 2.

[17] There is too little variation in the Central Bank's forward trading for this variable to be included as a regressor.

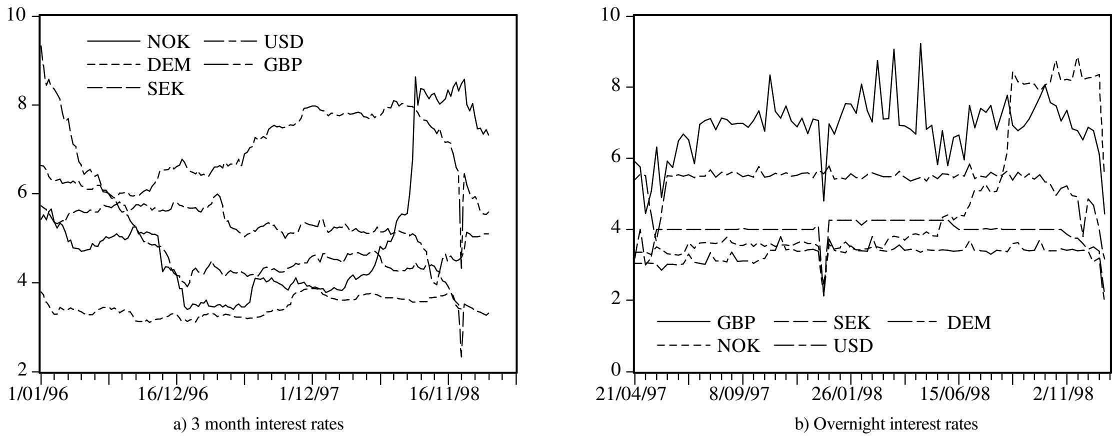
addressed below.

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. As a proxy for unexpected order flow, I use the one-week change of order flow. Estimating the expected flow as the forecast from some regression equation has also been tried. In general, the effects from the flow are the same, but the fit of the equation is lower.

4.2 Public information

As public information, I use the overnight interest rates ($i_{On,t}$) and the 3-month interest ($i_{3,t}$). The overnight rate is only available from week 17 of 1997 until the end of 1998, while the 3-month rate is available for the whole sample.[18] Figure 5 plots the interest rates.

Figure 5: Overnight and 3-month interest rates



Source: The overnight interest rates are from Reuters, while the 3-month rates are the so-called "EuroDollar" market interest rate. Both rates are provided by Norges Bank.

I also include information on the oil sector, due to Norway's dependence on oil revenues. First, the USD denominated spot price of Brent Crude oil from the North Sea is included, and available for the whole period. Second, the companies operating on the Norwegian shelf of the North Sea have to pay several kinds of transfers to the Norwegian Government on specific dates, and information on these dates is included. These predetermined dates may involve much currency trading, since the revenue of the oil companies comes in USD while the transfers are to be made in Norwegian krone (NOK). There is one dummy variable for each of the four kinds of transfers:

1. d_{Tax}: Ordinary taxes and Carbon dioxide taxes (C02) are due twice a year, on April 1 and October 1.

2. d_{Area}: Taxes for use of acreage are due before the New Year.

3. d_{Prod}: Production taxes are paid on the 15 of every month.

4. $d_{\text{SDØE}}$: The Norwegian government has direct ownership of parts of the fields operated,[19] called SDØE, and the return on the SDØE is transferred every month on

[18] The exception being DEM, which ends in December 1998 due the introduction of the Euro.

[19] The government's share of the fields is operated by government-owned Statoil.

Table 5: Correlation matrix of the flow variables

	For. Spot	Nor. Spot	CB Spot	For. Forward	Nor. Forward	D3. Corr.	D2. Ratelosses	D1. Income loss
For. Spot	1.0000							
Nor. Spot	-0.4881	1.0000						
CB Spot	-0.1697	-0.1840	1.0000					
For. Forward	-0.1949	-0.3845	-0.0813	1.0000				
Nor. Forward	0.0039	-0.1208	0.0869	-0.3774	1.0000			
D3. Corrections	-0.0200	-0.0110	0.0370	-0.2909	-0.0671	1.0000		
D2. Ratelosses	-0.1289	-0.0496	-0.1156	0.2438	-0.2405	-0.3067	1.0000	
D1. Income loss	0.0315	0.0325	-0.3109	0.0591	0.0213	-0.0265	0.0379	1.0000

the 20th. Since August 1998, these dates are confidential, and the transfers are no longer in NOK but in the currency generating the revenue.

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, $\Delta\left(i_{\ell,t} - i^*_{\ell,t}\right)$ ($\ell =$On,3m) with an * indicating the foreign interest rate.[20] In addition, the change in the spot price of Crude oil from the North Sea, $\Delta P_{\mathrm{Oil},t}$, will be used as public information in all formulations. In an alternative formulation, I also include dummies for transfers from the oil industry to the Norwegian government.

The correlation matrix of dependent and independent variables is given in table 6. Noteworthy is the correlation between the change in interest differentials and the change in logs of exchange rates and flow variables. Correlations with the dependent variables are rather high, while the correlations with the flow variables are rather low.

5 Results

Evans and Lyons formulated the model for the daily frequency, which can also be argued to be applicable at the weekly frequency. In the third round of trading, dealers trade with the public to share their risk with them. However, within a week, it is also 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. Another feature that makes the weekly frequency applicable on the Norwegian market is that NOK-dealers do not necessarily "square" their positions in e.g. NOK/DEM at the end of each day within the week, compared to what is normal for DEM/USD-dealers, due to the fact the NOK-market more or less closes when Norwegian banks end the day. Over the weekend, however, there is sufficient uncertainty to "square" the position. Furthermore, 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.

I will test three groups of models, each with both overnight and 3-month interest differentials. The two first models differ depending on whether the dummies for transfers from the oil industry are included in the public information set. In these two models, all flow variables enter with their difference. The first equation will be labeled "Model I" in the tables, the second "Model II". The two models are given by

$$\Delta P_t = \alpha + \beta_1 \Delta\left(i_{\ell,t} - i^*_{\ell,t}\right) + \beta_2 \Delta P_{\mathrm{Oil},t} + \beta_3 \Delta \mathrm{ForSpot}_t + \beta_4 \Delta \mathrm{NorSpot}_t + \beta_5 \Delta \mathrm{CBSpot}_t + \beta_6 \Delta \mathrm{ForForward}_t + \beta_7 \Delta \mathrm{NorForward}_t + u_t \quad (13)$$

[20] Using the level of the interest differential instead of the change does not affect the coefficients of the flow variables. However, the equations in general show poor fit.

