Trading in Foreign Exchange Markets

Four Essays on the Microstructure of Foreign Exchange

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PREFACE

Writing this dissertations has been like a long journey. In the beginning everything was new and exciting, with plenty of paths to follow, all leading down to the Great Big Beach of Doctoral Courses. Down at the beach I met this really cool guy (Geir), and after a couple of beers and deciding on a topic, I felt like I was cruising in a red Ferrari on the Highway to Completion. However, that was only in my too optimistic mind. I soon realized that the car rental had tricked me, it wasn't a Ferrari at all, and I probably had been reading the road map upside down or something. Anyhow, there I was, feeling alone the Jungle of No Progress. Things were quite frustrating. I worked hard to try to find my way back to the Highway to Completion, but nothing seemed to work. And suddenly, when all hope seemed to be gone, three people came to my rescue. Ingrid told me how to use my resources so that I could get out of the Jungle of No Progress (taught me a lesson about working habits), while Steinar and Geir helped me finding the way out (Steinar gave me a kick in my butt, while providing both a carrot and valuable advice. Geir helped me decipher Steinar's advice, and supported me on my way back). And finally I was at the Highway to Completion. Not in a red Ferrari — many were driving much faster than me even when I stepped on it with both feet —, and the highway wasn't as straight and free of bumps as in my dreams — I was close to running off several times —, but I knew I was on right track and I smiled as drove into Completion City in the sunset.

My journey had its ups and downs, but I don't regret a moment and would have done it again if I got the opportunity. But I wouldnt have made it without the help of many people. This dissertation is dedicated to my wife Ingrid and my parents Randi and Finn. Ingrid taught me a few lessons about working habits (when to work, how to work, and when to not work), and supported me through periods of heavy working. Randi and Finn has always supported me, and encouraged me in my pursuit of a doctoral degree.

My supervisor Professor Steinar Holden has been the best supervisor imaginable. He has read background papers very thoroughly, and returned my papers with comments sometimes more detailed than I wanted He also pushed when I needed it. Geir Høidal Bjønnes has been a great co-author, and I look forward to doing more research with him. I would like to thank my co-advisor Professor Arne Jon Isachsen for introducing me to research, and helping me get going with my doctoral work. I thank all my colleagues at the Department of Economics, University of Oslo for their friendship and support. Special thanks go to Professors Karl Ove Moene, Tone Ognedal, Ragnar Nymoen and Asbjørn Rødseth. Thanks also to the doctoral students of the department, in particular Ylva Søvik, to the football players, and to the RØLPers. Finally I would like to thank all my friends for being there when I needed something completely different.

Special thanks goes to the people in DnB Markets for providing the data set used in essay 1 and 2. In particular Head of FX department Jørn Pedersen, Chief dealer Ole Christian Presterud, Per Schøne, Joseph O'Malley, Øyvind Berre, Hege Tomter and Erik Kongslie. Not only did we receive a unique data set, we have also learned a lot from the dealers through discussion and by sitting next to them during the week in question.

The thesis was written during my time at the Norwegian School of Management in 1996–97 and later at the Department of Economics at the University of Oslo. I thank both institutions for their financial support and for providing a stimulating research environment. My thanks also go to the Institute for International Economic Studies at Stockholm University for their hospitality during the spring of 1997 and autumn of 1998, and the Research Department of Norges Bank for their hospitality during the autumn of 1997.

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Oslo, June 2001
Dagfinn Rime

ABSTRACT

Introduction

This dissertation is a collection of four essays on the trading activities in the foreign exchange market. Trading has traditionally not been an issue in research on the foreign exchange market. This has changed during the last decade. In my dissertation the subject is approached from the theory of market microstructure. Market microstructure theory studies the consequences for financial markets of heterogeneous agents, private information, and different trading institutions.

I believe that a dissertation on this subject may be justified given (i) the importance of the foreign exchange market, (ii) the shortcomings of our understanding of the market, (iii) the evidence that important assumptions of earlier theories may be violated, and (iv) the promising results so far of this recent approach.

The essays in this dissertation divide naturally into two groups, with two essays in each. The first two essays address intraday dealer behavior in the interbank market. These two essays are written together with Geir Hoidal Bjonnes.

The last two essays address the effect of order flow on the aggregate market level. The essays use two publicly available data sets on weekly currency positions in Norway and the U.S.

Essays on Dealer Behavior

Essay 1: FX Trading . . . LIVE! Dealer Behavior and Trading Systems in Foreign Exchange Markets

The introduction of electronic broker systems in the foreign exchange (FX) market at the end of 1992 changed the structure of the market and opened new channels for trading. We study the impact of these systems on intraday dealer behavior, using a unique data set on the complete trading activities of four FX dealers during one week in March 1998. The essay also contains a detailed section describing the trading options open to dealers. The essay take the work of Lyons (1995), “Tests of Microstructural Hypothesis in the Foreign Exchange Market”, as a starting point. We conclude that the model that Lyons used do not fit our data, even after several adjustments.

We are then lead to investigate different parts of our detailed data set more closely. With observations on the spreads from direct bilateral trading (D2000-1 system), we can investigate directly the effects of larger trade size. We find that the size contributes significantly to a wider spread, indicating protection against private information on behalf of the price setter. We also find an information effect in tests of the baseline model of Lyons when we only include the direct trades. We therefore conclude that there is an information effect in the direct trades.

Dealers give a lot of attention to the flow of trading on the electronic brokers (D2000-2 and EBS systems). We find that the cumulative flow on the electronic brokers cointegrates with the exchange rate. This may be interpreted as an information effect from order flow, since the effect is permanent.

Inventory control is the name of the game in FX. However, the new electronic systems have changed how dealers control their inventories by introducing new channels for this purpose. We do not find any evidence that dealers control inventory through quote shading. However, we find that there is a high degree of mean reversion in inventories, indicating that the dealers actively control inventory.

Comparing our results to previous research indicates that the introduction of electronic brokers have changed the behavior of dealers.

Essay 2: Customer Trading and Information in Foreign Exchange Markets

Recent research point to the possible existence of private information in foreign exchange markets. Dealers claim that customer orders are their most important source of private information, and that banks with a large customer base have a competitive advantage.

We use the data from Paper 1 to study two issues regarding private information in FX markets not previously addressed in the literature. First, how trading with customers affect the Market Makers price setting and their order placement strategy. Second, whether the identity of the counterparty influences the Market Makers' price setting and order placement strategy. The idea being that some dealers may be better informed than others and that through experience, dealers learn which banks/dealers are informed and which are not.

We find that customer trades influence the trading decision. Neither customer trades nor counterparty identity affect pricing decisions. Dealers do not price discriminate between dealers, but they do price discriminate customers. Spreads to customer are wider than to other dealers, which is made possible because customers have no access to the interbank market.

Essays on aggregate order flows

Essay 3: Private or Public Information in Foreign Exchange Markets? An Empirical Analysis

In macroeconomic models exchange rates are determined by public information and trading activities are completely irrelevant for price determination. In general, these models have low explanatory power for short horizons, which might be due to the possible existence of private information.

The model I test in this essay is a simple extension of the model of Evans and Lyons (1999), "Order Flow and Exchange Rate Dynamics". The model includes both macroeconomic variables and trading flow, where the trading flow may reflect private information. The model is tested for the NOK/DEM, NOK/SEK, NOK/USD and NOK/GBP exchange rates, with Norwegian banks' weekly trading with Norges Bank, foreigners and Norwegian customers as a measure of trading flow.

