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Dealer Behavior and Trading Systems in Foreign Exchange Markets

by

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Dealer Behavior and Trading Systems in Foreign Exchange Markets*

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Abstract

We study dealer behavior in the foreign exchange spot market using a detailed data set on the complete transactions of four dealers. There is strong support for an information effect in incoming trades. Although there is evidence that the information effect increases with trade size in direct bilateral trades, the direction of a trade seems to be more important. The large share of electronically brokered trades is probably responsible for this finding. In direct trades it is the initiating dealer that determines trade size, while in broker trades it is the dealer submitting the limit order that determines the maximum trade size. We also find strong evidence of inventory control for all the four dealers. Inventory control is not, however, manifested through a dealer's own prices as suggested in inventory models. This is different from the strong price effect from inventory control found in previous work by Lyons [J. Fin. Econ 39(1995) 321]. A possible explanation for this finding is that the introduction of electronic brokers allowed more trading options. Furthermore, we document differences in trading styles among the four dealers, especially how they actually control their inventories.
Keywords: Foreign Exchange, Trading, Microstructure
JEL Classification: G15; F31; F33

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1 Introduction

Short-term exchange rate fluctuations are notoriously difficult to explain (see e.g. Frankel and Rose, 1995). After extensive research over many years few stones have been left unturned when it comes to investigating the short-term explanatory power of macroeconomic variables. The microstructure approach to foreign exchange takes a different route and studies the agents that actually set the exchange rate: the dealers. We study dealer behavior using a very detailed data set with the complete trading records of four interbank spot foreign exchange dealers during the week March 2–6 1998. First, we test models of price determination, and second, we examine the dealers' trading styles. Our data set contains all relevant information about each trade such as transaction time, transaction prices and quantities, inventories, trading system used, and who initiated the trade. Despite the size and importance of foreign exchange (FX) markets, there are virtually no empirical studies using transaction prices and dealer inventories. A notable exception, however, is the study by Lyons (1995) using a data set from 1992 on transaction prices and dealer inventories for one dealer covering a week in August 1992.[1]

Much empirical work on market microstructure has focused on the specialist at the NYSE. However, due to its decentralized multiple dealership structure and its low transparency, the FX market is very different from the specialist structure on the NYSE. Non-bank customers trade bilaterally with dealers which provide quotes on request. The interdealer market has a hybrid market structure with two different trading channels available: direct (bilateral) trades and two options for brokered trades (electronic brokers and the more traditional voice-brokers). The FX market is also special in the sense that trading is largely unregulated. This means that e.g. low transparency has evolved endogenously. Details about direct interdealer trades and customer trades (e.g. bid and ask quotes, the amount and direction of trade) are only observed by the two counterparties. Brokers are more transparent. Electronic brokers announce best bid and ask prices and the direction (not amount) of all trades (voice-brokers announce a subset). This information is, however, only available to the dealers. Electronic brokers have become very popular since their introduction in 1992 and are now the dominant tool for interdealer trading. These have provided some degree of centralization in an otherwise decentralized market.

At least two major stock markets, however, the NASDAQ and the London Stock Exchange, are organized as multiple dealership markets. Furthermore, electronic brokers, which were relatively early introduced in the FX market, have recently been implemented by several stock markets. There are also many similarities between FX and bond markets, e.g. the UK gilt market studied by Vitale (1998) and the 5-year Treasury note interdealer broker market studied by Huang, Cai, and Wang (2002). Hence, our results may apply more broadly than just to FX markets.

Our first contribution is to test the two main branches of microstructure models, inventory control and adverse selection. Inventory control models (e.g. Amihud and Mendelson, 1980; Ho and Stoll, 1981) focus on how risk-averse dealers adjust prices to control their inventory of an asset. The idea is that a dealer with a larger inventory of the currency than desired will set a lower price to attract buyers. This is called "quote shading." Information-based models (e.g. Kyle, 1985; Glosten and Milgrom, 1985; Admati and Pfleiderer, 1988) consider learning and adverse selection problems when some market participants have private information. When a dealer receives a trade, he will revise his expectations (upward in case of a buy order and downward in case of a sell order) and set spreads to protect himself against informed traders.

We use different methods to test the two main microstructure models. We start by testing whether dealer inventories are mean reverting. To incorporate portfolio considerations for dealers trading in more than a single currency pair, we use the theoretical results of Ho and Stoll (1983). We find strong evidence of mean reversion for all four dealers, which is consistent with inventory control. The median half-lives of the inventories range from less than a minute to fifteen minutes. We then use two well-known models to test for inventory and information effects on price. The first, the Madhavan and Smidt (1991) model, which is similar to the model used by Lyons (1995),

[1] Other studies that should be mentioned are Yao (1998a,b) and Mende and Menkhoff (2003).

receives no support. In addition we use the indicator model suggested by Huang and Stoll (1997). The current paper is, to the best of our knowledge, the first to apply this model to FX markets. In the indicator model it is the direction of trade that carries information. Using this model we find much better support and, in particular, we find that adverse selection is responsible for a large proportion of the effective spread. Interestingly, we find no evidence of inventory control through dealers' own prices as predicted by the inventory models. The importance of private information in FX markets is further confirmed since order flows and prices are cointegrated. Cointegration means that order flows have a permanent effect on prices. Lyons (1995) finds evidence of adverse selection and, in contrast to our study, strong evidence of an inventory effect through price.

Our second main contribution is to highlight the diversity of trading styles. In particular, we examine more closely how dealers use different trading options to control their inventories. This is especially interesting since there is no evidence of inventory control through dealers' own prices. To understand the lack of any price effect from inventory, it is important to remember the multiple dealer structure of the market. In a single dealer structure, like the one in the Madhavan and Smidt (1991) model, the dealer must wait for the next order to arrive. His only possibility for inventory adjustment is to shade his quotes. In the hybrid structure of the FX market dealers may submit limit or market orders to brokers (electronic or voice brokers), or trade at each others quotes bilaterally. We find differences in trading styles among our dealers. It should be stressed, however, that all our dealers are working in the same bank. Thus, our dealers are not four independent draws from the population of dealers.

The strong information effect and weak price effect from inventory is similar to evidence in Vitale (1998) for the UK gilt market and in several studies of stock markets, e.g. Madhavan and Smidt (1991, 1993) and Hasbrouck and Sofianos (1993). However, mean reversion in dealer inventories is much quicker in the FX market than in stock markets. The extremely short half-lives of a few minutes documented here confirm that inventory control is the name of the game in FX. The evidence found in this study of strong mean reversion in dealer inventories, but weak inventory effect through price, is consistent with the findings in Manaster and Mann (1996) for futures dealers.

Recent studies like Evans and Lyons (2002) have integrated insights from microstructure to address the inability of macro models to explain exchange rate changes at frequencies higher than a year. They demonstrate that daily aggregate order flow may improve explanatory power significantly. This is a promising direction for FX research. Dealer analysis is likely to prove useful in the future for formulating realistic micro foundations for this microstructure-macro framework. It is comforting that the results presented here are consistent with the informational approach Evans and Lyons assume at the market wide level. Dealer analysis also has a wider scope, however. For example our results about inventory control have implications for an understanding of the large trading volumes in FX markets.

The next section describes our data and some important market characteristics of relevance for our study. Section 3 provides an analysis of dealer inventories. Our investigation of price effects from information and inventories is presented in section 4. Section 5 examines how the dealers actually control their inventories using other alternatives than price shading. The paper ends with conclusions and some directions for future research.

2 Description of data and market

2.1 The structure of the FX market[2]

The FX market is by far the world largest financial market, with a daily transaction volume of USD 1,200 billion (BIS, 2002). The spot market is not largest in size but still regarded as the most

[2]See Rime (2003) for a more detailed account of FX market structure and trading systems.

important market with its daily transaction volume of roughly USD 400 million. Since 1992, when Lyons collected his data set, the market has gone through major structural changes.

As mentioned above, the FX market is organized as a decentralized multiple dealership market. In the most active currency pair, USD/EUR (DEM/USD before 1999), there are hundreds of active dealers located all over the world.[3] Dealers give quotes to customers on request through bilateral conversations. Access to customer orders is regarded as the most important source of private information. Customer orders may signal changed sentiment, interpretation of public news, and future risk premia (see Lyons, 2001, for discussion of private information in FX). In the interdealer market, dealers have access to two different trading channels. First, dealers can trade directly (bilaterally) with each other, usually over the electronic system Reuters D2000-1 (or less commonly by phone).[4] The initiator of the trade typically requests bid and ask quotes for a certain amount. If the conversation ends with a trade, it is executed at the bid or the ask (quotes are given on a take-it-or-leave-it basis, leaving no room for improvement). The second channel for trading is through brokers, which there are two different types of. Voice-brokers are the traditional brokers, and communication takes place through closed radio networks. Most popular today is the electronic broker systems Reuters D2000-2 and EBS. The dealers use brokers either to post limit orders or to trade at posted limit orders (market order). The different trading options let dealers manage their inventory positions in several ways. In addition to adjusting prices in incoming trades (market making), the dealers may trade at other dealers' quotes (outgoing trades). In an incoming trade, the price-setting dealer trades at the most favorable side of the bid or ask. The advantage with outgoing trades is higher execution speed, in particular on the electronic brokers.

There are some noteworthy differences between the trading options. First, direct (or bilateral) trading is non-anonymous (the dealer sees the identity of the initiator), while in broker trades the identity of the counterpart is first revealed after the trade. Second, in direct trades the dealer gives quotes on request, and the initiator decides when to trade, the quantity traded and the direction of the trade. Limit orders are more flexible because the dealer decides when to post a limit order and the maximum quantity traded if the limit order is taken. Typically, in direct trades the dealer is expected to give two-way quotes, while in broker trades this is left to the dealer's discretion (i.e. he can decide direction as well). Third, dealers in the direct market are committed to providing quotes at which they are willing to trade, while participation in broker trading is voluntary. Fourth, transparency differs among the trading channels. As with customer trades, in a direct trade both prices and transaction volumes are kept secret by the two parties. A voice-broker announces the best bid and ask prices. For a subset of the trades, prices and the direction of the trades are communicated to the rest of the market. The electronic brokers announce bid and ask prices good for ten million euros (for EUR/USD) in addition to the best bid and ask prices and their respective quantities. Prices and directions for all trades are communicated to the rest of the market. Fifth, there are differences between voice-brokers and electronic brokers. In addition to the differences in transparency mentioned above, voice-brokers allow some communication between the dealers and the broker. For instance, the broker may search for and negotiate with potential buyers and sellers. The automatic matching on electronic brokers typically makes execution quicker than for voice-brokers.[5]

Since electronic brokers were introduced in 1992, their market share has increased rapidly. According to several surveys, the interdealer market was split evenly between direct trading and voice-broker trading in 1992 (see Cheung and Chinn, 2001; Cheung and Wong, 2000; Cheung, Chinn, and Marsh, 2000). In 1998 the market share of the voice-brokers had declined to roughly 15 percent, while the market share of direct trading had declined to roughly 35 percent. The remaining 50 percent represents the market share of electronic brokers. According to practitioners,

[3]We will use the following ISO codes for currencies: USD is US dollar, EUR is euro, DEM is Deutsche mark, NOK is Norwegian kroner, SEK is Swedish krona, DKK is Danish kroner, and CHF is Swiss franc.