Table 6: Correlation matrix of regression variables

	Δlog(NOK/*)	ΔOil Spot	ΔFor.Spot	ΔNor.Spot	ΔCB Spot	ΔFor.Forw.	ΔNor.Forw.
Δlog(NOK/DEM)	1.0000	-0.0578	0.1062	0.0605	0.0867	-0.0010	-0.0093
$\Delta\left(i_{\text{NOK}} - i_{\text{DEM}}\right)_{3\text{Month}}$	0.5493	-0.0475	0.1367	0.0547	-0.0031	-0.0168	-0.0659
Δlog(NOK/SEK)	1.0000	0.0133	-0.1298	0.2600	0.0336	-0.0373	-0.0139
$\Delta\left(i_{\text{NOK}} - i_{\text{SEK}}\right)_{3\text{Month}}$	0.2443	-0.0687	0.0065	0.0290	0.0045	0.0646	-0.0310
Δlog(NOK/USD)	1.0000	-0.0825	-0.1714	0.2410	0.0764	0.0019	-0.0235
$\Delta\left(i_{\text{NOK}} - i_{\text{USD}}\right)_{3\text{Month}}$	0.2761	-0.0994	0.0769	0.0648	-0.0250	-0.0454	-0.0517
Δlog(NOK/GBP)	1.0000	-0.0438	-0.1497	0.2141	0.0540	0.0346	-0.0741
$\Delta\left(i_{\text{NOK}} - i_{\text{GBP}}\right)_{3\text{Month}}$	0.1783	-0.0887	-0.0039	-0.0231	-0.0242	0.1111	-0.0386
ΔOil Spot		1.0000					
ΔFor. Spot		0.0044	1.0000				
ΔNor. Spot		-0.1110	-0.5050	1.0000			
ΔCB Spot		0.1527	-0.1104	-0.1734	1.0000		
ΔFor. Forward		0.0380	-0.2224	-0.4078	0.0006	1.0000	
ΔNor. Forward		0.0527	0.0173	-0.1372	0.0530	-0.2935	1.0000

The correlations in the first column are between change in interest differentials and the exchange rate of the currencies in which the interest rates are denominated.

and

$$\Delta P_t = \alpha + \beta_1 \Delta \left(i_{\ell,t} - i^*_{\ell,t} \right) + \beta_2 \Delta P_{\text{Oil},t} + \delta_1 d_{\text{Tax},t} + \delta_2 d_{\text{Area},t} + \delta_3 d_{\text{Prod},t} + \delta_4 d_{\text{SDØE},t} + \beta_3 \Delta \text{ForSpot}_t + \beta_4 \Delta \text{NorSpot}_t + \beta_5 \Delta \text{CBSpot}_t + \beta_6 \Delta \text{ForForward}_t + \beta_7 \Delta \text{NorForward}_t + u_t. \quad (14)$$

These two models are closest in spirit to equations (11) and (12). As a third model, labeled "Model III" in the tables, I include a version that strictly tests equation (10), where both the difference and the level of the order flow enter:

$$\Delta P_t = \alpha + \beta_1 \Delta \left(i_{\ell,t} - i^*_{\ell,t} \right) + \beta_2 \Delta P_{\text{Oil},t} + \beta_3 \Delta \text{ForSpot}_t + \beta_4 \Delta \text{NorSpot}_t + \beta_5 \Delta \text{CBSpot}_t + \beta_6 \Delta \text{ForForward}_t + \beta_7 \Delta \text{NorForward}_t + \beta_8 \text{ForSpot}_t + \beta_9 \text{NorSpot}_t + \beta_{10} \text{CBSpot}_t + \beta_{11} \text{ForForward}_t + \beta_{12} \text{NorForward}_t + u_t \quad (15)$$

In this equation, the change in flow variables is supposed to capture the updating information element, while the level of the flow variables captures the risk premium. The problem with this last specification is the high correlation between the difference and the level of the flow variables, as is evident from table 13 in the appendix. Furthermore, the lagged flow in the theoretical model enters as a correction to public information. At the weekly horizon, this correction seems less plausible, and I therefore focus on Models I and II. This comes at a cost, since I cannot disentangle the updating information part of order flow from the risk premium part. Both are, however, initially related to private information.

All regressions use the change in the log of nominal exchange rates for NOK/USD, NOK/DEM, NOK/SEK and NOK/GBP 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 using overnight rates are shown in table 7 and 9, respectively. Results using 3-month rates are shown in table 8 and 10. Model III is reported in 11.

The fit of the regressions, as measured by adjusted R^2, is unusually high for this frequency, with numbers as high as 33% for NOK/DEM. That the best fit is observed for NOK/DEM is natural since NOK/DEM is the most heavily traded spot exchange rate in the Norwegian market, meaning that the aggregate flow variables contain considerable NOK/DEM trading. The NOK/USD and NOK/GBP exchange rates are more volatile than the NOK/DEM and NOK/SEK, as shown in table 2, which also explains the some what weaker fit for the NOK/USD and NOK/GBP. The lower volatility of NOK/DEM (and NOK/SEK) is due the fact that the Norwegian Central Bank stabilizes the NOK against the ECU/EURO which, in practice, means stabilizing against the DEM.

In all regressions, one or more of the flow variables enter with a coefficient significantly different from zero at the 5%-level, and several of the flow variables are significant at the 10% level. The strongest effect is on NOK/DEM, which is, once more, as expected. The effect from flow variables is more or less equal for NOK/SEK, NOK/USD and NOK/GBP. Furthermore, if one accepts the presumption that a majority of these trades are initiated outside of Norwegian banks, all flow variables enter correctly signed. When there is buying pressure on currency in the overall market, this conveys information that pushes up prices, i.e. a depreciation of the NOK. The flow variable that is most often significant is the spot trading with Norwegian customers. This may be the flow most accurately capturing the portfolio shift, the information and the sentiment of the public in the theoretical model. This result may also indicate that even if high concentration may reduce the amount of private information, its utility may be large due to access to a larger share of customer trading. The size of the foreigners' and customers' flow coefficients is generally less than 0.1%, meaning that an unexpected increase in e.g. foreigners' spot buying of 1 billion depreciates the NOK with less than 0.1%. From table 4, the average absolute size of the customers' and foreigners' spot trading is 5.22 and 3.2, respectively.

Notice that Central bank trading also influences the exchange rate. When the central bank sells currency and buys NOK, the CB Spot flow is negative and leads to an appreciation of the NOK (a decrease in the exchange rate). This implies that interventions have an effect. The coefficient on Central bank trading is generally higher than that of the other flow variables.

The impact of forward trading is, in general, both smaller and statistically less significant than the impact of spot trading, which is consistent with the view that spot trading is the driving force of the market.

Exchange rates are not independent. Presumably, the DEM/USD rate is determined independently of the NOK market, so that when the NOK/DEM rate is determined, the NOK/USD rate will follow. It may still be of interest to study several exchange rates. Consider the case when there is some negative news on DEM that result in the selling of DEM to the banks. This should lead to a appreciation of NOK towards DEM. The same should be the case for SEK against the DEM, so the NOK/SEK rate should remain fairly constant with little trading in this exchange rate. If there is negative news about the NOK, this leads to a flow out of NOK, and NOK will depreciate both towards SEK and DEM. The flow variables may then contain a great deal of buying of SEK and DEM from the banks.

The single most important variable is the change in interest rate differentials. Interest rates are highly significant in all regressions, with a positive and larger coefficient than the flow variables. A 1% change in interest differentials changes the spot rate by more than 1%.The strongest effect is on NOK/DEM, and the weakest is, in general, on NOK/GBP. This means that the overshooting that Evans and Lyons find in their data, i.e. a negative coefficient, is a daily phenomenon and is finished and dominated by the usual depreciating effect at the weekly horizon. Given the weekly horizon, it is not surprising that public information is most important. Both previous empirical work and dealer surveys show that public information becomes increasingly important at longer horizons.