I find that the order flow contributes significantly to exchange rate changes, and have a permanent effect on exchange rates. When foreigners or customers buy currency, the Norwegian krone depreciates. In some cases the order flow also contributes more than the public information variables that are included in my regressions; change in interest rate differentials and oil prices (due to Norway's dependence on oil revenues). The strongest effect on exchange rates among the order flow variables is from the trading of customers. This result is new, and points to the importance of customer trading as the fundamental source of demand for foreign exchange.

Essay 4: U.S. Exchange Rates and Currency Flows

This essay is very much in the spirit of essay no. 3, and tests the same model. The data used for order flow are weekly data from the U.S. Treasury. The data has previously been used by Wei and Kim (1997) in a different setting than the present.

The model is tested for the DEM, JPY, GBP, CAD and CHF against US dollar, using weekly data for spot and options trading in the U.S. For three of the exchange rates, DEM/USD, GBP/USD and CHF/USD, I find that order flow is an important variable for explaining weekly changes in exchange rates, thereby indicating an important role for private information and confirming previous results.

CHAPTER 1

Overview and Introduction[1]

1.1 Introduction

Daily trading in the global currency markets was incredible US$1,500,000,000,000 in April 1998, or $1.5 trillions if you like. Daily trading in the Norwegian currency market was $9 billions.[2] Daily spot trading, which is the most important sub market, was almost $600 billions worldwide, and $3 billions in the Norwegian market. The most traded currency pair worldwide in April 1998 was the DEM/USD, while the NOK/DEM was most traded in Norway.[3] Daily spot trading worldwide of DEM/USD were $150 billions, while daily spot trading of NOK/DEM in Norway were $656 millions.

As a comparison, consider two causes of foreign exchange trading: International goods trade, and trade in assets. The *monthly* volume of global exports in April 1998 was $454 billions. The *monthly* volume of exports in Norway was $3.5 billions. This amounts to 4% and 6% of the spot trading volumes globally and in Norway, respectively. Alternatively, consider the volume on two stock exchanges, the New York Stock Exchange and Oslo Børs. The average daily volume on the New York Stock Exchange in April 1998 was $30 billions. The *monthly* volume on Oslo Børs was $5.6 billions, less than a tenth of the average monthly spot trading in Norway. Put bluntly: *The foreign exchange market is the largest financial market in the world, and trading volumes far exceeds that implied by international trade.*

This dissertation is a collection of four essays on the trading activities in the foreign exchange market. Trading has traditionally not been an issue in research on the foreign exchange market. This has changed during the last decade. In my dissertation the subject is approached from the theory of market microstructure. Market microstructure theory studies the consequences for financial

[1]I would like to thank Paal Longva, Ylva Søvik, Kalle Moene, Steinar Holden and Geir Høidal Bjønnes for helpful discussion and comments.

[2]By the Norwegian currency market it is meant currency trading by Norwegian banks. The numbers for Norway are corrected for national double-counting. All numbers from BIS (1998).

[3]I will use the following ISO-codes for exchange rates in this introduction: USD= US dollar; DEM = Deutsche mark; JPY = Japanese Yen; GBP = pound sterling; CAD = Canadian dollar; and CHF = Swiss franc.

markets of heterogenous agents, private information, and different trading institutions.

The important question is not the volume of trading itself, but if it matters. One may believe that foreign exchange trading only is moving currency back and forth between those that need currency, without any real effects. However, I will argue that the trading has real effects that we ought to take into consideration. In the microstructure approach, trading may be useful for the formation of expectations. The main conclusion of this dissertation is that trading is important for the determination of weekly and intraday movements in exchange rates. In periods of buying pressure of a currency, the value of the currency will increase (and vice versa in case of selling pressure).

The remainder of this introductory section will be used to make a justification for a study on the importance of trading. To sum up, I believe that such a study may be justified, given (*i*) the importance of the foreign exchange market, (*ii*) the shortcomings of our understanding of the market (addressed in section 1.1.1), (*iii*) the evidence that important assumptions of earlier theories may be violated, and (*iv*) the promising results so far of this recent approach (addressed in section 1.1.2).

Section 1.2 describes the structure of the foreign exchange market. Section 1.3 reviews microstructure theory, while section 1.4 gives an overview of the essays of this dissertation. Some concluding remarks are offered in section 1.5.

1.1.1 Why study the foreign exchange market?

The foreign exchange market is not only the largest financial market in the world, it is also the oldest.[4] Still, the most important aspects of foreign exchange are the same as back in the beginning. Exchange rates have implications for a country's competitiveness, and thereby for international trade. By influencing the return on international financial investments, the foreign exchange market also has implications for the determination of interest rates.

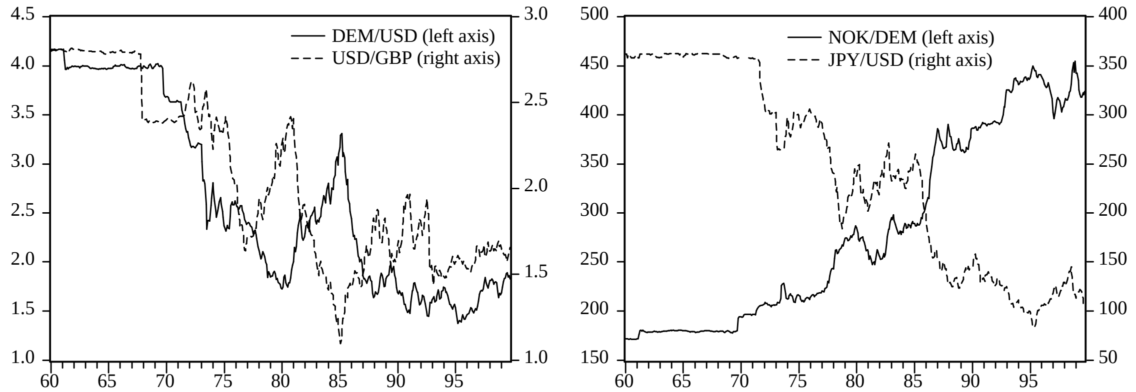
Trading of currencies started in the ancient Middle East (500 B.C. to 500 A.C) as a response to the Aristotelian prohibition of usury. While interest on ordinary lending was prohibited, trade in assets, including coins, were not. By writing contracts with payments in different currencies, one could hide interest bearing lending agreements as currency trades. Later, in the middle ages (500 to 1500 A.C.), currency trading also took place to meet the needs of travelling merchants.

Economic research on exchange rates did not reach the main research agenda before in the mid 1970s. After the breakdown of the Bretton Woods agreement on August 15, 1971, and an interim period with fixed rates under the Smithsonian Agreement that lasted until March 1973, the major currencies floated against each other. Currency trading reached levels never observed before, and the newly floating currencies were far more volatile than what most economists expected.

Figure 1.1 shows the DEM/USD, USD/GBP, NOK/DEM and JPY/USD exchange rates from the beginning of 1960 until the end of 1999. During the Bretton Woods era, exchange rates were very stable. Due to high inflation and trade balance deficit in the U.S, many felt that these fixed

[4] See Bingham (1992), de Cecco (1992) and Luca (2000).