[4]D2000-1 allows dealers to request or handle quotes with four different counterparts simultaneously. Moreover, the computerized documentation reduces the paperwork required by the dealers. These advantages explain why almost all direct interdealer trades are executed using D2000-1 and not by phone or telex as used to be the case.

[5]Voice-brokers' ability to search for counterparties may be important in less liquid instruments, e.g. options.

the market share of electronic broker trading has continued to increase. This suggests that the electronic brokers facilitate risk sharing in a way that was not previously available. Furthermore, since pre- and post-trade transparency is higher for electronic brokers than for voice-brokers and direct trades in particular, there is now more price and order flow information available. This increased transparency is, however, only relevant for the interdealer market. Non-bank customers do not have access to this information.[6] Note also that the increased transparency is chosen by the dealers themselves since they decide which trading system to use.

2.2 Description of the data set

The data set includes transaction prices, quantities and dealer inventories for four spot dealers working in a large Scandinavian bank for the period 2–6 March 1998.[7] The advantages of such a data set over other foreign exchange data alternatives (mostly indicative quotes), are that transaction prices better reflect market activity, and for a thorough analysis of dealer behavior one needs inventory observations (Lyons, 1995). Compared with new data sets with transaction prices from electronic trading systems, e.g. Payne (2003) (D2000-2) and Evans (2002) (D2000-1), our data set has the advantage that it includes dealer inventories and reflects the dealers' choice between different trading systems. Thus, our data allows a direct test of inventory models and the investigation of trading strategies.

The data set was constructed by matching two sources: (i) the dealers' records from an internal system used for controlling inventory positions, and (ii) information from electronic trading systems on their electronic trading. The first part of the data set contains all trades, including direct trades, trades with electronic brokers, trades with voice-brokers, internal trades and customer trades. From this component we are able to calculate dealers' inventory positions. There is information on transaction time, price, volume, counterpart and which currency the dealer bought and which he sold. Trades executed by electronic systems are electronically entered into the record. Other trades are entered manually.

The second component of the data set provides detailed information on trades executed on electronic systems: Reuters D2000-1, Reuters D2000-2 and EBS. The Reuters D2000-1 system provides the following information: (i) The time the communication is initiated and ended (to the second); (ii) the name of the counterpart; (iii) who is initiating the trade; (iv) the quantity requested; (v) the bid and ask quotes (may also be only bid or only ask); and if the conversation results in a trade, (vi) the quantity traded; and (vii) the transaction price. Trades executed by electronic broker systems (D2000-2 and EBS) provide the same information as the D2000-1 records, with the exception that only the transaction price, and not the bid-ask spread, can be observed.

2.3 Descriptive statistics

Table 1 reports statistics on the four dealers' trading activity measured in USD. Dealers 1, 3 and 4 trade in more than a single currency pair. The remaining dealer, Dealer 2, trades only in DEM/USD. Dealer 1 is the largest dealer in the NOK/DEM market, and can be labelled the "NOK/DEM Market Maker" in our sample. He estimates his market share at roughly 40 percent. The total trading volume amounts to USD 1,081, with a daily average of USD 216 million. The majority of his trading is in NOK/DEM. Nevertheless, more than 30 percent of his overall trading is in other currency pairs. Dealer 2 can be labelled the "DEM/USD Market Maker". His total transaction volume over the week is USD 2,214 million, which gives a daily average of USD 443 million. Compared with the daily trading volume in DEM/USD of USD 150 billion (BIS, 1999) this figure is small. Nevertheless, among the hundreds of dealers in the DEM/USD market he describes himself as a medium-sized market maker. The total transaction volume of Dealer 3 is USD

[6] Customers' ability to see tight spreads from the interdealer market may have increased as Reuters have started selling quotes from D2000-2.

[7] We use the term dealers for both market makers and position-taking traders.

777 million with a daily average of USD 155 million. The majority is in DEM/USD with some trading in European currency pairs. Due to his active use of electronic brokers we label him the "Nintendo dealer". Dealer 4's total transaction volume is USD 1,106 million, which gives a daily average of USD 221 million. Most important is trading in DEM/USD. Trading in SEK/DEM, for which she makes markets, is also important. She is therefore labelled the "SEK & USD Dealer".

Table 1: Dealers' trading volumes. March 2–6 1998

Volume numbers are in USD million. "Share of volume in currency pair" measures the percentage of overall volume that takes place in the currency pair.

	Dealer 1	Dealer 2	Dealer 3	Dealer 4
Volume (in USD m.)	1,081	2,214	777	1,106
No. of transactions	529	992	514	724
% of volume in currency pair:				
DEM/USD	3.7	100.0	91.6	65.0
NOK/DEM	68.6	0.0	0.2	9.1
SEK/DEM	0.7	0.0	0.0	19.7
NOK/USD	8.4	0.0	0.0	0.0
DKK/DEM	17.9	0.0	0.0	0.0
CHF/DEM	0.0	0.0	6.2	0.0
Other	0.6	0.0	2.0	6.2

Table 2 presents some statistics about the different types of trades. We focus on the most important currency pair for each dealer, i.e. NOK/DEM for Dealer 1, and on DEM/USD trades for Dealer 2 to Dealer 4. Volume is in DEM for dealer 1, and in USD for the three other dealers. Statistics on the dealers are presented in four panels, *a-d*.

All dealers have some direct trading, but it is primarily the two market makers (Dealer 1 and 2) that trade directly, and particularly Dealer 1. All the direct trading of Dealer 1 and 2 is incoming, meaning they act as typical market makers, giving prices on request. Since they have no outgoing direct trades, this means that they have to adjust prices or use brokers to adjust their inventories after incoming direct trades.

Dealer 3 and 4 rely almost exclusively on electronic broker systems when trading DEM/USD. Electronic broker systems are also important for the other two dealers, in particular for Dealer 2.[8] Voice brokers are only used sparingly by the two market makers, Dealers 1 and 2.

The two market makers (Dealer 1 and 2) trade with non-bank customers. This is most important for the NOK/DEM Market Maker (Dealer 1) who has roughly 18 percent of his trading in NOK/DEM with customers. His trading in other currency pairs is also mainly customer-driven. Dealers 3 and 4 also have some customer trading, but not in DEM/USD. In fact, most of their trading in other currency pairs is direct or customer driven.

All dealers have some internal trades, for example trading with other spot dealers or with option dealers within the bank. Internal trades may be used to adjust inventories. Instead of trading in the market, they can trade with another dealer in the same bank.

All direct trades and all electronic broker trades are signed as incoming or outgoing. The market maker style of Dealer 1 is confirmed by a low share of outgoing trades, only 22 percent. The market maker label of Dealer 2 is a bit misleading. Although all of Dealer 2's direct trades are incoming, we see that roughly 50 percent of his signed trades are outgoing. Dealer 3 has more outgoing than incoming trades (57 percent are outgoing), while for Dealer 4 the share of outgoing trades is 33 percent.

Table 2 shows that there are differences among our dealers. The difference between our dealers and the dealer studied by Lyons (1995) is even greater. Of his total trading activity during a week in August 1992, 66.7 percent was direct while the remaining 33.3 percent was with traditional

[8] Dealer 1 execute almost all his electronic broker trades by D2000-2 because there is no active trading in NOK/DEM at EBS.

Table 2: Dealers' transaction types. March 2–6 1998

The table lists different types of trades during the sample period, March 2–6 1998. If possible, the trades are separated into incoming or outgoing. Almost all direct trading is done through Reuters D2000-1, and all of the direct trades are incoming trades. Electronic broker trades are done through Reuters D2000-2 or EBS. Volume numbers are measured in DEM for Dealer 1 and in USD for Dealer 2–4.

Panel *a*	Direct	Electronic brokers		Voice		Internal	
Dealer 1	incoming	Incoming	Outgoing	broker	Customer	trades	Total
No. of trades	93	59	48	16	50	26	292
– % total	31.8	20.2	16.4	5.5	17.1	8.9	100
Volume	341	223	196	114	246	228	1348
– % total	25.3	16.5	14.5	8.5	18.3	16.9	100
Average size	3.7	3.8	4.1	7.1	4.9	8.8	
Median size	0.7	3.0	3.0	5.0	3.0	5.0	
St.dev.	6.1	3.1	3.1	3.2	7.7	13.6	
Min.	0.0	1.0	1.0	4.0	0.0	0.1	
Max	40.0	20.0	14.0	15.0	50.0	65.0	

Panel *b*	Direct	Electronic brokers		Voice		Internal	
Dealer 2	incoming	Incoming	Outgoing	broker	Customer	trades	Total
No. of trades	79	359	453	57	23	21	992
– % total	8.0	36.2	45.7	5.7	2.3	2.1	100
Volume	130	659	1053	242	72	59	2214
– % total	5.9	29.8	47.6	10.9	3.2	2.7	100
Average size	1.6	1.8	2.5	4.2	3.1	2.8	
Median size	1.0	1.0	2.0	5.0	1.0	2.5	
St.dev.	1.7	1.2	1.5	2.0	4.2	3.0	
Min.	0.3	1.0	1.0	1.5	0.1	0.1	
Max	10.0	10.0	9.0	10.0	15.0	10.5	

Panel *c*	Direct	Electronic brokers		Voice		Internal	
Dealer 3	incoming	Incoming	Outgoing	broker	Customer	trades	Total
No. of trades	5	186	256	0	0	5	452
– % total	1.1	0.412	56.6			1.1	100
Volume	5	278	422			7	712
– % total	0.7	39.0	59.3			1.0	100
Average size	1.0	1.5	1.6			1.4	
Median size	1.0	1.0	1.0			1.0	
St.dev.	0.4	0.7	0.9			1.1	
Min.	0.5	1.0	1.0			0.1	
Max	1.5	3.0	5.0			3.0	

Panel *d*	Direct	Electronic brokers		Voice		Internal	
Dealer 4	incoming	Incoming	Outgoing	broker	Customer	trades	Total
No. of trades	1	278	144	0	0	4	427
– % total	0.2	65.1	33.7			1.0	100
Volume	1	423	293			2	719
– % total	0.1	58.8	40.8			0.3	100
Average size		1.5	2.0			0.5	
Median size		1	2.0			0.5	
St.dev.		0.8	1.2			0.5	
Min.		1.0	1.0			0.1	
Max		5.0	8.0			1.0	

voice brokers.[9] Roughly 90 percent of his direct trades were incoming. Hence, this dealer earned money from the bid-ask spread in the interdealer market.[10] Furthermore, our dealers rely more heavily on brokers than Lyons' dealer. This reflects differences in trading styles, which may partly be explained by changes in the market environment. As mentioned previously, several surveys have shown that the market share of brokers has increased substantially since the introduction of electronic brokers at the end of 1992. Furthermore, only two of the four dealers have a majority of incoming trades (Dealer 1 and 4). Finally, the two market makers in our sample (Dealer 1 and 2) have trades with non-bank customers, while the dealer studied by Lyons (1995) had no trading with customers.