There are signs of ARCH-effects in the equations using 3-month rates. In table 14 and 15 in the appendix, I report the result of a GARCH-estimation for model I and III, which confirms the overall picture. One may argue that even if the forward flow is a trading flow, it is the only spot trading that should be included, since I use the spot exchange rate as the dependent variable. The spot and forward rates are, however, linked by covered interest rate parity. In table 16 of the appendix, I make an ARCH-estimation with only the spot trading of foreigners and Norwegians, and find the same pattern as earlier.

The effects of oil prices are insignificant. This may indicate that the oil price is not that important for NOK exchange rates as is commonly perceived. It might be that the effect from oil prices is non-linear, as in Akram (1999).

The effect of including the transfer dummies is shown in tables 9 and 10. These dummies identify weeks with a great deal of publicly know currency trading. Only the production tax dummy is significant, when using 3-month rates. These taxes are paid every month. It is only for NOK/SEK that this dummy is significant and, in that case, with a positive coefficient. One first thought might be that since these tax transfers would mean a demand for NOK, these date-dummies should lead to an appreciation (a negative coefficient) instead. However, since the dates are known in advance, this is already compounded into the prices. A significant coefficient can only be regarded as a sign of an important transfer. For flow variables and interest rates, the results are as above. Inclusion of the publicly known trading periods does not alter the effect of the flow variables, thereby strengthening the model.

Table 7: Model I: Regressing weekly change in log exchange rates on overnight interest rates and flow variables. (1997:18 to 1998:52)

	NOK/DEM	NOK/SEK	NOK/USD	NOK/GBP
Constant	0.000672	-0.000012	0.000413	0.001201
	(0.62)	(-0.01)	(0.24)	(0.66)
$\Delta(i_t - i_t^*)$	0.013458	0.010701	0.007850	0.004025
	**(2.14)	***(3.25)	**(2.29)	*(1.80)
ΔOil Spot	0.000313	-0.000114	-0.001450	0.001031
	(0.19)	(-0.07)	(-0.58)	(0.39)
ΔFor. Spot trading	0.000918	0.000287	0.000566	0.000813
	**(2.39)	(1.24)	(1.42)	*(1.91)
ΔNor. Spot trading	0.000443	0.000242	0.000631	0.000683
	*(1.76)	(1.32)	**(2.23)	**(2.24)
ΔCB Spot trading	0.001427	0.001183	0.001550	0.001654
	(1.16)	**(2.26)	(1.54)	(1.56)
ΔFor. Forward Trade	0.000346	0.000092	0.000430	0.000563
	(1.58)	(0.63)	(1.52)	*(1.87)
ΔNor. Forward Trade	0.000220	0.000166	0.000502	0.000476
	(0.68)	(0.91)	(1.54)	(1.37)
Adjusted R^2	0.27	0.23	0.10	0.06
Durbin-Watson stat	2.23	1.97	2.23	2.17

t-values are in parenthesis, and "***", "**" and "*" indicate the significance at the 1%, 5% and 10%-level, respectively. All equations are estimated with OLS. The NOK/DEM covariance matrix is corrected for heteroskedasticity of the White-form, while the NOK/SEK covariance is corrected with the Newey-West HAC correction.

Table 8: Model I: Regressing weekly change in log exchange rates on 3-month interest rates and flow variables. (1996:3 to 1999:10)

	NOK/DEM	NOK/SEK	NOK/USD	NOK/GBP
Constant	-0.000336	-0.000477	0.000906	0.001233
	(-0.62)	(-0.71)	(1.01)	(1.42)
$\Delta(i_t - i_t^*)$	0.024619	0.011570	0.014730	0.010922
	***(4.05)	***(2.94)	**(2.26)	(1.51)
ΔOil Spot	-0.000822	0.000675	-0.003423	-0.002950
	(-0.88)	(0.55)	**(-2.21)	**(-1.99)
ΔFor. Spot trading	0.000469	0.000317	0.000238	0.000410
	**(1.99)	(1.16)	(0.54)	(0.80)
ΔNor. Spot trading	0.000325	0.000561	0.000655	0.000859
	**(2.01)	**(2.44)	*(1.91)	*(1.82)
ΔCB Spot trading	0.000562	0.000577	0.000976	0.001303
	(1.19)	(1.33)	**(2.09)	**(2.01)
ΔFor. Forward Trade	0.000299	0.000323	0.000530	0.000641
	*(1.70)	(1.65)	*(1.78)	(1.65)
ΔNor. Forward Trade	0.000242	0.000315	0.000237	0.000266
	(1.07)	(1.56)	(0.81)	(0.70)
MA(1)	-0.226998	-0.348740	-0.350843	-0.453518
	*(-1.74)	**(-2.53)	**(-2.23)	***(-3.04)
Adjusted R^2	0.33	0.19	0.23	0.23
Durbin-Watson stat	1.91	1.97	2.08	2.05

t-values are in parenthesis, and "***", "**" and "*" indicate the significance at the 1%, 5% and 10%-level, respectively. All equations are estimated with NLS. The NOK/DEM covariance matrix is corrected for heteroskedasticity of the White-form, while the others are corrected with the Newey-West HAC correction.

Table 9: Model II: Regressing weekly change in exchange rates on overnight interest rates, transfer dummies and flow variables. (1997:18 to 1998:52)

	NOK/DEM	NOK/SEK	NOK/USD	NOK/GBP
Constant	0.000846	-0.001236	0.000176	0.000694
	(0.52)	(-0.98)	(0.08)	(0.29)
$\Delta(i_t - i_t^*)$	0.014244	0.010358	0.011201	0.004270
	***(3.59)	***(4.00)	***(2.80)	*(1.86)
ΔOil Spot	0.000218	-0.000055	-0.002016	0.001625
	(0.12)	(-0.04)	(-0.77)	(0.58)
d_{Tax}	0.003326	-0.003522	0.009650	-0.000274
	(0.47)	(-0.64)	(0.99)	(-0.03)
d_{Area}	0.002015	0.001995	0.018191	0.002503
	(0.22)	(0.30)	(1.40)	(0.20)
d_{Prod}	-0.001080	0.003872	-0.002265	0.004458
	(-0.35)	(1.61)	(-0.54)	(0.98)
d_{SDOE}	-0.000727	0.002470	-0.001267	-0.003028
	(-0.21)	(0.91)	(-0.27)	(-0.59)
ΔFor. Spot trading	0.000892	0.000296	0.000442	0.000879
	**(2.87)	(1.26)	(1.06)	**(2.00)
ΔNor. Spot trading	0.000423	0.000231	0.000555	0.000708
	*(1.84)	(1.34)	*(1.87)	**(2.24)
ΔCB Spot trading	0.001415	0.001135	0.001428	0.001578
	*(1.91)	**(1.99)	(1.41)	(1.45)
ΔFor. Forward Trade	0.000338	0.000082	0.000401	0.000577
	(1.58)	(0.50)	(1.40)	*(1.87)
ΔNor. Forward Trade	0.000225	0.000125	0.000488	0.000442
	(0.93)	(0.66)	(1.48)	(1.24)
Adjusted R^2	0.23	0.24	0.09	0.03
Durbin Watson stat	2.24	2.00	2.21	2.14

t-values are in parenthesis, and "***", "**" and "*" indicate the significance at the 1%, 5% and 10%-level, respectively. All equations are estimated with OLS, with Newey-West HAC corrections on the covariance matrix.