Figure 1.1: Monthly exchange rates (spot)



Source: Norges Bank. Observations from January 1960 to October 1999. The left panel shows the DEM/USD spot exchange rate on the left axis, and the USD/GBP spot exchange rate on the right axis. The right panel shows the NOK/DEM spot exchange rate on the left axis, and the JPY/USD on the right axis. All four exchange rates are very stable before the breakdown of the Bretton Woods agreement in 1973, and especially the three main exchange rates DEM/USD, USD/GBP and JPY/USD vary substantially after the breakdown.

exchanges rates drifted away from their equilibrium values. In the end of the 1960s tension within the Bretton Woods area started to build up. In 1967 the pound sterling were devalued. The other central banks in the Bretton Woods decided in 1968 to stop supporting the gold price, which was the anchor of the Bretton Woods. The US dollar was fixed against gold, and all other currencies fixed towards the dollar. The problems continued in 1969, with devaluation of the French franc and a revaluation of the Deutschemark.

After the breakdown of Bretton Woods, and later the breakdown of the Smithsonian Agreement in 1973, the main currencies USD, DEM, JPY and GBP were very volatile. Economists responded quickly with research on exchange rates. In 1976 *Scandinavian Journal of Economics* published a special issue on exchange rates containing three classics: two on the monetary approach (Frenkel, 1976; Mussa, 1976), and one on the portfolio balance approach to the determination of exchange rates (Kouri, 1976). In the same year, Dornbusch (1976) launched the "overshooting" model (also called the sticky price monetary model), to explain the large jumps in exchange rates.

These models, here addressed as the traditional macroeconomic models, share the reliance on macroeconomic variables as interest rates, inflation, growth, and in addition asset supply in the case of the portfolio balance model. They all use equilibrium in asset markets to determine exchange rates, and hence focus more on the asset aspect of currency than the international trade aspect. Currency trading is completely irrelevant in all three models.

The study of the relationships between macroeconomic variables and exchange rates has increased our understanding of exchange rates on long horizons. However, at shorter horizons these models have received little empirical support, as shown in the seminal papers by Meese and Rogoff (1983a,b). Meese and Rogoff demonstrated that monthly and biannual forecasts based on the traditional macroeconomic models performed even worse than a random walk, as can be seen in table 1.1 by the higher forecast errors.

Table 1.1: The failure of the traditional models (Root mean square forecast errors)

Exchange rate	Forecast horizon	Random Walk	Monetary model	Sticky price model	Portfolio balance model
DEM/USD	1 month	3.72	3.17	3.65	3.50
	6 month	8.71	9.64	12.03	9.95
JPY/USD	1 month	3.68	4.11	4.40	4.20
	6 month	11.58	13.38	13.94	11.94
GBP/USD	1 month	2.56	2.82	2.90	2.74
	6 month	6.45	8.90	8.80	7.11

Source: Meese and Rogoff (1983a), table 1.

Since the papers by Meese and Rogoff, there have been many papers trying to explain the lack of effect of most macroeconomic variables, to little avail (for surveys, see Frankel and Rose, 1995; Taylor, 1995).[5] This has led several researchers to declare that exchange rate economics is in crises. de Vries (1994) claims that the lack of effect from most macroeconomic variables is a stylized fact of exchange rate economics.

Hence, after 25 years of extensive research we still do not have a satisfactory understanding of the behavior of exchange rates on short horizons. Meanwhile the increased integration of international financial markets that we have seen the last decade has only made it more important to reach such an understanding. It is sufficient to mention the exchange rate crises of the last decade, the ERM-crisis of Europe in 1992–93, the Mexican crises in 1994, and latest the Asian crises in 1997. However, even if it is less in focus in the public debate, the large swings in both the major currencies, like the USD, JPY, and Euro, and smaller currencies, may be equally important for understanding the foreign exchange market.

1.1.2 Why a Microstructure approach?

The traditional macroeconomic models assume that:[6]

1. All market participants are identical
2. All relevant information is publicly available
3. Trading mechanisms are inconsequential

If it is reasonable to believe that these three assumptions do not hold for the foreign exchange market, one should worry how severe these violations are whether they have any consequences. After all, no macroeconomist believe literally in the three assumptions. They are rather made as hopefully innocent simplifications. Microstructure theory offers a suitable framework for the study of consequences of violating these assumptions.

[5] Vikøren (1994), Langli (1993), and Bernhardsen (1998) test macroeconomic models for the Norwegian market and show similar results.

[6] Relaxing these three assumptions may also be seen as a general characteristics of microstructure models. Madhavan (2000) defines market microstructure as "... the area of finance that is concerned with the process by which investor's latent demand are ultimately translated into transactions."

Several surveys of market participants indicate that at least the first two are violated in the foreign exchange market.[7] Dealers differ in their trading strategies. Some use several different trading strategies, among these fundamental and technical analysis, while other focus on one. Table 1.2 shows the heterogeneity of trading styles. In essay 1 “FX Trading ... LIVE! Dealer Behavior and Trading Systems in Foreign Exchange Markets” we study four dealers over a week, and show that dealers use different trading styles. This is an indication that all market participants are not equal, not even within the group of dealers.

Table 1.2: The best way to describe your trading style? (In %)

		UK	US	Hong Kong	Tokyo	Singapore
Driven by customer orders	now	37 %	22 %	25 %	27 %	29 %
	5-years ago	33 %	23 %	25 %	26 %	28 %
Based on technical trading rules	now	33 %	29 %	26 %	28 %	26 %
	5-years ago	14 %	19 %	24 %	23 %	20 %
Based on fundamental analysis	now	34 %	25 %	23 %	22 %	21 %
	5-years ago	31 %	23 %	23 %	26 %	21 %
The “jobbing” approach	now	36 %	21 %	26 %	24 %	25 %
	5-years ago	53 %	31 %	29 %	25 %	31 %

Source: Cheung and Wong (2000); Cheung and Chinn (1999b); Cheung et al. (2000). The table reports the answers that dealers gave to the question “The best way to describe your spot FX trading is ....?” Table shows percentages of all answers within each country. The “jobbing” approach is a trading style where the dealer continously buys and sells currency.

Furthermore, dealers differ in their expectations, and they believe that other dealers and banks may have different information from themselves. The heterogeneity of expectations has been well documented (see footnote 7), and may be a result of heterogeneous information. Essay 2 in this dissertation, “Customer Trading and Private Information in Foreign Exchange Markets,” contains some new evidence regarding heterogeneous information from a questionnaire.

One of the main lessons from microstructure theory is that the trading mechanism may be of importance for the equilibrium of a financial market. In the foreign exchange market an important consequence of the structure of trading is that very few trading initiatives and transactions are observed by the whole market. This will be treated in more detail in the next section, and is also addressed in essay 1.

How can violations of the three assumptions mentioned above make trading important? First we need a new term for trading. In equilibrium, supply will always equal demand. This is just to say that for every purchase there must be a corresponding sale. It is therefore not very informative to only know that somebody bought or sold.[8] Microstructure theory uses a more precise term for trading, namely order flow. While any transaction is a trade, in the order flow term the transactions have a sign. The convention used is if the party that take the initiative to the trade buys the asset, the order is given a positive sign, and negative if the initiator sells.[9] The initiator is often also called the aggressor. The order flow trading term makes it sensible to talk about buyer and seller

[7] See Allen and Taylor (1990), Cheung and Chinn (2000, 1999b,a), Cheung, Chinn, and Marsh (2000), Cheung and Wong (2000), MacDonald (2000), Lui and Mole (1998), and Menkhoff (1998).

[8] It is not completely uninformative neither. High volume may for instance signify increased uncertainty.