3 Mean reversion in dealer inventories

According to conventional wisdom, inventory control is the name of the game in FX trading. Fig. 1 communicates this very clearly. The figure presents inventory positions measured in USD for the three DEM/USD dealers and in DEM for the NOK/DEM Market Maker (Dealer 1). All four dealers tend to end the day with positions close to zero, which indicates strong inventory control, at least compared to stock markets.

Going home with a zero position is of course a sign of inventory control, but does not say much about the intensity of intra-day inventory control. This can be investigated more thoroughly. Inventory models suggest that dealer inventories are mean-reverting. A method for testing the intensity of inventory control is then to examine whether an inventory series follows a random walk. Consider a simple model of inventory time series:

$$\Delta I_{it} = \alpha + \beta I_{it-1} + \varepsilon_t, \tag{1}$$

where ΔI_{it} is the change in inventory from the previous trade, incoming or outgoing. Inventory is a random walk if $\beta = 0$, while mean reversion predicts that $\beta < 0$.

Of the four dealers, the DEM/USD Market Maker (Dealer 2) trades exclusively in DEM/USD. For this dealer, I_t corresponds to his (ordinary) DEM/USD inventory. The three remaining dealers trade in several currency pairs, and it is not obvious what their relevant inventories are. Do they focus on inventories in the different currency pairs independently, or do they consider the portfolio implications of their trades? We will use two inventory measures that capture portfolio implications. The first measure is the so called equivalent inventory introduced by Ho and Stoll (1983). We follow the approach suggested by Naik and Yadav (2003). The equivalent inventory ($EI^j_{m,t}$) of Dealer m in currency pair j at time t is calculated as follows:

$$EI^j_{m,t} = OI^j_{m,t} + \sum_{k \neq j} \beta_{j,k} OI^k_{m,t} \tag{2}$$

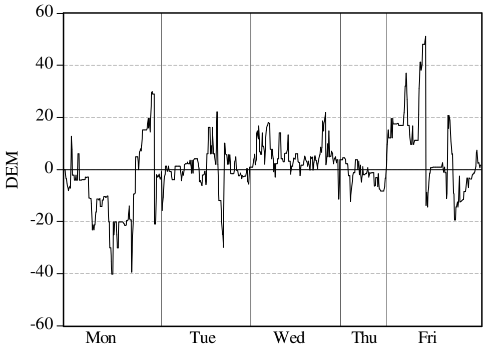
where $OI^j_{m,t}$ is the ordinary inventory of Dealer m in currency pair j at time t, which is simply the inventory from trades in a particular currency pair (e.g. DEM/USD). $\beta_{j,k}$ is the slope of the regression line capturing the dependence of return of currency pair k and the return of currency pair j $\left(Cov\left[R_j, R_k\right] / Var\left[R_j\right]\right)$. $\beta_{j,k}$ is calculated for all currency pairs ($k \neq j$) using daily exchange rates from Datastream (close) over a two-year period prior to the start of our sample. When calculating covariances and variances, we measure all returns from the viewpoint of a Norwegian FX dealer, that is, for all currency pairs we calculate returns in NOK. Similarly, all ordinary inventories are calculated in NOK.[11] When calculating equivalent inventories, we exclude β's that are not significantly different from zero at the five percent level (see Naik and Yadav, 2001).

[9] In August 1992 the electronic brokers had not yet gained popularity.

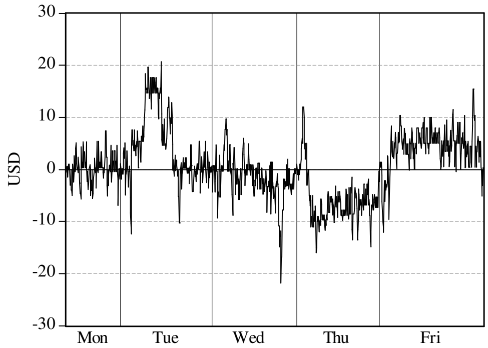
[10] We have no information on whether the voice-broker trades were incoming or outgoing.

[11] We use the last available transaction price to calculate inventories in NOK.

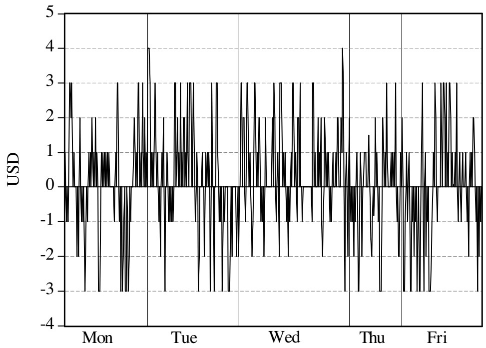
Figure 1: Dealer Inventory



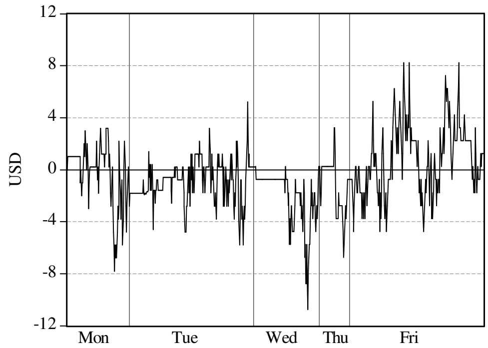
(a) Dealer 1: NOK/DEM Market Maker



(b) Dealer 2: DEM/USD Market Maker



(c) Dealer 3: Nintendo dealer



(d) Dealer 4: USD & SEK Dealer

The evolution of dealers' inventories over the week. Inventory is measured in DEM for Dealer 1, and in USD for the other dealers. The horizontal axis is in"transaction" time. Vertical lines indicate end of day.

A second measure that to some extent captures portfolio considerations is what we call ”the most risky part of inventory”. Instead of calculating the inventory from e.g. DEM/USD exclusively, we focus on the most risky part of the inventory. For a Norwegian DEM/USD dealer this will be the USD inventory. It is easy to find examples where this inventory measure will not capture portfolio considerations properly. Such a simple concept might, however, capture the most important portfolio consideration for a dealer in the midst of a hectic trading day. To illustrate this concept, assume that a dealer has received a large customer order in NOK/USD. Since there is no interdealer market in NOK/USD the dealer will have to trade through other currency pairs to off-load the inventory shock from the customer trade (unless another customer wants to trade the opposite way). Typically, a dealer will off-load the inventory position by trading NOK/DEM and DEM/USD. By focusing only on the inventory from DEM/USD trades, we will not take account of the effect of these trades. Focusing on the USD inventory will capture this effect.

Table 3 presents the results on mean reversion for the three different measures of I_{it} for the four dealers individually and at the desk level.[12] The null hypothesis of a unit root is rejected at the 1 percent level by the Phillips-Perron test (Perron, 1988) in all cases except one, in which the null hypothesis is rejected at the 10 percent level. For the individual dealers, the mean reversion parameter (β) varies between -0.11 and -0.81. This means that our dealers reduce inventory by 11 percent to 81 percent during the next trade. Hence, mean reversion in inventories is very strong. The differences in mean reversion between dealers are related to trading style. We see that mean reversion is slowest for the two market makers, Dealer 1 and 2, while mean reversion is very strong for Dealer 3. The implied half-life is calculated from β and the mean or median inter-transaction time. When median inter-transaction times are used, half-lives vary between 0.7 minutes (42sec) for Dealer 3 and 17.9 minutes (17min 54sec) for Dealer 1, while when average inter-transaction times are used, half-lives vary between 6.5 minutes (6min 30sec) for Dealer 3 and 49.3 minutes (49min 18sec) for Dealer 1. The short half-lives of Dealer 3 reflect his usage of the electronic brokers as Nintendo game machines. Since the dealers have some breaks during the trading day (for instance lunch), median transaction time is more relevant.

For the three dealers trading in more than a single currency pair, we see that the mean reversion coefficient tends to be somewhat higher for the “equivalent inventory” and the “most risky inventory” than the “ordinary inventory”. Mean reversion is strong for all three inventory measures, however. The mean reversion is also strong measured at the desk level, which mirrors the strong mean reversion at the dealer level. This indicates that the dealers do their own inventory control. Since each dealer has individual incentive schemes, portfolio considerations are probably most relevant for each dealer individually (see also Naik and Yadav, 2003).

Since the mean reversion coefficient tends to be slightly higher for ”the most risky part of inventory” than for “equivalent inventories”, and in particular “ordinary inventories”, we use this inventory measure in the tests presented in the following sections. Using one of the other measures does not, however, change any of the results significantly.

Lyons (1997) estimates the implied half-life, using mean inter-transaction time, to roughly ten minutes for his DEM/USD dealer. Using transaction data from Chicago Mercantile Exchange, Manaster and Mann (1996) find evidence of inventory control which is similar to our findings. Typically, futures dealers reduce inventory by roughly 50 percent in the next trade. Results from stock markets are much weaker. Hasbrouck and Sofianos (1993) examine inventory autocorrelations for 144 NYSE stocks, and find that inventory adjustment takes place very slowly. Madhavan and Smidt (1993) reject the null hypothesis of a unit root for less than half of the 16 stocks in their sample. Hence, specialist inventories exhibit slow mean reversion. They estimate the half-life to 49 days. This suggests that the inventory effect is weak. After controlling for shifts in desired inventories, the half-life falls to 7 days. However, this estimate is also much slower than what we observe for our dealers. Naik and Yadav (2001) find that the half-life of inventories varies between two and four days for dealers at the London Stock Exchange.

[12] Desk level is the aggregate inventory of all the four dealers. See Table 15 in the appendix for descriptive statistics.

Table 3: Mean reversion in inventories

$$\Delta I_{it} = \alpha + \beta I_{it-1} + \varepsilon_t,$$

The dependent variable is the change in dealer inventories from the previous trade in Norwegian kroner (incoming or outgoing). The explanatory variable is lagged inventory. "Ordinary inventory" is measured from trades only in DEM/USD (or NOK/DEM). "Most risky" is the USD inventory for DEM/USD dealers and DEM inventory for the NOK/DEM dealer. "Equivalent inventory" is calculated for NOK/DEM activity for Dealer 1 and for DEM/USD activity for the other dealers. Desk level refers to the inventory that includes the aggregate inventory of the four dealers. β is the mean reversion coefficient. The test statistic is from a Phillips-Perron test (Perron, 1988) unit root test. The Phillips-Perron test incorporates the Newey and West (1987) modification procedure with lags calculated from the sample size (Newey-West automatic truncation lag selection). ***, ** and * indicates that the null hypothesis of one unit root can be rejected at the 1, 5 and 10 percent levels respectively. Half-lives are calculated as mean or median inter-transaction time multiplied by ln(2)/ln(1-β).