Table 10: Model II: Regressing weekly change in exchange rates on 3-month interest rates, transfer dummies and flow variables. (1996:3 to 1999:10)

	NOK/DEM	NOK/SEK	NOK/USD	NOK/GBP
Constant	-0.000589	-0.001829	0.000812	0.000379
	(-0.63)	(-1.72)	(0.57)	(0.23)
$\Delta(i_t - i_t^*)$	0.025615	0.012525	0.017540	0.013607
	***(7.07)	***(3.48)	***(3.48)	***(2.85)
ΔOil Spot	-0.000848	0.000883	-0.002554	-0.001705
	(-0.78)	(0.69)	(-1.46)	(-0.83)
d_{Tax}	0.001013	-0.005819	-0.008223	-0.007700
	(0.25)	(-1.16)	(-1.19)	(-0.92)
d_{Area}	-0.004008	-0.004911	0.003045	-0.002210
	(-0.71)	(-0.72)	(0.33)	(-0.20)
d_{Prod}	0.000157	0.005777	0.001569	0.003623
	(0.08)	**(2.37)	(0.46)	(0.88)
d_{SDOE}	0.001155	0.001451	0.000116	0.001934
	(0.57)	(0.58)	(0.03)	(0.46)
ΔFor. Spot trading	0.000430	0.000278	0.000197	0.000300
	*(1.95)	(1.17)	(0.58)	(0.72)
ΔNor. Spot trading	0.000308	0.000532	0.000631	0.000829
	**(2.09)	**(2.93)	**(2.43)	**(2.59)
ΔCB Spot trading	0.000531	0.000531	0.000858	0.001145
	*(1.73)	(1.37)	(1.58)	*(1.72)
ΔFor. Forward Trade	0.000288	0.000299	0.000487	0.000569
	*(1.79)	(1.45)	*(1.67)	(1.56)
ΔNor. Forward Trade	0.000241	0.000217	0.000182	0.000200
	(1.32)	(0.90)	(0.54)	(0.48)
AR(1)	-0.169960	-0.287110	-0.355700	-0.406140
	*(-1.95)	***(-3.50)	***(-4.46)	***(-5.12)
Adjusted R^2	0.32	0.20	0.22	0.21

t-values are in parenthesis, and "***", "**" and "*" indicate the significance at the 1%, 5% and 10%-level, respectively. All equations are estimated with OLS, with Newey-West HAC corrections on the covariance matrix.

Table 11: Model III: Regressing weekly change in log exchange rates on 3-month interest rates and flow variables. (1996:3 to 1999:10)

	NOK/DEM	NOK/SEK	NOK/USD	NOK/GBP
Constant	0.000309	-0.000266	0.000701	0.000612
	(0.38)	(-0.338498)	(0.81)	(0.61)
$\Delta(i_t - i_t^*)$	0.023018	0.011596	0.009934	0.010154
	***(3.00)	**(2.58)	*(1.70)	(1.59)
ΔOil Spot	-0.000843	0.001160	-0.002806	-0.002719
	(-0.92)	(0.91)	**(-2.08)	**(-2.01)
ΔFor. Spot trading	0.000606	0.000306	0.000751	0.000676
	*(1.69)	(0.88)	(1.30)	(1.06)
ΔNor. Spot trading	0.000320	0.000383	0.000632	0.001113
	(1.54)	(1.42)	(1.38)	**(2.22)
ΔCB Spot trading	0.000983	0.000763	0.001277	0.001177
	*(1.69)	(1.43)	**(2.32)	(1.40)
ΔFor. Forward trade	0.000349	0.000528	0.000534	0.000810
	(1.34)	(1.54)	(1.04)	(1.19)
ΔNor. Forward trade	0.000190	0.000540	0.000756	0.000784
	(0.65)	*(1.80)	(1.50)	(1.31)
For. Spot trading	-0.000199	0.000067	-0.000775	-0.000552
	(-0.46)	(0.17)	(-1.21)	(-1.15)
Nor. Spot trading	0.000078	0.000312	0.000267	-0.000478
	(0.25)	(1.10)	(0.46)	(-0.93)
CB Spot trading	-0.000681	-0.000368	-0.000174	0.000174
	(-1.29)	(-0.84)	(-0.33)	(0.24)
For. Forward trade	-0.000094	-0.000473	0.000091	-0.000270
	(-0.27)	(-0.96)	(0.13)	(-0.34)
Nor. Forward trade	0.000120	-0.000542	-0.000980	-0.001000
	(0.33)	(-1.11)	(-1.23)	(-1.26)
MA(1)	-0.256143	-0.350559	-0.412228	-0.480796
	**(-2.11)	**(-2.57)	***(-2.67)	***(-3.49)
Adjusted R^2	0.33	0.21	0.26	0.23
Durbin-Watson stat	1.90	1.96	2.10	2.06

t-values are in parenthesis, and "***", "**" and "*" indicate the significance at the 1%, 5% and 10%-level, respectively. All equations are estimated with OLS, with the Newey-West HAC corrections on the covariance matrix.

The results above indicate that private information may be important in the Norwegian currency market. In table 12, I present evidence of whether private information is more or less important than public information. Each cell reports how large a share the two information sources explain, based on partR^2 from stepwise regression for each variable in the regression with overnight rates.

Table 12: PartR^2 for public and private information

		NOK/DEM	NOK/SEK	NOK/USD	NOK/GBP
I	Public information	0.156	0.184	0.067	0.041
	Private information	0.254	0.110	0.171	0.200
II	Public information	0.153	0.226	0.146	0.067
	Private information	0.232	0.103	0.139	0.205

In the case of NOK/DEM, the private information source (flow variables) explains more of the weekly changes in the exchange rate in both models. The same holds for NOK/USD and NOK/GBP. For NOK/SEK, public information is the dominant source in both regression models.

5.1 Discussion

For the validity of the interpretations, two issues must be addressed: Whether the order flow primarily measures private information, and whether the order flow is an exogenous variable.

In a market microstructure theory, there are two dominant reasons for trading; speculation or information based trade, and hedging or inventory-adjustment. In time series approaches to microstructure (see Hasbrouck, 1996), the information effect from trading is captured by a permanent component in price changes, and the inventory-adjustment as a temporary component in price changes. In the aggregate order flow, it is likely that inventory management by the different agents is uncorrelated and will cancel out over the week, while the information effect from trading will have a lasting and significant price impact.

Furthermore, Lyons (1996, 1997) found that the impact of order flows on price discovery is smaller when there is a great deal of inventory management, which he refers to as "hot potato" trading in the market. Consequently, the significant effect from order flow may be interpreted as coming from the market's learning of private information.

Finally, the effect from order flow on price is more than merely "supply and demand," or quantity adjustment. Information on volume of trade only would not give much structural information about the supply and demand of currency. It is not clear what is supply and what is demand, however. The key to say anything structural about the relationship between trading and price is the signing of the trades. Since all dealers both play the role as suppliers and demanders, and it is possible to determine which role the dealer has in a transaction, we can sign the trades. This makes it sensible to talk about "buyer"-pressure or "seller"-pressure in equilibrium, despite the necessary equality between selling and buying. Only unexpected flow, however, will influence prices. Expected transfers will already be discounted in the price, and hence have no effect. If the flow is unexpected, it will carry more informational content. So while order flow in the foreign exchange market serves the role of influencing prices to balance supply and demand, as in other markets, it also influences prices through changing beliefs. The results of Model III in tables 11 and 15 give some evidence of this being the most important effect of the two. However, as noted above, one should be careful in drawing conclusions from these regressions, due to high correlations between regressors.