[9] The asset in foreign exchange transactions is the base currency. An exchange rate is the price of one currency (base currency) measured in another currency. So in a DEM/USD transaction USD is the base currency (the currency that the initiator buys or sells), and DEM is the unit of account (the amount he has to pay or receives to fulfill the trade).

pressure in the market, even when supply and demand always is equal.

The order flow is the key variable in all microstructure models, irrespective of the structure of the market. Order flow has this key property because it is the best variable to measure the motives for a trade. There may be several reasons for a transaction. Yet, the primary reason for buying an asset is to make money. An agent buys an asset when he expects its price to rise, and sells it when he expects the price to fall. If a dealer has private information, the rest of the market learn about this information through the trading of the informed dealer. If he buys, he most likely has information that the exchange rate should go up, and vice versa if he sells.[10] Other reasons to trade, e.g. risk management, are of second-order compared to this primary reason.

Several recent studies have indicated that order flow may be informative about exchange rate movements (see Lyons, 1995; Evans and Lyons, 1999; Evans, 1998, 1999; Payne, 1999). Essay 3 "Private or Public Information in Foreign Exchange Markets", and essay 4 "U.S. Exchange Rates and Currency Flows" builds upon this, and confirm earlier results.

1.2 The structure of the foreign exchange market[11]

This section describes the structure of the foreign exchange market. The discussion focus on how the microstructure approach relaxes the three assumptions mentioned in the previous section. The section ends with a description of the trading environment.

1.2.1 The agents of the market

The microstructure approach to foreign exchange markets has generally focused on three different types of agents:

1. Dealers working in banks, operating in the interbank market
2. Brokers operating in the interbank market
3. Customers that trades with the banks, but do not have access to the interbank market.

Currency trading typically follows a sequence. The trading of the customers of the banks is the primary source of currency demand, so the sequence starts with a customer contacting his bank with a wish to trade. A customer may be a non-bank financial corporation, any non-financial corporation, or a central bank. The customer relations dealers in the bank then turns to the spot dealers in the FX Department, and asks a dealer to cover the customer trade in the interbank market. Customers do not have access to the interbank market, and this is very important for the banks, because it gives the banks some monopoly power towards the customers.

[10] Customers' reasons for currency trade include international trade and trade in other assets. It is important to distinguish between expected and unexpected customer trade. Only the latter may have price effects if the trade is not related to trading in currency per se. This kind of price effects is not considered in the standard theories of effects from order flow. See Cao and Lyons (1998), and page 10 on portfoilio shifts.

[11] This section borrows extensively from Lyons (2000).

The dealer then contacts another dealer in the interbank market, waits for another dealer to contact him, or contacts a broker. Brokers work as pure intermediaries, and operate only in the interbank market. They collect prices from dealers, announce the best bid and ask prices in the market, and then match dealers that want to trade at these prices with the pricesetting dealers.

Table 1.3 shows some numbers from the triennial surveys of the foreign exchange market conducted by the Bank for International Settlements (BIS). Some of the volume reported in the “financial customer” group contains some brokered trading which is strictly interdealer. This means that interbank trading accounts for between two-thirds and 80% of total volume in foreign exchange. According to Lyons (2001) customer trading amounts to approximately one-third, while interbank trading splits into equal parts of brokered trading and direct interdealer trading.

Table 1.3: Foreign exchange market activity

	Norway			World		
	1992	1995	1998	1992	1995	1998
Total	5.2	7.6	8.8	785	1,137	1,442
Spot	2.0	3.4	3.0	394	494	578
- dealers	1.6	2.1	2.5	282	325	348
- financial customers	0.2	0.7	0.1	47	94	121
- customers	0.3	0.6	0.4	62	75	109
Swaps	3.0	3.9	5.7	324	546	734
Forward	0.2	0.2	0.2	58	97	130
Customer share	16%	28%	14%	26%	26%	27%
- Spot	18%	28%	16%	22%	25%	29%

Source: BIS (1993, 1996, 1998). Daily averages of market activity in April 1992, 1995, and 1998. All numbers in billion USD. The customer share is calculated as the average of the share when only “customers” are treated as customers, and the share when customers includes both “financial customers” and “customers”. The Spot share indicates the customer share of the spot market.

The five most important trading venues centers in the world are London, New York, Tokyo, Singapore and Frankfurt, with approximate 70% of all trading. In the UK, US, Singapore and Japan, 75% of the trading is covered by approximately 20 banks, while in Germany 9 banks cover 75% of the trading. Norway is ranked as the 20th largest country on trading volume, with four banks covering 75% of the trading.

1.2.2 The interbank market institutions

With a share of the trading volume between two-thirds and 80%, the interbank market has a special position. The interbank market can be described by the following market institutions:

1. Decentralized market with a minimum of public regulations

2. Multiple dealership market

3. Low transparency

The interbank foreign exchange market is a decentralized market in the sense that there is no centralized exchange where dealers meet each other and customers. Consequently, since there are banks operating in the market in all time zones, the foreign exchange market is also a continuous market that is open 24 hours a day all year.

It is a multiple dealer market in the sense that any bank that wants to trade currency may start giving quotes in the interbank market. This means that a foreign exchange dealer may both function as a market maker (set quotes),[13] and trade on other market makers' quotes.

Transparency is defined as the ability of market participants to observe information about the trading process (see O'Hara, 1995). Information refers to prices, transactions, volumes, and the identities of market participants. There are no disclosure requirements in the foreign exchange markets, due to the low level of regulation. Furthermore, the decentralized structure makes it difficult to observe the trading of other dealers. Bilateral trading between two dealers (called direct trading) is only observed by the two parties. For brokered trades (called indirect trading) the dealers can observe the direction and prices, but not the identity of the parties, of a subset of the transactions. This makes the transparency of the foreign exchange market low compared to stock markets.

1.2.3 Information

The possible existence of private information is closely related to transparency. If an asset market is completely transparent, it will soon end up in the no-trade situation of Milgrom and Stokey (1982) where prices always reflect all information.[14] In an opaque market, the dealers only observe a small amount of the initiatives to trade, and therefore can only infer a small amount of the motives for trade in the overall market. This means that the prices at any time may reflect only a small part of the potentially available private information in the market, since the dealers learn less about overall order flow than in a perfectly transparent market.

Even so, many see the possible existence of private information in the foreign exchange market as rather far-fetched. What may constitute private information in the foreign exchange market? The following general definition may be useful. Private information is

- information that is not common knowledge, and
- that may be useful to predicting prices.

Due to the low transparency, the first point is obviously fulfilled for the foreign exchange market. Order flow is not observed by all dealers, and the customers do not observe any of the order flow in the interbank market.

Dealers claim that their most important source of information is trading with customers, and this information is private for the dealers in the bank (see Lyons, 1995; Yao, 1998a,b).[15] Table 1.4

[13] A market maker is a dealer that stands ready to give buy (bid) and sell (ask/offer) prices on demand, and fulfill orders on this prices. The market maker is a provider of liquidity, and makes money by buying on the low bid and selling on the higher ask price.

[14] The foreign exchange market is different from other asset markets, because there always is gains from trade in currency due to international trade. The conditions for the "No-Trade" theorems are therefore not fulfilled.

[15] Yao (1998b) also stress that customer trades is more profitable due to larger spreads. See also essay 2.