	β	Test statistic	Half-life (Mean)	Half-life (Median)	Obs.
(*a*) Dealer 1 (NOK/DEM):					
Ordinary inventory	-0.12	***(-4.06)	49.3 min.	17.9 min.	287
Most risky	-0.18	***(-5.16)	33.9 min.	12.3 min.	
Equivalent inventory	-0.15	***(-4.61)	40.8 min.	14.8 min.	
(*b*) Dealer 2 (DEM/USD):					
Ordinary inventory	-0.11	***(-6.39)	15.8 min.	3.7 min.	987
(*c*) Dealer 3 (DEM/USD):					
Ordinary inventory	-0.75	***(-17.11)	7.0 min.	0.7 min.	447
Most risky	-0.81	***(-17.91)	6.5 min.	0.7 min.	
Equivalent inventory	-0.80	***(-17.79)	6.7 min.	0.7 min.	
(*d*) Dealer 4 (DEM/USD):					
Ordinary inventory	-0.21	***(-6.80)	19.9 min.	1.7 min.	423
Most risky	-0.24	***(-7.47)	17.5 min.	1.5 min.	
Equivalent inventory	-0.24	***(-7.58)	17.2 min.	1.4 min.	
(*e*) DEM/USD desk:					
Ordinary inventory	-0.10	***(-8.76)	10.3 min.	2.9 min.	1888
Most risky	-0.08	***(-7.21)	13.3 min.	3.8 min.	
Equivalent inventory	-0.09	***(-7.87)	12.0 min.	3.4 min.	
(*f*) NOK/DEM desk:					
Ordinary inventory	-0.04	*(-2.64)	92.2 min.	29.3 min.	433
Most risky	-0.19	***(-6.40)	22.0 min.	7.0 min.	
Equivalent inventory	-0.12	***(-4.72)	35.0 min.	11.1 min.	

4 Price impact from information and inventories

This section presents the empirical models for dealer behavior and the related empirical results. As mentioned earlier, theoretical models distinguish between problems of inventory management and adverse selection. In inventory-based models, risk averse dealers adjust prices to induce a trade in a certain direction. For instance, a dealer with a long position in USD may reduce his ask to induce a purchase of USD by his counterpart. Information-based models consider adverse selection problems when some dealers have private information. When a dealer receives a trade initiative, he will revise his expectation conditioned on whether the initiative ends with a "Buy" or a "Sell". For both main categories of models, buyer-initiated trades will push prices up, while seller-initiated trades will push prices down. Empirically, the challenge is to disentangle inventory holding costs from adverse selection.

Unfortunately, there is no theoretical model based on first principles that incorporates both effects. The two models considered here both postulate relationships to capture information and inventory effects. The model by Madhavan and Smidt (1991) (MS) is a natural starting point since this is the model estimated by Lyons (1995). The trading process considered in this model is very close to the one we find in a typical dealer market, for example the NYSE. The FX dealer studied by Lyons (1995) was a typical interdealer market maker. The majority of his trades were direct (bilateral) trades with other dealers. Also, in the majority of trades he gave bid and ask prices to other dealers on request (i.e. most trades were incoming). Hence, the trading process was very similar to that described in the MS model. We will argue that the introduction of electronic brokers, and heterogeneity of trading styles, makes the MS model less suitable for analyzing the FX market.

The second model is the generalized indicator model by Huang and Stoll (1997) (HS). This model is less structural than the MS model, but also less restrictive and may be less dependent on the specific trading mechanism. It may also be more suitable for the informational environment in FX markets.

4.1 The Madhavan and Smidt (1991) model (MS)

The MS model is structural in the sense that the equations are consistent with optimizing models, have an explicit informational setting, and expectations are formed by Bayes rule. There are two key equations. The first, the pricing equation, is consistent with inventory models. The price set by Dealer i (P_{it}) is linearly related to the dealer's conditional expectation about the true value (μ_{it}), and current inventory measured at the beginning of the period (I_{it}):

$$P_{it} = \mu_{it} - \alpha\left(I_{it} - I_i^*\right) + \gamma D_t, \tag{3}$$

where I_i^* is Dealer i's desired inventory position. The inventory response effect (α) is negative to capture "quote shading". The D_t term is a direction dummy that takes the value 1 if Dealer i sells (trades at the ask) and -1 if Dealer i buys (trades at the bid). One may think of γD_t as covering order processing costs, such as labor and equipment costs, and rents.

The second key equation is the demand $\left(Q_{jt}\right)$ of the informed Dealer j, who has exponential utility over terminal wealth. The demand equation enables the market maker to extract information from Dealer j's trade using Bayes rule, hence private information effects enter through the conditional expectation term μ_{it} in Eq. (3).

Dealer i's price schedule is a function of his conditional expectation (μ_{it}) at the time of quoting. The expectation is based on a public signal (prior belief), and the noisy signal on Dealer j's information that he can extract from Dealer j's trading behavior. Dealer i will set the price such that it is ex post regret-free after observing the trade Q_{jt}. Regret-free, in the sense of Glosten and Milgrom (1985), means that if the contacting dealer buys, the bid price reflects the expectation conditional on a buy.

After inserting for conditional expectation and unobservable priors the empirical model is as follows:[13]

$$\Delta P_{it} = \underbrace{\left(\frac{\alpha}{\phi} - \alpha\right) I_i^*}_{\beta_0 \approx 0} + \underbrace{\left(\frac{1-\phi}{\phi\theta}\right)}_{\beta_1 > 0} Q_{jt} - \underbrace{\left(\frac{\alpha}{\phi}\right)}_{\beta_2 < 0} I_{it} + \underbrace{\alpha}_{\beta_3 > 0} I_{it-1} + \underbrace{\left(\frac{\gamma}{\phi}\right)}_{\beta_4 > 0} D_t \underbrace{-\gamma}_{\beta_5 < 0} D_{t-1} + \varepsilon_{it}. \quad (4)$$

where ΔP_{it} is the price change between two incoming trades. The coefficients β_1 and β_3 measure the information effect and inventory effect, respectively, while β_5 measures order processing costs and rents. The parameter ϕ is a function of the weight on prior belief in the conditional expectation, and measures how much Dealer i emphasizes the information contained in a trade. If ϕ is low, i.e. low weight on prior belief, this means that the information in a trade is important when updating expectations. The parameter θ is a constant from Dealer j's demand. The regression constant β_0 is close to zero if the desired inventory I_i^* is close to zero. The model predicts that: $\{\beta_1, \beta_3, \beta_4\} > 0$; $\{\beta_2, \beta_5\} < 0$; $|\beta_2| > \beta_3$; $\beta_4 > |\beta_5|$.

4.2 The Huang and Stoll (1997) model (HS)

In the MS model, information costs increase with trade size. Although not obvious, this can be a natural assumption in a typical dealer market with bilateral trades. In a limit order-based market, however, it is less clear that trade size will affect information costs. For instance, in these systems it is Dealer i (submitter of the limit order) that determines trade size. A large market order may thus be executed against several limit orders. The dealer submitting a limit order must still, however, consider the possibility that another dealer (or other dealers) trade at his quotes for informational reasons. Furthermore, on the electronic brokers, which represent the most transparent trading channel, only the direction of trade is observed.

In the baseline HS model, it is by assumption the direction and not the size of the trade that is important. Hence, in this model Q_{jt} equals D_t. On electronic brokers, trade sizes are standardized to integer millions. The two equations that give us the equivalent to Eq. (3) are the following:

$$P_{it} = M_{it} + \frac{S}{2} D_t + \eta_t, \quad (5)$$

$$M_t = \mu_{it} - \delta \frac{S}{2} I_{it}. \quad (6)$$

M_t is the quote midpoint, $S/2$ is the half-spread (constant),[14] η_t is error due to discreteness, inventory prior to trade, I_t, equals $-\sum_{\tau=0}^{t-1} D_\tau$ when trade size is equal to one, and δ is the proportion of the half-spread attributable to quote shading due to inventory control. μ_{it} is again the expected value of currency value.[15] These two equations give a pricing rule very similar to (3), with price equal to expectation and a correction for inventory control. Desired inventory is implicitly set equal to zero.

The expectation is modelled according to

$$\mu_{it} = \mu_{it-1} + \lambda \frac{S}{2} D_{t-1} + \varepsilon_t, \quad (7)$$

where λ is the percentage of the half-spread attributable to updating beliefs conditioned on a signal in the direction of previous trade, and ε_t is the serially uncorrelated public information

[13] We refer the reader to Madhavan and Smidt (1991) or Lyons (1995) for derivations.

[14] The constant spread assumption is less restrictive in FX markets than it may be perceived to be. When the European market is open, which is the most liquid period, spreads on the electronic brokers are more or less constant up 10 millions.

[15] Huang and Stoll (1997) refer to μ_{it} as the unobservable fundamental value in the absence of transaction cost. We choose to interpret it similarly to the conditional expectation in the MS model.

shock. This equation is the equivalent of the explicit modelling of informed dealer's demand and the Bayesian expectation formation in MS.

Using equations (5)-(7), with $-\sum_{\tau=0}^{t-1} D_\tau$ inserted for I_{it}, yields the basic regression model in HS:

$$\Delta P_t = \frac{S}{2}(D_t - D_{t-1}) + (\lambda + \delta)\frac{S}{2} D_{t-1} + e_t, \tag{8}$$

where ΔP is the change in price between two incoming trades. Huang and Stoll show that this model generalizes other indicator models.

On the basis of Eq. (8), we cannot separate adverse selection and inventory costs. Huang and Stoll suggest several ways to do this. Here we use information based on observed inventory, which is among Huang and Stoll's suggestions (p. 1028). Since they do not have inventories they have to use other methods. Since dealers trade with customers, on other dealers' quotes, and have internal (intra bank) trades, observed inventory will differ from $-\sum_{\tau=0}^{t-1} D_\tau$ so we will not have a collinearity problem. When using observed inventory I_{it} instead, as suggested in Eq. (6), we obtain:

$$\Delta P_t = \frac{S}{2}(D_t - D_{t-1}) + \lambda\frac{S}{2} D_{t-1} - \delta\frac{S}{2}\Delta I_t + e_t' \tag{9}$$

An alternative to using the change in inventory is to use an indicator variable taking the value $+1$ if the change in inventory is positive and -1 if the change is negative. Then the degree of bid shading will not depend on the exact size of the inventory, but rather on the sign.