The interpretation of order flow as an indication of private information can be tested. If the lagged flow variables are also significant, or make the contemporaneous flow variables insignificant, we should doubt the private information interpretation. This is reported in table 17 of the appendix. The contemporaneous flow variables remain significant, while all lagged flow variables are insignificant except for the foreigner's spot trading in the NOK/SEK equation. In this equation, the contemporaneous effect is still significant, however. Furthermore, the effect from order flow is permanent, as would be the case if contributing new information.

On the exogeneity issue, in all standard models of market microstructure order flow cause price changes. Even when order flow and price changes are simultaneous, causality goes from order flow to price changes. However, this need not be the case in reality. The kind of behavior necessary to create causation the other way, namely some mechanical trading rule, seems less likely on a weekly horizon than in intra day trading. Furthermore, for there to be a positive effect from order flow on exchange rates due to feedback trading, positive autocorrelation in exchange rates is required for this to be optimal. This positive autocorrelation is not present in the data, nor in exchange rates in general (Goodhart, Ito, and Payne, 1996). I address the issue of feedback trading by lagging the exchange rate. If order flow were driven by exchange rates, as in feedback trading, this would make the flow variables insignificant while the lagged exchange rate would be significant. As table 18 reports, this is not the case. In the NOK/DEM equation, the lagged rate is insignificant. In the other equations, the lagged rate is significant, but does not alter the significance of the flow variables for NOK/SEK and NOK/GBP. In these cases, the lagged rate simply picks up the autocorrelation estimated earlier on. The choice of end-of-week exchange rates is also made to partly circumvent such a problem.

To finish the issue of exogeneity of flow variables, I also estimate a system approach. I use a two-stage procedure where, in the first step, I form instruments for the flow variables by regressing these on lagged values of the flow variables and an ARMA error term.[21] Then, I use these instruments in an ARCH-estimation, reported in table 20. The method is not efficient, but gives consistent estimates and should be sufficient to document that the coefficients on the flow variables are not biased. Notice that the size of the coefficients is not affected.

A related question is whether the interest differential is exogenous. Imagine that authorities use interest rates to smooth exchange rate changes. When there is a depreciation pressure on the exchange rate, the Central Bank will increase the interest rates to prevent depreciation and/or make the exchange rate return to its initial level. This would imply that the flow related to the depreciation pressure will not be accompanied by an actual depreciation, resulting in a downward bias in the coefficient of the interest rate and flow variables.

Finally, to show that the effect from order flow is not just an extreme event issue, I allow the coefficient to be time varying. The coefficient on the flow variable equals

$$\lambda = \pi + \rho = \pi + \frac{\theta Var\left[P_{3,t+1}|\Omega_{3,t}^{P}\right]}{\alpha}.$$

In the appendix, I show that the second part of this coefficient is increasing in the conditional variance of the price in the next period. Although the variance is a constant in the model, it may be time varying in reality. To implement this empirically, I let the coefficient λ be given by

$$\lambda = \pi + \rho_1 Var\left[P_{3,t+1}|\Omega_{3,t}^{P}\right]. \tag{16}$$

Since change in log exchange rate is the dependent variable, I cannot use the residual as a proxy for the variance. Instead, I use the squared of the level forecast from the equation minus the realized exchange rate, $\left(\widehat{\text{NOKDEM}} - \text{NOKDEM}\right)_{t+1}^{2}$. I then iterate over a two-step procedure where the first step is to obtain the forecast, and the second step includes the suggested variance proxy, conditioned on all information up to period t. The results reported in table 21 in the appendix show that the fixed component of the flow coefficient is significant, correctly signed and of the same magnitude as earlier. The variable component is much smaller, not correctly signed, and not significant.

6 Conclusion

Since the float of the major currencies in the 1970s, there have been enormous amounts of empirical research on exchange rates. However, our knowledge of the functioning of the market is still limited. Most research has been within the asset approach to foreign exchange. It has proved difficult to explain several of the puzzles of the foreign exchange market, e.g. the volume of trading and the large swings in exchange rates. In fact, there is little evidence that macroeconomic variables have consistent strong effects on floating exchange rates, except in extraordinary circumstances, such as hyperinflation. In a classic

[21] The instruments have a fit between 15% and 30%.

study, Meese and Rogoff (1983a) find that three structural macroeconomic models do not perform better than a random walk model, even when uncertainty about future values of the explanatory variables is removed.

Recently, the approach of market microstructure theory has made some progress in explaining the short-term aspects of the foreign exchange market. The microstructure approach seeks to relax the most constraining assumptions of the macroeconomic approach, namely that (*i*) agents are identical, (*ii*) information is perfect, and (*iii*) that the trading mechanism is inconsequential (Lyons, 2000; Frankel, Galli, and Giovannini, 1996). So far, the microstructure approach has been concerned with intraday and daily analysis. In that respect, the microstructure approach can be viewed as a complementary approach to macroeconomic models.

In most microstructure models, order flow carries information and leads to an aggregation of private information into prices. In this paper, I test a model combining the two approaches, by integrating order flow into a model where public (macroeconomic) information is important. Moreover, the weekly frequency employed enables me to in a meaningful way study both the microstructure and the macroeconomic information source. This is rather new, as there often is difficult to identify public macroeconomic information in intraday studies, the most common frequency of microstructure studies.

The order flow in the model influences prices through two channels. First, there is imperfect capital mobility, so when there are large (portfolio) shifts on the behalf of the customers the agents absorbing these shift need to be compensated by a risk premium. Secondly, since these portfolio shifts may be functions of agents private beliefs about future macroeconomic fundamentals, unexpected changes in the order flow may signal some new information on fundamentals, i.e. changes in "market sentiment".

The results are strong. The model fit the data well, with adjR^2 as high as 33% for NOK/DEM and, in other cases, well above 20%.The flow variables enter significantly and with the correct sign, indicating an important role for private information in the Norwegian currency market. When there is a pressure for buying currency in the market, dealers adjust expectations upward (appreciation of the currency). This is the standard story in intraday trading. On the longer weekly horizon, dealers use their customer trades as signals of such market wide pressure that could push prices up. The effect from order flow is also shown to be permanent, which signifies that the order flow really leads to the aggregation of new information into prices. The results are shown to be robust against alternative formulations as well.

That the order flow 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. Central Bank spot trading of currency leads to a depreciation of NOK. Thus, the regressions also indicate that Central Bank interventions work to stabilize the exchange rate.

The trading of the customer sector is the primary source of demand for currency. Dealers claim that trading with customers is their primary source of private information. The customer order flow is the most signficant flow variable, thus supporting the importance that market participants attach to these flows. This result is new.

Interest rates are significant in all regressions with a positive coefficient. At the weekly horizon, increased interest differentials also mean that the NOK depreciates. The possible positive effect of the interest weapon in fighting speculation may seem to be shorter than one week. This must, however, be more closely investigated in a model including central bank interest rates.