Table 1.4: The most important sources for competitive advantage for the large players in the Foreign exchange market? (In %)

	UK	US	Hong Kong	Tokyo	Singapore
Large customer base	33	33	27	27	30
Better information	22	23	22	21	22
Can deal in large volumes	16	15	17	15	12
Can influence exchange rates	14	9	12	12	9
Access to global trading network	4	5	8	9	11

Source: Cheung and Wong (2000); Cheung and Chinn (1999b); Cheung et al. (2000). The table reports the answers that dealers gave to the question "Select the 3 (or fewer) most important sources of competitive advantage for the large players in the FX market?" Table shows percentages of all answers within each country

shows what the dealers believe is the competitive advantage of the large banks in the interbank market. The most important source of advantage is a large customer base. The second most important is better information. If customer trading is important information, these two should be related. The third one may also be related to information. By dealing in larger volumes the dealers in a bank will also observe more order flow, and thereby learn more about motives for trade.

What kind of information do order flows convey? Again, this can be split in two categories. To fix ideas, consider what determines an asset price (Lyons, 2001). An asset price equals a discounted expected value,

$$P_t = \frac{E\left[V_{t+1}|\Omega\right]}{1+\delta}, \tag{1.1}$$

where V is a expected "fundamental" value (think of a terminal value), Ω is the conditioning information set, and δ is the discount rate. A dealer may be able to predict prices if he has information on either $E\left[V|\Omega\right]$ or δ. Lyons (2001) calls this payoff information and discount rate information, respectively.

One example of payoff-relevant information that may be revealed by order flow is central bank interventions. These may convey information about future interest rates. Another example may be that by observing order flow dealers can learn about changes in the trade balance before these are announced (see Lyons, 1997). Even if international trade is only a small part of currency trading, the dealers can observe the identity of their customers and thereby infer some of the motives for trade. If the trading of large industrial corporations is closer related to the trade balance than that of a hedge fund, then the dealer may learn something about the trade balance by observing the interbank order flow together with his customer order flow.

Customer order flow may be informative about fundamental values through three channels. These three may work simultaneously: (i) Customers may have private information (receive different "signals") on fundamental value; (ii) customers may use different "models" to evaluate new information; or (iii) customers may use different probability distributions to evaluate new information. The first of these three is similar to the two mentioned in the previous paragraph in that it provides a signal of the fundamental value V.

The two others are ways to measure the expectations of agents, and may be important even if exchange rates are determined by public information only. Order flow may be informative also when exchange rates are determined only by public information, if it is so that the mapping from information to exchange rates is not common knowledge. With the lack of support of the traditional macroeconomic models, such a common knowledge mapping can hardly be realistic for exchange rates. Dealers learn about how the customers interpret e.g. the latest interest rate increase from the central bank by observing the order flow. If customers' interpretations will influence their demand for currency, this learning will obviously influence prices. The simple bottom line is that order flow may be important information because it may reflect expectations backed by money!

Discount rate information may also be related to order flow. Lyons distinguishes between two effects here: Inventory effects and portfolio-balance effect. Both result in a risk premium, and are therefore related to the discount rate. The first is temporary, and the second is permanent. Consider the inventory effect first. As mentioned above, dealers in the interbank market both function as market makers, and trade on other dealers' prices. As a market maker, he accepts any trade on his posted prices, so he may end up with an inventory of currency different from his preferred. He provides liquidity, and demands a compensation (risk premium) to take the additional risk. If the risk is diversifiable, the unbalanced inventory of the market maker will eventually return to his preferred and the risk premium will vanish. In this case, the market maker absorbs the risk in the first place, but later it will be spread to the whole market. If the total volume of currency in the market is unchanged during this process, and the order flow did not conveyed any new fundamental information, prices will return to their initial values.

If the total volume of currency in the market changed during this process, we call it a portfolio shift. For the new volume to be willingly held by the market, with no new information on fundamental values, the holders must be compensated with a risk premium. This will be a permanent risk premium since the risk involved in the new volume is not diversifiable (Evans and Lyons, 1999).

1.2.4 Trading environment

Since the interbank market is a multiple dealer market, dealers can both trade at other dealers prices and serve as market makers. When trading at other dealers' prices, a dealer acts as an aggressor, and the trade is called an outgoing trade. When giving quotes he is passive, and the trade is an incoming trade. The dealers have two channels for trading. Either bilaterally with each other, which is a direct trade, or through a broker which is an indirect trade. These trading options can be illustrated in a 2×2 matrix as in figure 1.2.

Most trading today is conducted electronically, while telephone and telex were widely used earlier. The dealer has three computer screens in front of him: One screen is for a newswire, like Reuters or Bloomberg; one is for a electronic broker called EBS (see figure 1.4); and one for a trading system called Reuters Dealing 2000 (see figure 1.3).

Direct trading is usually done through the Reuters D2000-1, a system for bilateral communication over a computer-network which is part of the Dealing 2000. This system started up in 1981.

Figure 1.2: Interbank trading options

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

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

In direct trading, Market Makers are expected to give quotes on request. The initiating dealer, the aggressor, contacts a dealer that he believes may give competitive quotes, at the expense of revealing his identity. Direct trading is the preferred channel when the volume traded is either of an unusual size or very large. Direct trading is only observed by the two dealers involved in the transaction. Figure 1.3 shows one possible setup of the Reuters Dealing screen, where a direct conversation for USD 4 million can be seen in the middle of the screen.

Indirect trading takes place through a broker, either a traditional voice-broker or an electronic broker system.[17] A dealer may give quotes to brokers. The dealer decides whether to give two-way quotes (bid and ask) or only one-way quotes (bid or ask). Brokers are mainly used for smaller trades between USD 1 and 10 million. In contrast to direct trading, the identity of the counterpart is not revealed in indirect trading. Furthermore, in an incoming direct trade, the dealer does not decide when to trade. In an incoming *in*direct trade there is a timing decision, since the dealer decides when to place quotes to brokers. The brokers are very important in the foreign exchange market because they are the only view the dealers have of the aggregate order flow.

The upper part of the screen in figure 1.3 shows the D2000-2 electronic broker system, while figure 1.4 shows the screen of the EBS electronic broker systems. We can see from both figures how the dealers get a view of aggregate order flow through indicators of whether the aggressor bought at the ask or sold at the bid.