4.3 Empirical results

Table 4 presents the results for the MS model. In the regressions, we include all incoming inter-dealer trades.[16] The results of Lyons (1995) are reported for comparison. We have omitted the overnight price changes since it is the intra day pricing decision the model is intended to explain. The model is estimated by the Generalized Method of Moments (GMM) of Hansen (1982), with the Newey and West (1987) correction of the covariance matrix for heteroscedasticity and autocorrelation of unknown form.[17]

The model receives very little support for our data set. The "+" and "-" in parentheses in the first column indicate the expected sign of the coefficient. The only variables that are correctly signed and significant are the coefficients on D_t, and D_{t-1} (for Dealer 1). There is no evidence that the effective spread increase when volume (Q_{jt}) increases. Similarly, there is no evidence that dealers control inventory by adjusting their quotes.

This is in contrast to the results of Lyons, where all coefficients have the expected signs and are significantly different from zero. From the coefficient on D_t, the estimated baseline spread is 2.1 pips (2×1.04). The dealer widens his spread by 2.8 pips $(2 \times 0.14 \times 10)$ per USD ten million to protect against adverse selection. Furthermore, the dealer tends to motivate inventory decumulation by shading the price by 0.8 pips (10×0.078) for every USD ten million of net open position.

Apparently there is no information effect for our dealers. A possible explanation is that it is trade direction, and not size, that is informative, as argued above. When we investigate the coefficients closer this becomes clearer. Notice that the absolute value of the coefficients on D_t are much larger and those on D_{t-1} are much lower for the DEM/USD dealers than for the Lyons' dealer. From Eq. (4) we see that the coefficient on D_t is inversely related to the weight on prior information. When we back out this weight for Dealer 1 and 2, the dealers with correct signs for

[16]See Table 16 in the appendix for descriptive statistics.

[17]We choose GMM because (i) it does not require the usual normality assumption, and because (ii) standard errors can be adjusted to take account of both heteroscedasticity and serial correlation. In all of the regressions, the set of instruments equals the set of regressors. In this case, the parameter estimates parallel OLS parameter estimates. We have also estimated the model with the Hildreth-Lu procedure, as Lyons did, which is a linear estimation procedure for autoregressive error terms, and with MA error terms (results not shown here). Whether we use GMM, Hildreth-Lu or MA does not affect any of our results significantly.

Table 4: Results for the MS model, Eq. (4). Regression of ΔP_{it} between incoming trades

$$\Delta P_{it} = \beta_0 + \beta_1 Q_{jt} + \beta_2 I_{it} + \beta_3 I_{it-1} + \beta_4 D_t + \beta_5 D_{t-1} + \varepsilon_{it}.$$

The coefficients are estimated by GMM and variable Newey-West correction. t-values in parenthesis, and ***, ** and * indicate significance at the 1 percent, 5 percent and 10 percent levels, respectively. All coefficients are multiplied by 10^4. "Lyons DEM/USD" is from Lyons' (1995). The dependent variable, ΔP_{it}, is the change in price between two incoming trades. Q_{jt} is signed incoming trade measured in millions, positive for a purchase from Dealer j, and negative for a sale. I_{it} is inventory at the beginning of period t. D_t is an indicator variable picking up the direction of the trade, positive for purchases (at the ask) from Dealer j and negative for sales (at the bid). The "+" and "-" in parentheses in the first column indicate the expected sign of the coefficient. We use all incoming trades at the D2000-1 (direct trading), D2000-2 and EBS (indirect trading). Observations where the inter-transaction time is larger than 45 minutes have been deleted for Dealer 2, 3 and 4.

	NOK/DEM	DEM/USD			
	Dealer 1	Dealer 2	Dealer 3	Dealer 4	Lyons
Constant	1.28	0.01	0.17	0.08	-0.13
	(1.15)	(0.04)	(0.32)	(0.17)	(-0.99)
Trade (+)	0.14	-0.19	-2.24	0.08	0.14
(Q_{jt})	(0.52)	(-0.77)	**(-2.26)	(0.20)	***(3.03)
Inventory (-)	-0.11	-0.02	1.42	0.16	-0.10
(I_t)	(-0.78)	(-0.13)	**(2.37)	(0.42)	***(-3.56)
Inventory (+)	-0.01	0.06	-0.63	-0.37	0.08
(I_{t-1})	(-0.09)	(0.47)	(-0.80)	(-0.81)	***(2.95)
Direction (+)	6.54	1.77	4.25	2.17	1.04
(D_t)	***(4.91)	***(3.12)	***(2.76)	**(2.28)	***(4.86)
Direction (-)	-2.95	-0.40	0.06	0.25	-0.92
(D_{t-1})	*(-1.90)	(-1.20)	(0.05)	(0.26)	***(-6.28)
Adj. R^2	0.17	0.03	0.05	0.09	0.22
Observations	144	430	169	263	838

lagged direction, we get weights for trade information equal to 0.8 and 0.55 respectively. This may suggest that the direction variables pick up an information effect. We therefore proceed with estimation of the HS indicator model in Eq. (8). The results are presented in Table 5.

In contrast to the results for the MS model, we see that both coefficients are significantly different from zero and have the expected signs. The implied constant effective spread for DEM/USD ranges from 2.9 pips (Dealer 2) to 4.9 pips (Dealer 3) $(2 \times 1.45$ and $2 \times 2.45)$. Pooling all incoming trades, the estimated effective spread is 3.2 pips. By way of comparison, Goodhart, Love, Payne, and Rime (2002) find that the average difference between best bid and ask quotes on D2000-2 was 2.8 pips in 1997. Given that we estimate effective and not quoted spread, 3.2 pips is very close to where the market was trading at the time.

The proportion of the effective spread that is explained by adverse selection or inventory holding costs is remarkably similar for the three DEM/USD dealers. It ranges from 76 percent (Dealer 2) to 82 percent (Dealer 4). Using all incoming trades, we find that 78 percent of the effective spread is explained by adverse selection or inventory holding costs. Compared to stock markets, this number is high. For instance, Huang and Stoll (1997), using exactly the same regression, find that only 11 percent of the spread is explained by adverse selection or inventory holding costs for stocks traded at NYSE. For FX markets, however, this number is reasonable. Payne (2003) finds that 60 percent of the spread in DEM/USD can be explained by adverse selection using D2000-2 data.

For NOK/DEM we find a half-spread of roughly 7 pips, which corresponds to an effective spread of 14 pips. By way of comparison, the average quoted spread in direct trades for Dealer 1 was 15 pips. This is equivalent to a basis point spread of 0.034 percent. As expected, the basis point spread is higher than that for DEM/USD, which is approximately half the size (0.017 percent). Of the entire spread of 14 pips, roughly 50 percent can be attributed to adverse selection or inventory holding costs. The fact that a lower share is attributable to information or inventory, i.e. a higher share is attributable to the fixed part, can be related to (i) rents since the NOK/DEM

Table 5: Results for the HS model, Eq. (8). Regression of ΔP_{it} between incoming trades

$$\Delta P_t = \frac{S}{2}(D_t - D_{t-1}) + (\lambda + \delta)\frac{S}{2}D_{t-1} + e_t$$

The coefficients are estimated by GMM and variable Newey-West correction. t-values are in parenthesis, and ***, ** and * indicate significance at the 1 percent, 5 percent and 10 percent levels, respectively. $(S/2)$, the half-spread, is multiplied by 10^4. The dependent variable, ΔP_{it}, is the change in price between two incoming trades. We use all incoming trades at the D2000-1 (direct trading), D2000-2 and EBS (indirect trading). Adj. R^2 is from the same regression including a constant. Observations where the inter-transaction time is larger than 45 minutes have been deleted for Dealer 2, 3 and 4.

	NOK/DEM		DEM/USD				
	All	Dealer 1	All	Dealer 2	Dealer 3	Dealer 4	Lyons
Half-spread	7.14	6.57	1.58	1.45	2.45	2.21	1.74
$(S/2)$	***(6.16)	***(5.21)	***(7.57)	***(3.95)	***(3.22)	***(4.95)	***(13.11)
Info. and inv.	0.49	0.50	0.78	0.76	0.81	0.82	0.49
$(\lambda + \delta)$	***(3.78)	***(2.61)	***(7.35)	***(3.24)	***(3.78)	***(4.14)	***(5.54)
Adj. R^2	0.25	0.18	0.09	0.03	0.04	0.09	0.18
Obs.	187	144	914	430	169	263	838

market is less competitive,[18] and (ii) the fact that the fixed costs are split over fewer trades.

Next, we try to determine how much of the spread that is explained by adverse selection, and how much that is explained by inventory holding costs. Table 6 shows the regression results for equation (9).[19] We find no evidence of inventory holding costs. The spread can thus be separated into two parts: order processing costs/rents and adverse selection costs. The information component for the NOK/DEM Market Maker (Dealer 1) is approximately 50 percent. For the DEM/USD dealers we see that for Dealer 2 the information part is 72 percent of the spread. The figures for Dealer 3 and 4 are larger than 1 but not significantly different from e.g. 0.8.

Table 6: Results for the indicator model, Eq. (9). Regression of ΔP_{it} between incoming trades. Components of the spread

$$\Delta P_t = \frac{S}{2}(D_t - D_{t-1}) + \lambda \frac{S}{2} D_{t-1} - \delta \frac{S}{2} \Delta I_t + e_t'$$

The coefficients are estimated by GMM and variable Newey-West correction. t-values in parenthesis, and ***, ** and * indicate significance at the 1 percent, 5 percent and 10 percent levels, respectively. $(S/2)$ is multiplied by 10^4. Inventory is divided by the median trade size in incoming inter-dealer trades. The dependent variable is ΔP_{it}, and is the change in price between two incoming trades. We use all incoming trades at the D2000-1, D2000-2 and EBS. Adj. R^2 is from the same regression including a constant. Observations where the inter-transaction time is larger than 45 minutes have been deleted for Dealer 2, Dealer 3 and Dealer 4.

	NOK/DEM	DEM/USD			
	Dealer 1	Dealer 2	Dealer 3	Dealer 4	Lyons
Half-spread	6.56	1.46	1.84	2.06	1.43
$(S/2)$	***(5.28)	***(3.78)	**(2.17)	***(4.79)	***(11.55)
Information	0.49	0.72	1.24	1.00	0.43
(λ)	**(2.34)	***(3.28)	**(2.53)	**(2.28)	***(4.66)
Inventory	0.00	0.00	-0.43	-0.13	0.21
(δ)	(0.11)	(-0.40)	(-1.06)	(-0.63)	***(3.31)
Adj. R^2	0.17	0.03	0.04	0.09	0.20
Obs.	144	430	169	263	838

Finally, we consider whether there are any differences in order processing costs or adverse selection costs in direct and indirect trades, and if inter-transaction time matters. These tests are implemented with indicator variables in the HS model. The results are summarized in Table 7. We find no significant differences between direct and indirect trades, in contrast to Reiss and Werner (2002) who find that adverse selection is stronger in the direct market at the London Stock Exchange. As regards intertransaction time, Lyons (1996) finds that trades are informative when intertransaction time is high, but not when the intertransaction time is short (less than a minute). We define short inter-transaction time as less than a minute for DEM/USD and less than five minutes for NOK/DEM. It turns out that the effective spread is larger when inter-transaction time is long, while the proportion of the spread that can be attributed to private information (or inventory holding costs) is similar whether the inter-transaction time is long or short. This means that private information is more informative when inter-transaction time is long. This finding can be consistent with the model by Admati and Pfleiderer (1988) where order flow is less informative when trading intensity is high due to bunching of discretionary liquidity trades.