The results documented in this paper clearly raise the question of what causes currency flows in the first place, an issue that should be addressed in future research.

A Tables

Table 13: Correlation matrix for change and level of flow variables

	For. Spot	Nor. Spot	CB Spot	For. Forward	Nor. Forward
ΔFor. Spot	0.80	-0.50	-0.11	-0.12	0.04
ΔNor. Spot	-0.33	0.82	-0.07	-0.37	-0.19
ΔCB Spot	-0.01	-0.17	0.58	0.02	0.01
ΔFor. Forward	-0.24	-0.27	-0.02	0.78	-0.18
ΔNor. Forward	0.01	-0.10	0.06	-0.26	0.76

Table 14: Model I: ARCH estimation of weekly change in log exchange rates on 3-month interest rates and flow variables. (1996:3 to 1999:10)

	NOK/DEM	NOK/SEK	NOK/USD	NOK/GBP
Constant	-0.000445	-0.000071	0.001320	0.002718
	(-1.33)	(-0.07)	(1.30)	***(5.00)
$\Delta(i_t - i_t^*)$	0.020126	0.011880	0.011548	0.001085
	***(3.34)	**(2.53)	***(3.08)	(0.33)
ΔOil Spot	-0.000221	0.000726	-0.002628	-0.000126
	(-0.40)	(0.63)	*(-1.71)	(-0.16)
ΔFor. Spot trading	0.000347	0.000368	0.000456	0.000646
	***(3.22)	**(2.10)	(1.59)	***(4.71)
ΔNor. Spot trading	0.000245	0.000439	0.000573	0.000307
	***(3.36)	**(2.46)	***(3.00)	**(2.38)
ΔCB Spot trading	0.000390	0.000380	0.001078	0.000818
	**(2.08)	(0.95)	**(2.15)	***(3.00)
ΔFor. Forward Trade	0.000098	0.000234	0.000605	0.000188
	(1.27)	(1.65)	***(2.66)	(1.28)
ΔNor. Forward Trade	0.000038	0.000278	0.000732	0.000163
	(0.42)	(1.56)	***(2.65)	(1.05)
MA(1)			-0.169063	-0.174719
			*(-1.67)	*(-1.84)
Adjusted R^2	0.26	0.08	0.14	0.04
Durbin-Watson stat	2.33	2.55	2.45	2.53

t-values are in parenthesis, and "***", "**" and "*" indicate the significance at the 1%, 5% and 10%-level, respectively. NOK/DEM, NOK/SEK are estimated with a Threshold GARCH(1,1), a TARCH(1,1), while NOK/USD is estimated with a TARCH(1,0). NOK/GBP is estimated by an ARCH(1).

Table 15: Model III: ARCH estimation of weekly change in log exchange rates on 3-month interest rates and flow variables. (1996:3 to 1999:10)

	NOK/DEM	NOK/SEK	NOK/USD	NOK/GBP
Constant	-0.000087	0.001725	0.002306	0.001737
	(-0.166)	*(1.71)	***(3.78)	**(2.54)
$\Delta(i_t - i_t^*)$	0.019432	0.010125	0.004475	0.014989
	***(8.46)	**(2.06)	(0.85)	***(4.28)
ΔOil Spot	-0.000699	0.001148	-0.001687	0.000068
	(-1.34)	*(1.85)	**(-2.04)	(0.07)
ΔFor. Spot trading	0.000644	0.000084	0.000855	0.000575
	***(3.22)	(0.35)	***(3.76)	*(1.88)
ΔNor. Spot trading	0.000359	0.000080	0.000181	0.000589
	**(2.52)	(0.48)	(0.96)	***(2.92)
ΔCB Spot trading	0.000716	-0.000093	0.000566	0.000455
	***(3.66)	(-0.27)	(1.50)	(1.26)
ΔFor. Forward trade	0.000264	0.000222	0.000013	0.000117
	*(1.89)	(1.12)	(0.06)	(0.52)
ΔNor. Forward trade	0.000032	0.000217	0.000581	0.001091
	(0.20)	(0.88)	*(1.97)	***(3.48)
For. Spot trading	-0.000439	0.000339	-0.001178	-0.000649
	(-1.46)	(0.96)	***(-3.35)	(-1.39)
Nor. Spot trading	-0.000113	0.000263	-0.000458	-0.001044
	(-0.46)	(0.94)	*(-1.80)	***(-3.80)
CB Spot trading	-0.000480	-0.000552	-0.000541	-0.000052
	(-1.37)	(-1.01)	(-1.37)	(-0.12)
For. Forward trade	-0.000219	-0.000316	0.000105	-0.000312
	(-0.98)	(-1.00)	(0.32)	(-0.95)
Nor. Forward trade	0.000071	-0.000450	-0.001345	-0.001204
	(0.24)	(-1.18)	***(-3.26)	***(-2.70)
MA(1)			-0.331656	-0.273323
			***(-5.17)	***(-4.15)
Adjusted R^2	0.25	0.01	0.07	0.05
Durbin-Watson stat	2.34	2.51	2.37	2.45

t-values are in parenthesis, and "***", "**" and "*" indicate the significance at the 1%, 5% and 10%-level, respectively. NOK/DEM, NOK/SEK and NOK/USD are estimated with a GARCH(1,1) procedure. NOK/GBP is estimated by an ARCH(1).

Table 16: ARCH estimation of weekly change in log exchange rates on 3-month interest rates and spot flow variables. (1996:3 to 1999:10)

	NOK/DEM	NOK/SEK	NOK/USD	NOK/GBP
Constant	-0.000677	-0.000152	0.001887	0.002342
	(-1.53)	(-0.19)	*(1.93)	***(4.46)
$\Delta(i_t - i_t^*)$	0.019870	0.010516	0.020673	0.002263
	***(17.73)	***(6.77)	***(13.12)	(0.92)
ΔOil Spot	-0.000089	0.000581	-0.001171	-0.000391
	(-0.19)	(0.56)	(-0.98)	(-0.33)
ΔFor. Spot trading	0.000185	0.000195	0.000257	0.000496
	*(1.84)	*(1.85)	*(1.70)	***(4.57)
ΔNor. Spot trading	0.000147	0.000183	-0.000034	0.000179
	***(2.87)	**(2.46)	(-0.34)	**(2.20)
MA(1)			-0.125549	-0.157115
			(-1.33)	***(-5.47)
Adjusted R^2	0.24	0.04	0.05	0.04
Durbin-Watson stat	2.38	2.56	2.58	2.57

t-values are in parenthesis, and "***", "**" and "*" indicate the significance at the 1%, 5% and 10%-level, respectively. NOK/DEM is estimated with a GARCH(1,1). NOK/SEK and NOK/USD are estimated with a Threshold GARCH(1,1), a TARCH(1,1). NOK/GBP is estimated by an ARCH(1).