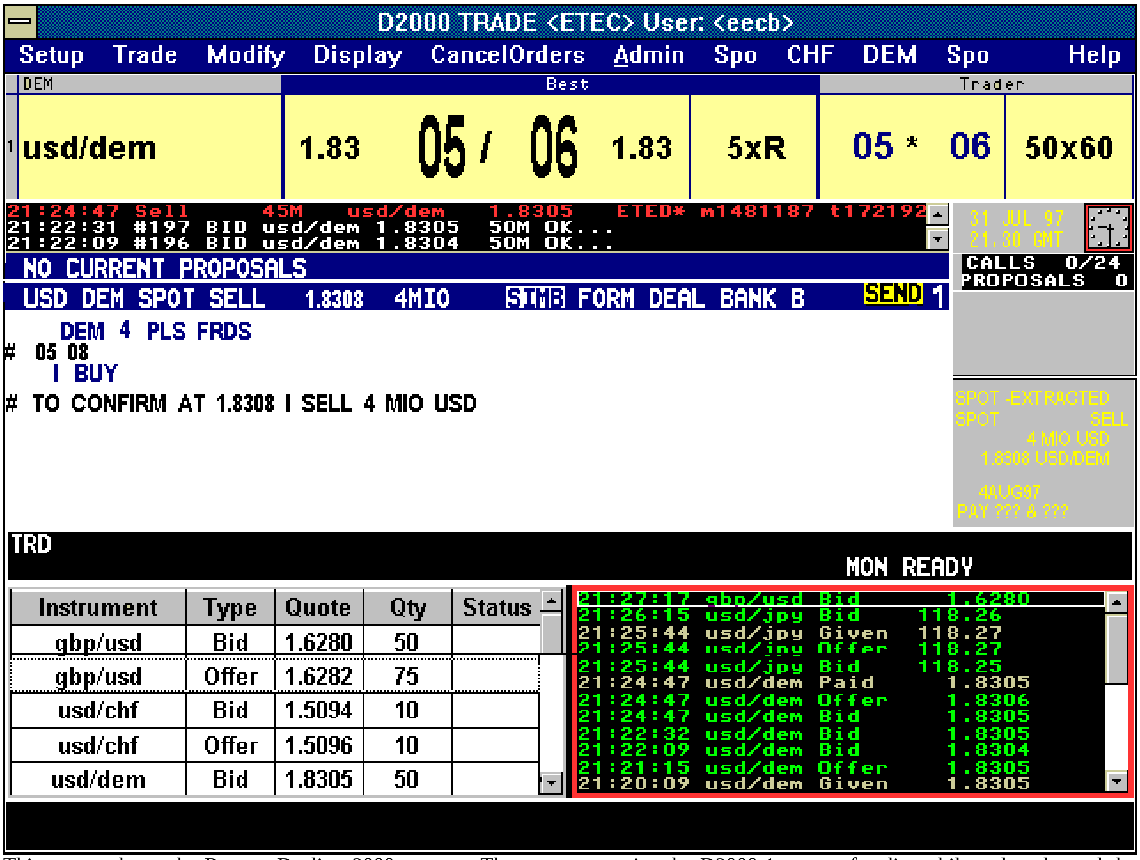
1.3 Microstructure theory and empirical evidence

Microstructure theory for the foreign exchange market builds upon the *inventory* approach and the *information* approach.[18] Inventory control models (e.g. Garman, 1976; 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". An example may clarify. Assume that a Market Maker's quotes are 1.8050-53 for DEM/USD. Another dealer contacts the market maker to buy dollars, and buys at 1.8053. After the trade, the market maker wants to buy dollars to reduce his exposure to variation in the foreign exchange rate. Instead of buying at other dealers

[17] During the 1970s and most of the 1980s, traditional voice brokers were the dominant tools for trading. Voice brokers have lost much of their market share to electronic broker systems, because these offer tighter spreads and faster execution of trades. In 1998, the voice brokers' market share of spot transactions in New York was only 24% compared to 47% in 1995. In the same period, electronic brokers have become very popular, with a market share of 31% in 1998 up from 10% in 1995 (FED NY, 1998). In London, electronic brokers are used in 25% of all spot transactions.

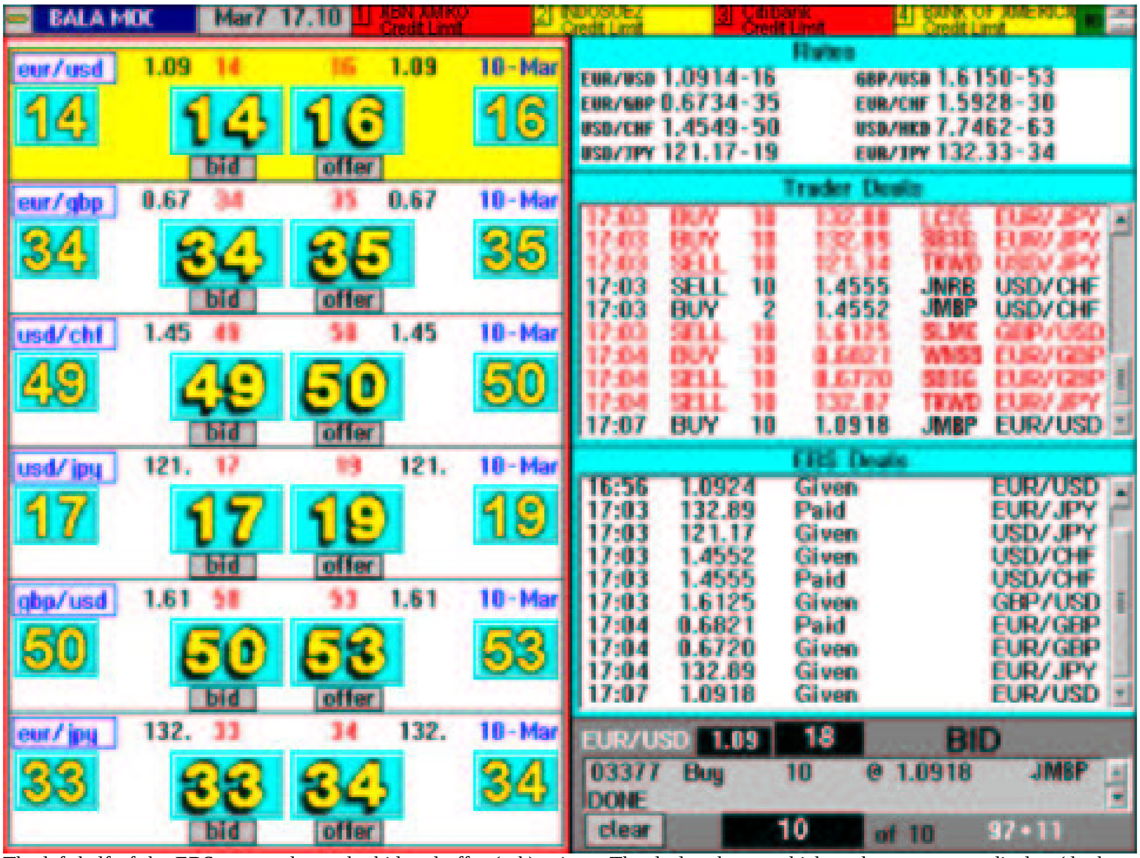
[18] These two canonical microstructural theories were developed for a generic financial market, however with a special motivation to understand stock markets;

Figure 1.3: Reuters Dealing 2000 system



This screen shows the Reuters Dealing 2000 system. The system contains the D2000-1 system for direct bilateral trade, and the D2000-2 electronic broker. The dealer may choose the content of the screen. The top part shows the D2000-2 system. The dealer may choose which exchange rates to display, and whether to display the best prices in the market or only the best available to him. The part in the middle contains a D2000-1 conversation. The dealer has been contacted for a quote for 4 million USD against DEM. The dealer replies with the quote 05 08, which is understood to be bid 1.8305 and ask 1.8308. The contacting dealer responds with "I BUY", and the system automatically fills in the line "TO CONFIRM AT 1.8308 ...." In the lower right corner of the screen, the dealer can see the price and direction of the last trades through the D2000-2 system.

Figure 1.4: EBS (electronic broker)



The left half of the EBS screen shows the bid and offer (ask) prices. The dealer choose which exchange rates to display (the base currency is written first). The prices shown are either the best prices in the market, or the best available (from credit-approved banks only). The upper part of the right half of the screen show the dealer's own trade. The lower part show the price and direction of all trades through the system for selected exchange rates. "Given" means that it was traded at the bid-price, and "Paid" means it was traded at the offer-price. The intuition is that the dealer that entered the quote is "Given" currency (buys).

quotes, he can shade his own quotes to induce other dealers to sell at his quotes. For instance, he may post the quotes 1.8051-54, making it more attractive for other dealers to sell at 1.8051 instead on the previous price of 1.8050. The spread arises as a price to compensate the Market Maker for not being able to hold the preferred portfolio. In a multiple dealer market like the foreign exchange market, a dealer may also control inventory through trading with other dealers.