Further confirmation of the information effect from order flow to price can be established by means of cointegration. Cointegration is predicted in several microstructure models with Bayesian learning, e.g. Glosten and Milgrom (1985), Kyle (1985) and Back (1992). To see this, we abstract from inventory considerations, as in the models mentioned. At time t the dealer give quotes equal to his conditional expectation, which is a weighted average of his prior and the current order flow (signal). This conditional expectation will then become the prior belief at time

[18]Dealer 1 has a market share of about 40 percent.

[19]We also run a similar regression with a dummy variable instead of changes in inventory. The dummy takes the value $+1$ if $(-\Delta I)$ is positive and -1 if $(-\Delta I)$ is negative. In this case, the degree of quote shading would not depend on the size of inventory changes. The results are similar to those presented in Table 6.

Table 7: Results for the indicator model with different dummies for different trading systems and different inter-transaction time ,respectively

The regressions are estimated by GMM and variable Newey-West correction. The HS model is estimated with indicator variables for (1) direct or indirect trading on electronic brokers and (2) short or long inter-transaction time. Inter-transaction time is short when the time between two incoming orders are less than one minute for DEM/USD, and less than five minutes for NOK/DEM. Spread is the fixed spread estimated by the model, while Info is the share of the spread that is explained by private information (or inventory costs, however, other regressions suggest that inventory has no effect on dealers own prices). We report the F-value and the corresponding p-value from the Wald test that the coefficients are similar. If the coefficients are significantly different, (<) (or >) indicates whether e.g. spread is larger (smaller) when inter-transaction time is long. We use all incoming trades at the D2000-1 (direct trading), D2000-2 and EBS (indirect trading).

	NOK/DEM		DEM/USD	
	Spread	Info	Spread	Info
Direct=Electronic broker	0.05	0.82	0.17	0.04
p-value	0.81	0.37	0.68	0.84
Short=Long intertrans. time	(<) 3.85	0.15	(<) 5.20	0.38
p-value	0.05	0.69	0.02	0.54

$t+1$. So when he gives quotes, order flows from all previous periods are part of his prior belief, while the order flow in the current period will be his current signal.

In Table 8 we report results from the Johansen procedure. Since the most important source of order flow information is the direction indicator on electronic brokers we use the cumulative flow of directions.

Table 8: Cointegration of price and cumulative order flow

The coefficients are estimated using the Johansen procedure. Cumulative flow is created using the direction of all the trades (D2000-1, D2000-2 and EBS). "Flow coeff." reports the coefficient on cumulative flow in the cointegrating vector, and is multiplied by 10^4. "ECM coeff." is the error-correction coefficient in the VeqM. The last line reports the trace statistic for unique cointegrating vector, and ***, ** and * indicate significance at the 1 percent, 5 percent and 10 percent levels, respectively. The VAR includes one lag, which is determined using the Aikake and Schwartz information criterion. Removing the lag does not change any of the results. The cointegrating vector includes a constant and a trend in the NOK/DEM equation, and a constant in the DEM/USD equation.

	NOK/DEM	DEM/USD
Flow coeff.	4.41	1.01
	(3.48)	(7.16)
ECM coeff	-0.09	-0.01
	(-3.87)	(-2.17)
Half-life (min.)	19.53	29.20
Unique coint vector	*22.76	***22.36
Observations	321	2079

The flow is aggregated over all the trades that our dealers participate in on the electronic trading systems. The sign of a trade is given by the action of the initiator, irrespective of whether it was one of our dealers or a counterparty who initiated the trade. The flow coefficients are significant and have the expected sign. A larger positive cumulative flow of USD purchases appreciates the USD, i.e. depreciates the DEM. The coefficient is 4.41 for NOK/DEM and 1.01 for DEM/USD, meaning that an additional purchase of DEM with NOK will increase the NOK price of DEM by approximately 4.4 pips. We can compare this with the results from the HS regressions (Table 5, all dealers). In the HS analysis we found a fixed half spreads of 7.14 and 1.6 pips, and information shares of 0.49 and 0.78 for NOK/DEM and DEM/USD respectively. The coefficients from the HS analysis that are comparable with the cointegration coefficients are 3.57 and 1.28. The cointegration coefficients on flow are very close to this, only slightly lower for DEM/USD and slightly higher for NOK/DEM. The higher effect from the HS analysis for DEM/USD may reflect that we use the coefficient for inventory and information combined in Table 5. If the information share from Table 6 for the DEM/USD Market Maker is used the comparable coefficient is 1.05. The slightly lower effect for NOK/DEM may reflect that we pick up effects from order flows that our dealers do not take part in, and that are correlated with this flow. Flows in the NOK/DEM market are more likely to be correlated than in the DEM/USD market due to the higher concentration. The error-correction coefficient (ECM) may pick up inventory shocks, which are temporary deviations from conditional expectation, and the bid-ask bounce.

Is cointegration a meaningful concept in intra-day analysis? First, theory suggests that the impact of order flow information on prices should be permanent. Second, as we see from Table 8, the half-lives of deviations from the cointegrating equation are quite short, 20 and 30 minutes for NOK/DEM and DEM/USD respectively, which implies that we see far more returns to equilibrium in our sample than one usually does in e.g. cointegration analysis on Purchasing Power Parity. Finally, cointegration between cumulative flow and the exchange rate is also documented in Killeen, Lyons, and Moore (2001) and Rime (2001).

Finally, we turn to analyzing the direct trades alone. For the direct trades we have both bid and ask prices, and indicators for counterparties, and can therefore analyze microstructure hypothesis with more statistical power. In Table 9 we regress the quoted spread variables that microstructure theories predict should influence the spread. Easley and O'Hara (1987) suggest that spreads should widen with size to deter informed dealers, while some inventory models suggest that spreads should widen with inventory to cover the risk in taking on extra inventory. First, the constant parts of the spreads are 1.7 and 9–10 pips for DEM/USD and NOK/DEM respectively.

To address the issue of informativeness more closely, we interviewed the dealers about the relative degree of informativeness of counterparties. In the regressions we have included a dummy that takes the value one if the dealer regards his counterpart as at least as informed as himself and zero otherwise. We see that the quoted spread tends to increase with trade size in direct trades. There is also some evidence that Dealer 1 makes an extra adjustment in trades with better informed dealers. For the DEM/USD dealer, however, we find no evidence of any extra adjustment when trading with better informed dealers. The lack of spread adjustment when trading with better informed banks may be due to the norms of the market. Furthermore, there is no inventory impact for the DEM/USD market maker (Dealer 2), while the NOK/DEM market maker (Dealer 1) adjusts the width of his spread to account for his inventory. Dealer 1 is in a less liquid market, and it therefore makes sense to adjust spreads for inventory.

Table 9: Regression of observed spread from D2000-1 trades on absolute quantity traded and absolute inventory

The coefficients are estimated by ordinary least square. t-values are in parenthesis, and ***, ** and * indicate significance at the 1 percent, 5 percent and 10 percent levels, respectively. $Abs(Q_{jt})$ is the trade (absolute) quantity measured in millions. $Abs(I_{it})$ is the absolute value of inventory before quoting. Informed is a dummy that takes the value one if the dealer regards his counterpart as at least as informed as himself. The dependent variable is the observed spread in pips (multiplied by 10^4).

	NOK/DEM		DEM/USD	
	Dealer 1		Dealer 2	
Constant	9.180	9.597	1.739	1.706
	***(10.32)	***(9.73)	***(16.02)	***(14.46)
Informed		-0.979		0.115
(dummy d_{jt})		(-0.57)		(0.43)
Abs. trade	1.504	1.153	0.139	0.179
($\|Q_{jt}\|$)	***(11.50)	***(5.06)	***(3.95)	***(2.89)
Informed trade		0.532		-0.068
($d_{jt} \times \|Q_{jt}\|$)		*(1.77)		(-0.79)
Abs. inventory	0.182	0.163	0.002	-0.000
($\|I_{it}\|$)	**(2.32)	**(2.08)	(0.13)	(-0.01)
Adj. R^2	0.72	0.72	0.20	0.17
Observations	61	61	62	62

In the MS and HS analysis we found no trace of inventory control through prices. The inventory impact on quotes for the NOK/DEM Market Maker in Table 9 may, however, be result of quote shading. If he is long (wish to induce a sale, trade at the ask) he can lower his bid to make that side unattractive. In Table 10 we report the result of a probit-regression on direct trades. If there is quote shading then one would expect that trading at the ask is more likely when inventory prior to the current trade is positive, and at the bid if inventory was negative. In Table 10 we let the dependent variable equal 1 if there is trading at the ask and 0 if there is trading at the bid. We see that inventory from the trade prior to this has no impact in this regression, in contrast to quote shading and in line with our previous results.

Table 10: Probit-regression of quote shading in incoming direct trades

Probit regression of the choice of bid or ask quote. Transactions at the ask are 1, while transactions at the bid are 0. The explanatory variable is inventory prior to trading. z-values are in parentheses, and * indicates significance at the 10 percent level. R^2 is McFadden's analog to ordinary R^2 measures.

	NOK/DEM	DEM/USD
	Dealer 1	Dealer 2
Constant	-0.311	-0.045
	*(-1.96)	(-0.28)
Inventory (+)	-0.016	0.048
(I_{it})	(-1.08)	(1.38)
McFadden's R^2	0.01	0.02
Observations	67	62

5 Inventory control and profits

Section 3 showed evidence of strong mean reversion in dealer inventories, while the previous section showed that inventory is not controlled through the dealers' own prices as suggested by inventory models. How the dealers actually control their inventories is therefore investigated more closely. Subsection 5.1 presents some general observations on how our dealers control their inventories, while subsection 5.2 examines inventory control and dealer profits for different types of positions.

5.1 Some general observations on inventory control

Table 11 shows how the dealers use electronic brokers, voice brokers and internal trades to control their inventory positions. Trades that increase the absolute size of their inventory are accumulating, while trades that decrease the absolute size of their inventory are decumulating. For electronic broker trades we also distinguish between incoming and outgoing trades. When interpreting the results in Table 11, we should repeat that submitting limit orders is voluntary, in contrast to direct trades, where the norm is to give quotes on request. Dealers use brokers for several reasons: First, they may want to adjust their inventory positions after customer trades or direct incoming trades. Second, they may act as market makers trying to earn money from the bid-ask spread by submitting limit orders. Finally, they may use the electronic brokers for speculative purposes (i.e. to establish a position).