Table 17: ARCH estimation of weekly change in log exchange rates on 3-month interest rates, spot flow and lagged spot flow. (1996:3 to 1999:10)

	NOK/DEM	NOK/SEK	NOK/USD	NOK/GBP
Constant	-0.000660	0.000004	0.002665	0.001530
	(-1.43)	(0.00)	***(2.69)	*(1.76)
$\Delta(i_t - i_t^*)$	0.020062	0.009956	0.020936	0.002748
	***(17.37)	(1.57)	***(11.28)	(1.17)
ΔOil Spot	-0.000146	0.001079	-0.001048	0.000204
	(-0.30)	(1.50)	(-0.82)	(0.14)
ΔFor. Spot trading	0.000134	0.000385	0.000290	0.000598
	(1.02)	***(3.36)	*(1.72)	***(3.27)
ΔNor. Spot trading	0.000133	0.000239	-0.000012	0.000256
	*(1.88)	***(3.51)	(-0.10)	**(2.14)
ΔFor. Spot trading(-1)	-0.000064	0.000225	0.000001	0.000178
	(-0.53)	*(1.76)	(0.01)	(0.94)
ΔNor. Spot trading(-1)	-0.000025	0.000089	-0.000076	0.000046
	(-0.35)	(1.07)	(-0.70)	(0.44)
AR(1)			-0.073338	-0.163320
			(-0.85)	***(-3.59)
Adjusted R^2	0.23	0.05	0.01	0.04
Durbin-Watson stat	2.38	2.55	2.64	2.53

t-values are in parenthesis, and "***", "**" and "*" indicate the significance at the 1%, 5% and 10%-level, respectively. NOK/DEM and NOK/SEK are estimated by a TARCH(1,1). NOK/USD is estimated by ARCH(1), while NOK/GBP is estimated by an Exponential ARCH(1), EGARCH(1,0).

Table 18: ARCH estimation of weekly change in log exchange rates on 3-month interest rates, spot flow variables and lagged dependent variables. (1996:3 to 1999:10)

	NOK/DEM	NOK/SEK	NOK/USD	NOK/GBP
Constant	-0.000694	-0.000147	0.002962	0.002752
	(-1.55)	(-0.26)	***(2.85)	***(4.52)
$\Delta(i_t - i_t^*)$	0.020084	0.011401	0.026670	0.002681
	***(18.19)	*(1.92)	***(11.95)	-0.99
ΔOil Spot	-0.000051	0.000592	-0.001902	-0.000223
	(-0.10)	(0.83)	(-1.47)	(-0.18)
ΔFor. Spot trading	0.000167	0.000184	0.000184	0.000421
	*(1.66)	*(1.76)	(1.17)	***(4.05)
ΔNor. Spot trading	0.000136	0.000157	0.000045	0.000155
	**(2.50)	**(2.40)	(0.45)	*(1.94)
Δlog(NOK/rate(-1))	-0.106689	-0.230935	-0.336376	-0.155075
	(-1.19)	***(-3.06)	***(-5.37)	***(-4.99)
Adjusted R^2	0.30	0.15	0.20	0.08
Durbin-Watson stat	2.20	2.24	2.19	2.57

t-values are in parenthesis, and "***", "**" and "*" indicate the significance at the 1%, 5% and 10%-level, respectively. NOK/DEM and NOK/SEK are estimated by a TARCH(1,1), while NOK/USD and NOK/GBP are estimated by an ARCH(1).

Table 19: ARCH estimation of weekly change in log exchange rates on 3-month interest rates, spot flow variables, lagged flow and lagged dependent (1996:3 to 1999:10)

	NOK/DEM	NOK/SEK	NOK/USD	NOK/GBP
Constant	-0.000674	-0.000056	0.002928	0.002316
	(-1.44)	(-0.10)	***(2.79)	***(3.11)
$\Delta(i_t - i_t^*)$	0.020368	0.011049	0.026781	0.001945
	***(18.17)	*(1.80)	***(11.19)	(0.68)
ΔOil Spot	-0.000116	0.000966	-0.001654	0.000302
	(-0.21)	(1.31)	(-1.26)	(0.25)
ΔFor. Spot trading	0.000139	0.000352	0.000320	0.000555
	(1.09)	***(3.00)	*(1.75)	***(4.45)
ΔNor. Spot trading	0.000132	0.000204	0.000121	0.000164
	*(1.85)	***(3.10)	(0.97)	*(1.75)
ΔFor. Spot trading(-1)	-0.000041	0.000229	0.000145	0.000212
	(-0.31)	*(1.74)	(0.87)	(1.60)
ΔNor. Spot trading(-1)	-0.000012	0.000100	0.000105	0.000023
	(-0.15)	(1.22)	(1.05)	(0.33)
Δlog(NOK/rate(-1))	-0.105274	-0.233716	-0.350992	-0.140574
	(-1.13)	***(-3.00)	***(-5.52)	***(-4.08)
Adjusted R^2	0.25	0.11	0.16	0.01
Durbin-Watson stat	2.20	2.22	2.14	2.57

Table 20: Model I: Two stage system ARCH estimation of weekly change in log exchange rates on 3-month interest rates and flow variables. (1996:3 to 1999:10)

	NOK/DEM	NOK/SEK	NOK/USD	NOK/GBP
Constant	-0.000619	0.000748	0.002649	0.001881
	(-1.65)	(0.77)	***(3.13)	***(2.66)
$\Delta(i_t - i_t^*)$	0.021504	0.011002	0.016578	0.013579
	***(3.19)	***(5.51)	***(6.29)	***(4.95)
ΔOil Spot	-0.000475	0.001306	-0.001305	0.001279
	(-0.86)	(0.86)	(-1.02)	(1.24)
$\widehat{\text{For.Spot}}$ – For. Spot(-1)	0.000285	0.000426	-0.000138	-0.000060
	**(2.30)	*(1.74)	(-0.50)	(-0.27)
$\widehat{\text{Nor.Spot}}$ – Nor. Spot(-1)	0.000231	0.000384	-0.000225	0.000287
	***(3.09)	**(2.41)	(-1.15)	*(1.89)
$\widehat{\text{CBSpot}}$ – CB Spot(-1)	0.000541	0.001166	0.001153	0.000809
	*(1.95)	**(2.13)	***(4.22)	*(1.93)
$\widehat{\text{For.Forward}}$ – For Forward(-1)	0.000082	0.000163	-0.000283	-0.000391
	(0.83)	(0.88)	(-1.38)	***(-2.65)
$\widehat{\text{Nor.Forward}}$ – Nor. Forward(-1)	0.000026	0.000433	0.000248	0.000803
	(0.27)	*(1.97)	(1.00)	***(3.97)
AR(1)			-0.269775	-0.304329
			***(-2.79)	***(-5.07)
Adjusted R^2	0.27	0.19	0.12	0.11
Durbin-Watson stat	2.35	2.02	2.27	2.32

t-values are in parenthesis, and "***", "**" and "*" indicate the significance at the 1%, 5% and 10%-level, respectively. NOK/DEM and NOK/USD are estimated with a GARCH(1,1) procedure. NOK/SEK is estimated by an ARCH(1), while NOK/GBP is estimated by an EGARCH(1,0).