Information-based models (e.g. Kyle, 1985; Glosten and Milgrom, 1985; Admati and Pfleiderer, 1988) consider adverse selection problems when some dealers have private information. When dealers receive trades, they revise their expectations (upward in case of a buy order, and downward in case of a sell order) and set spreads to protect themselves against informed traders. The first to bring in asymmetric information was Bagehot (1971). In a short paper, writing under pseudonym, Bagehot distinguished between informed and uninformed traders. The market maker always loses to better informed dealers because they will only trade when they win. In order to stay in business the market maker must make at least as much from uninformed dealers as he loses to the informed dealers. These gains arise from the bid-ask spread. The spread may therefore be seen as an information cost.

Both inventory control models and information-based models imply that buyer-initiated trades push up prices, while seller-initiated trades push prices down. Empirical studies try to disentangle the two effects. There is no model that incorporates the two effects based on first principles. In order to empirically study inventory effects and information effects together, Madhavan and Smidt (1991) developed a model that integrates the two effects based on two postulated behavioral equations. This model has been widely used to test dealer behavior in stock markets.

Empirical analysis of microstructure models on the foreign exchange market has been constrained by lack of observations on trading. The first attempt, to my knowledge, is Fieleke (1979). The problem is due to decentralized structure of the market, combined with low levels of regulation. There is no disclosure requirements imposed on the banks, and observations on trading are the property of the banks and often regarded as sensitive information.

The early attempts to study microstructure issues in the foreign exchange market used instead high-frequency quote observations from Reuters, called FXFX (see Goodhart and Figliuoli, 1991; Bollerslev and Domowitz, 1993; Bollerslev and Melvin, 1994). These observations were useful for the analysis of volatility. The authors also addressed transaction costs. Using the Lee and Ready (1991) procedure to sign trades according to previous price movements, they also test for information effects. However, these quote data were not transacted at, they were not firm, making it difficult to say anything about transaction cost and private information.

For empirical analysis of dealer behavior in foreign exchange markets one need the complete records of dealer transactions. This is necessary to construct the inventories. Lyons (1995) was the first to present such an analysis, covering one dealer for one week in august 1992. Lyons found strong support for the two main microstructural models, inventory control and information protection. To the best of my knowledge, the only other paper utilizing dealer observations from the foreign exchange market, in addition to Lyons and essay 1 and 2 in this dissertation, is Yao

(1998a).[19] Yao also only studies a single dealer, and the data are from 1995. He finds no support for inventory effects, and mixed support for information effects.

Studies considering the effect of private information on the aggregate market have also been constrained by the availability of observations on order flow. Evans (1998, 1999), Evans and Lyons (1999) and Payne (1999) address the overall market issue based on observations on market-wide trading on DEM/USD. Evans' paper covers all direct (bilateral) trading through the Reuters D2000-1 computer system over 79 days in 1996, and he finds a strong correlation between price changes and order flow over the whole period. Evans and Lyons (1999) develops a model that integrates both macroeconomic information and information based on order flow, and tests it on the same data as in Evans (1998). They find that order flow is more significant than change in interest differentials. Payne studies all trades through the electronic brokerage system Reuters D2000-2 in one week.[20] Using the VAR-approach of Hasbrouck (1991), he finds a permanent effect on prices from trading which may be interpreted as an information effect.

This dissertation builds in particular on the work by Lyons (1995) and Evans and Lyons (1999).

1.4 Description of essays

The essays in this dissertation divide naturally into two groups, with two essays in each. The first two essays address dealer behavior in the interbank market, using a unique data set on the complete trading activities of four dealers during the week March 2–6, 1998. The data set was provided by DnB Markets for Geir Høidal Bjønnes and myself.

The last two essays address the effect of order flow on the aggregate market level. The essays use two publicly available data set on weekly currency positions in Norway and the U.S.

1.4.1 Essays on Dealer Behavior[21]

Essay 1: FX Trading ... LIVE! Dealer Behavior and Trading Systems in Foreign Exchange Markets

The introduction of electronic broker systems in the foreign exchange (FX) market at the end of 1992 changed the structure of the market and opened new channels for trading. We study the impact of these systems on dealer behavior, using a unique data set on the complete transactions of four FX dealers. The essay also contains a detailed section describing the trading options open to dealers. The essay take the work of Lyons (1995), "Tests of Microstructural Hypothesis in the Foreign Exchange Market", as a starting point. We conclude that the Madhavan and Smidt (1991) model that Lyons used do not fit our data, even after several adjustments.

We are then lead to investigate different parts of our detailed data set more closely. With observations on the spreads from direct trading (D2000-1), we can investigate directly the effects of larger trade size. We find that the size contributes significantly to a wider spread. We also find

[19] Both data set have been used in other settings: See Lyons (1996, 1998) and Yao (1998b).

[20] See also Goodhart et al. (1996).

[21] Essay 1 and 2 are written together with Geir Høidal Bjønnes of the Norwegian School of Management.

a information effect in tests of the Madhavan-Smidt framework only including the direct trades. We therefore conclude that there is an information effect in the direct trades.

Dealers give a lot of attention to the flow on the electronic brokers (D2000-2 and EBS). We find that the cumulative flow on the electronic brokers cointegrates with the exchange rate. This may be interpreted as an information effect from order flow, since the effect is permanent.

The new electronic systems have changed how dealers control their inventories by introducing new channels for this purpose. We do not find any evidence that dealers control inventory through quote shading. However, we find that there is a high degree of mean reversion in inventories, indicating that the dealers actively control inventory. Inventory control is also known to be "the name of the game in FX." Dealers use outgoing trades on electronic brokers to control inventory.

Comparing our results to previous research indicates that the introduction of electronic brokers have changed the behavior of dealers.

Essay 2: Customer Trading and Information in Foreign Exchange Markets

Recent research point to the possible existence of private information in foreign exchange markets. Dealers claim that customer orders are their most important source of private information, and that banks with a large customer base have a competitive advantage. The essay gives a detailed discussion of the role of customer trades in FX markets.

We use the data from Paper 1 to study two issues regarding private information in FX markets not previously addressed in the literature. First, how trading with customers affect the Market Makers price setting and their order placement strategy. Second, whether the identity of the counterparty influences the Market Makers' price setting and order placement strategy. The idea being that some dealers may be better informed than others, and that through experience, dealers learn which banks/dealers are informed and which are not. The analysis of price setting is done within an extension of the Madhavan and Smidt (1991) framework.

We find that customer trades influence the trading decision. Neither customer trades nor counterparty identity affect pricing decisions. Dealers do not price discriminate between dealers, but they do price discriminate customers. Spreads to customer are wider than to other dealers, which is made possible because customers have no access to the interbank market.

1.4.2 Essays on aggregate order flows

Essay 3: Private or Public Information in Foreign Exchange Markets? An Empirical Analysis

In macroeconomic models exchange rates are determined by public information. Trading activities are completely irrelevant for price determination. In general, these models have low explanatory power for short horizons, which might be due to the possible existence of private information. As mentioned above, dealers in the foreign exchange market consider the order flow from customers to be the most important source of private information.