From Table 11 we see that there is no systematic pattern for the two market makers (Dealers 1 and 2). Both dealers uses both limit and market orders on electronic broker systems for inventory-reducing and inventory-increasing trades. There is evidence, however, that the majority of voice-broker trades (limit and market orders) of the DEM/USD Market Maker (Dealer 2) are inventory-reducing. For Dealer 3 and 4 a systematic pattern arises. Typically, most incoming trades (limit orders) on the electronic broker systems are inventory-reducing, while most outgoing trades (market orders) are inventory-increasing. In both cases the difference between decumulating and accumulating trades is highly significant. A difference between Dealer 3 and 4 is that the majority of Dealer 4's trades are incoming (66 percent of trades are incoming, while 42

Table 11: Accumulating and decumulating trades

Trades that increase the absolute size of the inventory are accumulating, while trades that decrease the absolute size of the inventory are decumulating. Voice-broker trades or internal trades are not signed. P-values are based on the binomial distribution.

	Electronic broker		Voice-	Internal
	Incoming	Outgoing	broker	trades
Dealer 1:				
Decumulating trades	24	22	9	12
Accumulating trades	35	26	7	8
Test (p-value)	0.19	0.67	0.80	0.50
Dealer 2:				
Decumulating trades	192	211	36	9
Accumulating trades	166	242	21	10
Test (p-value)	0.19	0.16	0.06	1.00
Dealer 3:				
Decumulating trades	138	95	0	4
Accumulating trades	48	160	0	1
Test (p-value)	0.00	0.00		0.38
Dealer 4:				
Decumulating trades	188	50	0	3
Accumulating trades	90	93	0	1
Test (p-value)	0.00	0.00		0.63

percent of Dealer 3's trades are incoming). We find no systematic pattern for the internal trades. The fact that there are few observations could, however, be part of the explanation.

Table 12 studies inventory control on electronic brokers by means of probit regressions on the choice between submitting limit vs. market orders. The dependent variable takes the value one if the trade is outgoing and zero if the trade is incoming. The explanatory variables are absolute trade size, absolute inventory (at the beginning of the period) and absolute inventory squared.

Table 12: Probit regression of incoming/outgoing trade

Probit regression of incoming/outgoing trade decision. Incoming trades are coded 0, while outgoing trades are coded 1. R^2 is McFadden's analog to ordinary R^2 measures.

	NOK/DEM	DEM/USD		
	Dealer 1	Dealer 2	Dealer 3	Dealer 4
Constant	-0.295	-0.183	0.462	-0.609
	(-1.17)	*(-1.69)	***(2.70)	***(-3.42)
Absolute trade size	0.014	0.153	0.189	0.347
$(\lvert Q_{jt} \rvert)$	(0.34)	***(4.71)	**(2.11)	***(5.17)
Absolute inventory	0.020	-0.014	-0.993	-0.271
$(\lvert I_{it} \rvert)$	(0.58)	(-0.44)	***(-5.29)	***(-2.85)
Inventory squared	-0.000	0.002	0.205	0.025
$\left(\lvert I_{it} \rvert^2\right)$	(-0.51)	(0.97)	***(3.17)	*(1.93)
McFadden's R^2	0.00	0.02	0.11	0.08
Observations	109	812	441	426

DEM/USD dealers tend to trade outgoing when trade size is large. When hitting other dealers' limit orders (outgoing trade), the dealer may have several counterparts. Execution is immediate, and we record this as a single order. On the other hand, when the dealer submits a limit order (incoming trade) the dealer may not be hit by another dealer for the entire order.[20] This difference

[20]If the entire order is not fulfilled, the dealer may choose to withdraw the rest of his limit order.

may explain the significant coefficient on absolute trade size. The negative and significant coefficient on inventory for Dealer 3 and 4 is consistent with the findings in Table 12. These dealers control their inventory by submitting limit orders. For the same two dealers we find a positive and significant coefficient on squared inventory. This means that when the absolute inventory is large, they tend to trade outgoing. Mean reversion of inventories is also strongest for these two dealers. For the NOK/DEM Market Maker (Dealer 1) we find no significant coefficients.

5.2 Different types of positions and inventory control

In this subsection we distinguish between different types of trades. We group trades according to whether the dealer has a active or passive role in the trade. Liquidity provision in direct trades or to customers are passive trades because the dealer can only influence the prices he quotes, while all trades on brokers are active trades because he can also decide on the timing.[21] This enables us to measure profit from different types of trades and to say more about inventory control conditional on the type of trade. It is also of interest just to test whether these dealers are making money. Dealers that consistently lose money are less likely to be representative of the market. In the literature, different methods are suggested for measuring profitability (e.g. Hasbrouck and Sofianos, 1993; Lyons, 1997; Harris and Schultz, 1998). All the different alternatives have, however, shortcomings when applied to our dealers.

To identify different positions, we focus on the currency pair in which the specific dealer does most of his trading. Direct incoming trades (i.e. direct liquidity-providing trades) and customer trades can easily be identified by our data. Using this information, profits from traditional market making to other dealers and customers can be calculated by using a benchmark. As a benchmark we use the first trade after the D2000-1 trade or customer trade which is not a D2000-1 or a customer trade. By using this trade as a benchmark, the inter-transaction time between the benchmark trade and the direct trade or customer trade will usually be short. The suggested benchmark will also tell us something about how dealers control their inventories after direct trades or customer trades. The benchmark trade will usually be inventory-reducing and can be incoming or outgoing. We did not construct a "neutral" benchmark as an average between bid and ask prices for the following two reasons: First, it is difficult to measure bid-ask spread at a single point in time, and second, and more important, is that the dealers probably decide how to control their inventory after a direct trade or customer trade when giving quotes.

In addition to direct trades and customer trades, dealers may establish positions through other types of trades. We call these trades accumulating active trades. These trades can be speculative, but need not be so. For instance, dealers may act as market makers by submitting limit orders to brokers. If the majority of these trades are outgoing it is, however, more likely that the trades are speculative. We identify accumulating active position taking as accumulating trades if they are not immediately followed by direct trades or customer trades of the opposite sign. The last condition was included since we sometimes see a position buildup prior to these trades (front-running). We use the first non-accumulating trade as a benchmark. By using the first non-accumulating trade our profit measure will, to some extent, take into account the time horizon of the position.

Table 13 presents the results for the direct trades and customer trades, while Table 14 shows the results for the accumulating active trades. Since the DEM/USD Market Maker (Dealer 2) trades only in DEM/USD, we get an indication of how well our separation of different types of trades works by comparing estimated and actual profit. By adding the estimated profits in the two tables, our estimated total profit is DEM 75,545. This is quite close to the actual profit of DEM 68,206. The actual (overall) profits for the remaining three dealers are DEM 229,471 (Dealer 1), DEM 54,482 (Dealer 3), and DEM 97,242 (Dealer 4). For comparison, total estimated profits for their most active currency pair are DEM 133,615 for Dealer 1 (68.6 percent of overall trading volume identified), DEM 40,600 for Dealer 3 (91.6 percent of total trading volume identified), and

[21] Placing a limit order with a broker would also be liquidity provision. The dealer is however more active in this trade since he can choose time and which side of the market.

DEM 30,000 for Dealer 4 (65 percent of overall trading volume identified). Since their share of customer trades is larger for the other currency pairs in which these dealers trade, and because customer trades on average are more profitable than other types of trades, we think our estimates are reasonable. It should also be noted that all of the dealers earn money on average.

Table 13: Direct incoming trades and customer trades. Profit and inventory
t-values are in parenthesis. ***, ** and * indicate significance at the 1 percent, 5 percent and 10 percent levels, respectively. To estimate profits from interdealer market making and customer trades, we use the next trade as a benchmark (not direct incoming trade or customer trades). No. of trades measures the number of trades where we can calculate profit (that is, where we have a benchmark).

	NOK/DEM (Dealer 1)		DEM/USD (Dealer 2)	
Direct trades:	Direct	Customer	Direct	Customer
Average size (per trade)	3.7	4.9	1.6	3.1
Median size (per trade)	0.6	3.0	1.0	1.0
Average profit (per million)	4.5	22.0	1.4	2.0
	***(3.18)	***(31.15)	***(2.91)	(1.00)
Median profit (per million)	5.0	20.0	1.0	2.0
% outgoing benchmark	52.9	38.0	42.3	40.0
No. of trades	87	49	78	20
Estimated profit (in DEM)	22,584	92,686	11,043	12,046
% of volume identified positions	43.3	31.7	11.1	6.5

The NOK/DEM Market Maker (Dealer 1) makes money on both direct incoming trades and customer trades. On average, he earns 4.5 pip per million on the direct incoming trades. This number is very close to what we would predict from the results in section 4. His customer trades are very profitable. Measured per million he earns 22 pip on average, which is roughly five times more than the average for the direct trades. We also note that a larger share of the benchmark trades are outgoing when he trades direct than when he trades with a customer. The estimated profits document that customer trades are highly profitable. Of his total activity in NOK/DEM, 43.3 percent is related to incoming direct trades, while 31.7 percent is related to customer trades. The DEM/USD Market Maker (Dealer 2) earns, on average, 1.4 pip per million in direct incoming trades. The median is 1 pip. This number is high compared with our results in section 4, although the majority of benchmark trades are incoming. The average profit on his customer trades is larger, 2 pip per million. Of the total positions of this dealer, 11.1 percent is related to incoming direct trades, while 6.5 percent is related to customer trades.

In Table 14 we see that all dealers make significant positive profits on their accumulating active trades. Dealer 1 earns on average 4.9 pip per million on his accumulating active trades. The size of a typical position is DEM 5 million. He makes positive profits in 76 percent of the positions. The majority of the accumulating active trades are incoming. The same is true of the benchmarks. Of his overall activity we see that 25 percent is related to accumulating active positions. Total profits from these positions in NOK/DEM is DEM 18,345, which is small compared with his profits from direct incoming trades and in particular customer trades.

For the DEM/USD dealers the typical size of a position is from USD one million to USD three million. On average they earn roughly one pip per million. The t-values are all significantly different from zero. We also see that the dealers make money in significantly more than 50 percent of the positions. Taking all positions with positive or negative profits, Dealer 2 is making positive profits in 67 percent of the cases. Dealer 4 earns money in 80 percent of the positions, while Dealer 3 earns money in 84 percent of the positions. Consistent with results in Table 11 we see that most of the accumulating active trades of Dealer 3 are outgoing, while the majority of the decumulating trades are incoming. For Dealer 4 we see that roughly 50 percent of the accumulating active trades are outgoing, while the majority of decumulating trades are incoming.

To sum up, we see that the two market makers execute all three types of trades in their most important currency pair (direct incoming trades, customer trades and accumulating active trades). All three types of activities are profitable. Most profitable are, however, customer trades.