Table 21: Model I: Two-step ARCH estimation of weekly change in log exchange rates on 3-month interest rates, flow variables and variance of future price. (1996:3 to 1999:10)

	NOK/DEM
Constant	-0.000549
	(-1.65)
$\Delta(i_t - i_t^*)$	0.021924
	***(3.46)
ΔOil Spot	-0.000337
	(-0.56)
ΔFor. Spot	0.000339
	***(3.16)
ΔNor. Spot	0.000215
	***(3.38)
$\left(\widehat{\text{NOKDEM}} - \text{NOKDEM}\right)^2_{t+1}$ ΔFor. Spot	-0.000002
	(-1.28)
$\left(\widehat{\text{NOKDEM}} - \text{NOKDEM}\right)^2_{t+1}$ ΔNor. Spot	-0.000001
	(-1.07)
Adjusted R^2	0.27
Durbin-Watson stat	2.34

t-values are in parenthesis, and "***", "**" and "*" indicate the significance at the 1%, 5% and 10%-level, respectively. Estimated with an GARCH(1,1) procedure.

B Model solution

Each dealer chooses quotes and trading strategy by maximizing a negative exponential utility function defined over expected nominal terminal wealth.[22] 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:

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

subject to

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

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:

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

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:

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

[22] 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.

B.1 Equilibrium prices

Equilibrium prices are given by

$$P_{1,t} = P_{3,t-1} + r_t - \pi x_{t-1} = P_{2t},\ \forall i \tag{B.4}$$
$$P_{i3t} = P_{2t} + \lambda x_t. \tag{B.5}$$

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:

$$E\left[c_{i1,t} + D_{i2,t}\left(P_{1,t}\right)|\Omega_{1,t}\right] = 0 \tag{B.6}$$
$$E\left[\sum_{i=1}^{N}\left[c_{i1,t} + D_{i2,t}\left(P_{2,t}\right)\right]|\Omega_{1,t}\right] = 0 \tag{B.7}$$
$$E\left[\sum_{i=1}^{N} c_{i1,t} + c_{3,t}\left(P_{3,t}\right)|\Omega_{3,t}^{P}\right] = 0. \tag{B.8}$$

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

$$c_{3t}\left(P_{3,t}\right) = -\sum_{i=1}^{N} c_{i1t}. \tag{B.9}$$

The conjectured trading strategy of dealers equal

$$T_{i2,t} = \alpha c_{i1,t}. \tag{B.10}$$

We can now write the sum on the right-hand-side of (B.9) in terms of observed interbank order flow:

$$x_t = \sum_{i}^{N} T_{i2,t} = \alpha \sum_{i}^{N} c_{i1,t}$$
$$\sum_{i}^{N} c_{i1,t} = \frac{1}{\alpha} x_t. \tag{B.11}$$

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

$$\Delta P_{3,t} = r_t + \pi x_{t-1} + \pi x_t + \rho x_t,\ \rho = 1/\gamma\alpha,\ \pi = \phi/\alpha. \tag{B.12}$$

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

$$T_{i2,t} = \alpha c_{i1t}. \tag{B.13}$$

The problem the dealers must solve is the following:

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

subject to

$$W_{i3,t} = W_{i0,t} + c_{i1t}\left(P_{i1t} - P_{i2t}'\right) + \left(D_{i2,t} + E\left[T_{i2,t}'|\Omega_{i2,t}^D\right]\right)\left(P_{i3t} - P_{i2t}\right) + T_{i2t}'\left(P_{i3t} - P_{i2t}\right).$$

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[23]

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

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

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

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

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

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

Hence, I can write the problem as

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

The first-order condition is

$$2\lambda D_{i2t}+c_{i1t}-\theta\sigma^2 D_{i2t}=0, \tag{B.14}$$

which implies a speculative demand of

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

Trading then becomes

$$T_{i2}=D_{i2t}+c_{i1t}=\left(\frac{1}{\theta\sigma^2-2\lambda}+1\right)c_{i1t}=\alpha c_{i1t}. \tag{B.15}$$

The second-order condition,

$$2\lambda-\theta\sigma^2<0\Rightarrow\theta\sigma^2-2\lambda>0, \tag{B.16}$$

ensures that $\alpha>1$.

C Time-varying risk premium parameter

The parameter I estimate on the flow variables equals

$$\lambda=\pi+\rho=\frac{1}{\alpha}\left(\phi+\frac{1}{\gamma}\right),$$

where $\pi=\phi/\alpha$ captures the updating of information while $\rho=(\alpha\gamma)^{-1}$ is the risk premium parameter. The α parameter is a constant in the dealers' trading strategy in round 2, and is given by

$$\alpha=\frac{1}{\theta\sigma^2-2\lambda}+1,$$

where θ is the coefficient of absolute risk aversion, and σ^2 is defined as $Var\left[P_{3,t}-P_{2,t}|\Omega_{i2,t}^D\right]$. The second-order condition for optimum ($2\lambda-\theta\sigma^2<0$) ensures $\alpha>1$, which also ensures that $\lambda>0$.

The parameter $\gamma=\left(\theta Var\left[P_{3,t+1}|\Omega_{3,t}^P\right]\right)^{-1}$ is a constant in the model. In the data, however, this variance may change with time. To find the effect on the risk premium from increased uncertainty about future prices, we total differentiate λ with respect to $\sigma_P^2:=Var\left[P_{3,t+1}|\Omega_{3,t}^P\right]$:

$$\frac{d\lambda}{d\sigma_P^2}=-\frac{1}{\alpha^2}\frac{\partial\alpha}{\partial\lambda}\frac{d\lambda}{d\sigma_P^2}\left(\phi+\frac{1}{\gamma}\right)+\frac{\theta}{\alpha}$$
$$\frac{d\lambda}{d\sigma_P^2}=-\frac{1}{\alpha^2}\left(\frac{2}{\left(\theta\sigma^2-2\lambda\right)^2}\right)\frac{d\lambda}{d\sigma_P^2}\left(\phi+\frac{1}{\gamma}\right)+\frac{\theta}{\alpha}$$

In the second line, I have inserted for $\partial\alpha/\partial\lambda$. Collecting terms and solving for $d\lambda/d\sigma_P^2$ yields

$$\frac{d\lambda}{d\sigma_P^2}\left[\frac{\alpha^2\left(\theta\sigma^2-2\lambda\right)^2+2\left(\phi+1/\gamma\right)}{\alpha^2\left(\theta\sigma^2-2\lambda\right)^2}\right]=\frac{\theta}{\alpha}$$
$$\frac{d\lambda}{d\sigma_P^2}=\frac{\alpha\theta\left(\theta\sigma^2-2\lambda\right)^2}{\alpha^2\left(\theta\sigma^2-2\lambda\right)^2+2\left(\phi+1/\gamma\right)}>0 \tag{C.1}$$

Similarly, the effect from changed risk aversion is given below.

$$\frac{d\lambda}{d\theta} = -\frac{1}{\alpha^2}\left(\frac{-\left(\sigma^2 - 2d\lambda/d\theta\right)}{\left(\theta\sigma^2 - 2\lambda\right)^2}\right)\left(\phi + \frac{1}{\gamma}\right) + \frac{\sigma_P^2}{\alpha}$$

$$\frac{d\lambda}{d\theta}\left[1 + \frac{2\left(\phi + 1/\gamma\right)}{\alpha^2\left(\theta\sigma^2 - 2\lambda\right)^2}\right] = \frac{1}{\alpha^2}\left(\frac{\sigma^2}{\left(\theta\sigma^2 - 2\lambda\right)^2}\right)\left(\phi + \frac{1}{\gamma}\right) + \frac{\sigma_P^2}{\alpha}$$

$$\Rightarrow \frac{d\lambda}{d\theta} > 0. \tag{C.2}$$

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