Table 14: Accumulating active trades. Profit and inventory

t-values are in parenthesis. ***, ** and * indicate significance at the 1 percent, 5 percent and 10 percent levels, respectively. A trade is accumulating if the absolute inventory position in USD (DEM/USD dealers) or DEM (NOK/DEM dealer) increases. An accumulating active position is a sequence of trades that accumulate inventory and that are not immediately followed by a direct trade or customer trade. To estimate profits, we use the first non-accumulating trade as benchmark (not a D2000-1 or a customer trade). No. of accumulating active positions measures the number of sequences with accumulating active trades. Estimated profits is the sum of profits from all accumulating active trades.

	NOK/DEM	DEM/USD		
	Dealer 1	Dealer 2	Dealer 3	Dealer 4
Average size (per position)	6.59	3.35	1.81	2.57
Median size (per position)	5.00	3.00	1.00	2.00
Average profit (per million)	4.9	0.94	1.1	1.22
t-value	***(2.89)	**(2.45)	***(8.44)	**(2.09)
Median profit (per million)	5.0	1.0	1.0	1.5
% positive profits	76.0	66.8	83.9	79.9
p-value	***(0.00)	***(0.00)	***(0.00)	***(0.00)
% outgoing accumulating active trade	34.2	60.2	76.6	50.5
% outgoing benchmark trade	40.0	59.6	43.3	25.3
t-value (difference)	(-0.42)	(0.14)	***(7.20)	***(5.27)
No. of accumulating active positions	30	276	197	139
Estimated profits (in DEM)	18,345	52,456	40,600	30,000
% of volume identified positions	25.0	82.5	98.7	100

Almost all positions of Dealer 3 and 4 in their most important currency pair can be characterized as accumulating active positions. Moreover, their trading has a lot in common with the future dealers studied in Manaster and Mann (1996). Similar to the futures dealers, the inventories of Dealer 3 and 4 show strong mean reversion, while there is no sign of quote shading in incoming trades. Consistent with the findings of Manaster and Mann (1996), their execution price will be better when the absolute value of their inventory is high rather than low as predicted by inventory models. The reason is that they typically trade outgoing when increasing the absolute value of their inventories, while they trade incoming when reducing the absolute value of their inventories. As noted by Manaster and Mann (1996) with regard to futures dealers, the FX dealers are not merely passive order fillers, but are profit-seeking individuals with heterogeneous levels of information and/or trading skills.

6 Conclusions

This paper studies the behavior of four interbank spot foreign exchange dealers using a detailed data set for the week March 2–6 1998, with transaction prices, trading quantities, dealer inventories, exact timing, and information regarding the trading system used for the transactions. The four dealers trade in different exchange rates and have different trading styles. Using our data, we study whether dealers set prices to protect against private information and how they control inventory to adjust their risk exposure.

In a widely cited paper, Lyons (1995), using data from 1992, finds support for both information and inventory effects in the pricing of an FX dealer. Using a version of the Madhavan and Smidt model, Lyons finds, consistent with the model predictions, that the dealer increase his spread with trade size to protect against private information, and adjusts the midpoint in the spread (quote shading) to induce trade in a preferred direction to adjust inventory. Using the same model as Lyons for our dealers, we find no support for such information or inventory effects. Our results suggest that the Madhavan and Smidt model may not be as applicable to foreign exchange trading as first believed because of differences in trading styles among the dealers. A likely explanation is the change in the trading environment caused by the introduction of electronic brokers.

Using an indicator model (the Huang and Stoll model), we show that private information is indeed important in the FX market. For DEM/USD, we find that private information is responsible for as much as 80 percent of the effective spread in the interdealer market. For NOK/DEM, roughly 50 percent of the effective spread is explained by private information. Order flow as a carrier of information since cointegration analysis show that order flow has a permanent effect on prices.

Interestingly, we find strong evidence of mean reversion with half-lives of dealer inventories that range from less than a minute to fifteen minutes. Little of this is, however, manifested through dealers' own prices as predicted by the inventory models.

We show how the dealers control their inventories and how different types of positions contribute to their overall profitability. In doing this we distinguish between three types of trades. In general, dealers use the electronic brokers to unwind their positions using both limit and market orders. We find that customer trades are highly profitable. This business is particularly important for the NOK/DEM Market Maker in our sample. However, the dealers also earn money from their direct incoming trades and from actively establishing positions through electronic brokers. Active position taking seems to represent an important share of the trading for three of the dealers. The dealers provide liquidity by submitting limit orders on electronic broker systems, and may thus earn money from the bid-ask spread. Or they submit market orders to establish speculative positions. Hence, the dealers do not only use the interdealer market to off-load unwanted positions from their customer business. For two of the dealers, we find that the share of outgoing trades is higher when they establish a position than when they unwind the same position. This finding may suggests that these dealers submit market orders when they have information. This behavior also means that the dealers increase their absolute inventory position at worse prices (trade outgoing) than when they reduce their absolute inventory position (trade incoming). Similar evidence can be found in Manaster and Mann (1996) for futures dealers. Manaster and Mann (1996) conclude that dealers may have different levels of private information and/or trading skills. Hence, the effect of inventory on price need not be as predicted by standard market microstructure models where the dealer/market maker is assumed to have no private information when setting prices, while the initiator of the trade may have private information.

As mentioned, electronic brokering has become the dominant tool for interdealer trading since its introduction at the end of 1992. Interestingly, we do not find evidence that the price impact from direct trades is different from the price impact of electronic broker trades in contrast with the results of Reiss and Werner (2002) for the London Stock Exchange. This may suggest that (at least during the week we study) electronic brokers can provide enough liquidity. This is also supported by the fact that the market share of electronic brokers has continued to rise also after 1998 and has now (according to practitioners) a market share of roughly 85 percent of all interdealer trading.

What can we learn about FX trading from these four dealers? They are not dealers in one of the large US banks. However, the bank in question has a long history of FX trading and have been among top 15 banks in DEM/USD over a long period. In NOK/DEM they are probably the largest bank. The introduction of electronic brokers has also made tight spreads available to more than just the key dealers in the largest banks, thus making the terms between dealers in the market more equal. Furthermore, their trading strategy seems quite successful. The fact that we document differences in trading strategy, roughly the older market makers and the young electronic broker dealers, also means that we cover different aspects of FX trading even if the dealers are from the same bank.

Still, there is a great demand for more knowledge about the microstructure of the FX market due to the lack of dealer-specific trading data and inventories. This is especially true for the new trading environment resulting from the introduction of electronic broker systems. In this respect, this study fills a gap in the literature.

A Descriptive statistics

Table 15: Descriptive statistics on inventories

Ordinary inventory is measured from only trades in DEM/USD (or NOK/DEM). Most risky is USD inventory for DEM/USD dealers and DEM inventory for the NOK/DEM dealer. Desk level refers to the inventory at the desk level, that is, it includes the aggregate inventory of the four dealers.

		Ordinary Inventory	Most risky	Equiv. Inventory	Δt (min.)
	Average	27.65	5.32	1.38	8.11
Dealer 1	Median	34.57	7.96	-2.79	2.95
NOK/DEM	Max	286.81	212.39	247.61	80.20
	Min.	-149.34	-167.79	-175.39	0.00
	Std.dev.	68.77	56.46	62.29	11.71
	Average	2.42			2.38
Dealer 2	Median	1.38			0.55
DEM/USD	Max	156.59			62.57
	Min.	-164.82			0.00
	Std.dev.	45.64			5.32
	Average	3.26	1.15	1.52	5.66
Dealer 3	Median	0	0	0.19	0.58
DEM/USD	Max	30.45	30.24	30.43	64.95
	Min.	-22.77	-22.84	-22.8	0.00
	Std.dev.	10.84	10.42	10.49	11.49
	Average	-29.44	-4.18	-2.65	5.40
Dealer 4	Median	-28.94	-5.81	-3.73	0.45
DEM/USD	Max	32.08	62.77	64.35	371.05
	Min.	-111.83	-81.38	-70.13	0.00
	Std.dev.	23.18	21.43	21.26	28.12
	Average	0.48	-11.54	-11.44	1.46
Desk level	Median	-3.56	-13.98	-13.02	0.42
DEM/USD	Max	118.23	108.64	117.44	81.48
	Min.	-165.35	-188.52	-186.07	0.00
	Std.dev.	40.24	46.39	44.54	3.70
	Average	91.03	-10.42	40.46	5.52
Desk level	Median	107.68	-7.24	47.52	1.75
NOK/DEM	Max	414.36	282.89	300.64	80.20
	Min.	-152.33	-188.49	-137.82	0.00
	Std.dev.	98.97	63.84	63.81	9.37

Table 16: Descriptive statistics on regression variables: Sample moments for incoming trades

ΔP_{it} is the change in price between two incoming trades in pips (fourth decimal), and Abs(ΔP_{it}) is the absolute value of this change. Q_{jt} is the quantity transacted at Dealer i's quoted prices measured in millions (USD or DEM), positive for a purchase from Dealer j, and negative for a sale. Abs(Q_{jt}) is the absolute value of Q_{jt}. I_{it} is inventory at the end of period t, and Abs(I_{it}) is the absolute value of the inventory. Δt is inter-transaction time between two incoming trades in minutes. Sample: One week in March 1998.

		ΔP_{it}	Abs(ΔP_{it})	Q_{jt}	Abs(Q_{jt})	I_{it}	Abs(I_{it})	Δt
	Mean	0.4	12.1	-0.72	3.66	0.37	8.57	15.69
Dealer 1	Median	0.0	10.0	-0.27	2.00	1.76	5.26	7.64
NOK/	Max.	50.0	55.0	20.00	40.00	41.13	41.13	102.60
DEM	Min.	-55.0	0.0	-40.00	0.02	-35.17	0.15	0.02
	Std. Dev.	16.8	11.7	6.22	5.08	12.11	8.53	20.03
	Mean	0.1	4.5	0.25	1.80	0.20	4.18	5.22
Dealer 2	Median	0.0	3.0	1.00	1.00	0.18	3.55	2.33
DEM/	Max.	46.0	82.0	10.00	10.00	17.65	17.65	62.57
USD	Min.	-82.0	0.0	-5.00	0.25	-16.01	0.02	0.00
	Std.dev.	7.7	6.3	2.22	1.32	5.54	3.64	8.14
	Mean	-0.3	6.9	0.18	1.48	0.24	1.30	13.46
Dealer 3	Median	0.0	4.0	1.00	1.00	0.00	1.00	4.88
DEM/	Max.	51.0	51.0	3.00	3.00	4.00	4.00	69.75
USD	Min.	-50.0	0.0	-3.00	0.50	-3.00	0.00	0.02
	Std.dev.	11.0	8.6	1.64	0.71	1.64	1.02	17.47
	Mean	-0.1	4.5	-0.20	1.53	-0.71	2.41	7.34
Dealer 4	Median	-1.0	2.0	-1.00	1.00	-0.79	2.20	0.55
DEM/	Max.	40.0	41.0	5.00	5.00	8.24	10.76	373.42
USD	Min.	-41.0	0.0	-5.00	1.00	-10.76	0.00	0.00
	Std.dev.	8.0	6.7	1.73	0.83	2.92	1.79	30.71

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