The model I test in this essay is a simple extension of the model of Evans and Lyons (1999), "Order Flow and Exchange Rate Dynamics". The model, a microstructural trading model incorporating private information, includes both order flow and macroeconomic variables. As my order flow observations I use weekly data collected by Norges Bank, the Central Bank of Norway, on the trading that Norwegian banks do with Norwegian customers, Norges Bank, and Foreigners. The model is tested for the NOK/DEM, NOK/SEK, NOK/USD and NOK/GBP.

I find that this order flow measure contributes significantly to exchange rate changes, and have a permanent effect on exchange rates. When foreigners or customers buy currency, the Norwegian krone depreciates. In some cases the order flow also contributes more than the public information variables that are included in my regressions; change in interest rate differentials and oil prices (due to Norway's dependence on oil revenues). The strongest effect on exchange rates among the order flow variables is from the trading of customers. This result is new, and points to the importance of customer trading as the fundamental source of demand for foreign exchange.

Essay 4: U.S. Exchange Rates and Currency Flows

This essay is very much in the spirit of essay no. 3, and tests the same model. The data used for order flow are weekly data from the U.S. The data has previously been used by Wei and Kim (1997) in a different setting than the present.

The model is tested for the DEM, JPY, GBP, CAD and CHF against US dollar, using weekly data for spot and options trading in the U.S. For three of the exchange rates, DEM/USD, GBP/USD and CHF/USD, I find that order flow is an important variable for explaining weekly changes in exchange rates, thereby indicating an important role for private information.

1.5 Concluding remarks

The microstructure approach to foreign exchange has made many advances since the early contributions in the beginning of the 1990s. Microstructure is now used to study a host of topics within international finance not mentioned here. One particularly interesting direction is the study of intervention. Furthermore, with increasingly more trading conducted electronically, it may in the future be possible to regulate the foreign exchange market by regulating the vendors of the electronic systems. Maybe, in a not too distant future, we will see microstructure theories used to address the design of the foreign exchange market, much in the same way as we have seen for stock markets?

With respect to dealer behavior, and aggregate order flow, there is still a lot work to do. With the four dealers presented in this dissertation, the total number of dealers studied is six. Obviously, we need more data to better understand dealer behavior in the interbank market.[22] Furthermore, when it comes to dealer behavior in the foreign exchange market, it seems important to test alternatives to the Madhavan and Smidt (1991) framework.

[22] Geir Høidal Bjønnes and I have several projects coming up, both utilizing the data set presented in this dissertation and a new data set covering several dealers in the fall of 1999.

On the aggregate level it is important to investigate at what horizons the order flow is important. Maybe we can move from the daily and weekly horizon to empirical implications on the monthly horizon? This dissertation adds to the evidence that order flow may be informative on the weekly level. A natural next step would be to determine what causes order flows. As more data becomes available, this is within our reach.

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CHAPTER 2

FX Trading . . . LIVE! Dealer Behavior and Trading Systems in Foreign Exchange Markets[1]

2.1 Introduction

Empirical work on foreign exchange market microstructure is still in its infancy. So far, most microstructure research in foreign exchange spot markets relies on indicative quotes from Reuters FXFX (Goodhart and Figliuoli, 1991; Bollerslev and Domowitz, 1993, among others). Indicative quotes make it possible to address important microstructure issues regarding bid and ask spread, volatility and heterogeneity issues. However, these studies do not test dealer behavior directly since the FXFX data provide no direct measures of quantity or dealer inventories. This information is the property of the banks, and is regarded as confidential information. The study by Lyons (1995) represents the first attempt to use proprietary inventory and transaction data, covering one dealer for a week in August of 1992.

Lyons (1995) found strong support for the two main microstructure issues, inventory control and adverse selection. Inventory control models (e.g. Garman, 1976; 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." Thus, the spread arises as compensation to the Market Maker for not being able to hold the preferred portfolio. Information-

[1]Co-authored with Geir H. Bjønnes. This paper is a slight revision of of *Memorandum 29/2000, Department of Economics, University of Oslo*. We like to thank Steinar Holden, Asbjørn Rødseth, Richard Payne, Bernt Arne Ødegaard, Kristian Rydqvist and Narayan Naik for helpful comments, and Richard Lyons for stimulating discussions. Any errors are entirely our own.

based models (e.g. Kyle, 1985; Glosten and Milgrom, 1985; Admati and Pfleiderer, 1988) consider adverse selection problems when some dealers have private information. When dealers receive trades, they revise their expectations (upward in case of a buy order and downward in case of a sell order) and set spreads to protect themselves against informed traders. Both inventory control models and information-based models imply that buyer-initiated trades push up prices, while seller-initiated trades push prices down. Empirical studies try to disentangle the two effects.

This paper studies dealer behavior using a very detailed data set with the complete trading records of four foreign exchange dealers during one week in March 1998. The data set contains all relevant information about each trade such as transaction time, transaction prices and quantities, and who initiated the trade. Compared with the previous studies using similar data sets (Lyons, 1995; Yao, 1998), our data set is more detailed. For instance, we can more often determine which dealer was initiating the trade. Using this data set we make two contributions.

First, we replicate the study by Lyons (1995). This is particularly interesting because the introduction of electronic brokers at the end of 1992 has changed the structure of the foreign exchange market.[2] In 1992, interbank trading volume was equally split between direct bilateral trades and traditional voice-broker trades (Cheung and Chinn, 1999; Cheung, Chinn, and Marsh, 2000). However, the market share of the electronic brokers has increased rapidly. Cheung and Chinn (1999) and Cheung et al. (2000) estimated their market share to be roughly 50% of interbank trading in 1998 (time of our data set). In 1998, direct bilateral trading and voice-broker trading constituted 35% and 15% of total interbank trading, respectively. We believe that the strong inventory control and information effects found by Lyons are weakened under this new trading environment. The information effect may be weakened because the introduction of the electronic brokers has increased transparency. Transparency has increased since the electronic brokers let the dealers see the price and direction of the last trades going through the systems. The inventory control effect may be weakened because the electronic brokers have introduced new channels for trading. Compared with traditional voice-brokers, the electronic brokers offer higher execution speed and competitive quotes.

Second, we highlight the diversity of trading styles in the foreign exchange market. The previously mentioned studies by Lyons (1995) and Yao (1998) focus on a single dealer each. With this paper the number of dealers studied in the literature increases from two to six. Since our data set is very detailed we are able to examine all aspects of dealer behavior, and not only quote setting. In particular, we examine more closely how they use the different trading channels to control their inventories. Inventory models predict that bidders will use their price quotes to control their inventories. However, dealers can also control their inventory position by trading at other dealers' quotes. In this case, the dealer decides timing, magnitude and direction of his trading, participating more actively as seller (buyer) when holding long (short) positions. This may explain the weak inventory effect found in other market microstructure studies (e.g. Madhavan and Smidt, 1991; Hasbrouck and Sofianos, 1993; Yao, 1998). Another possible explanation for weak inven-

[2] The data set of Yao (1998) is from 1995, during the introductory phase of the electronic brokers.

tory effects, suggested by Manaster and Mann (1996), is 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.

Our results indicate that there are differences in informativeness of the different trading systems. We find some support for an information effect in (single) trades conducted directly (bilaterally). Consistent with the Madhavan and Smidt (1991) model used by Lyons (1995), dealers tend to increase the bid and ask spread when quantity requested by the initiator increases. For trades executed by electronic broker systems we find no relationship between trade size and spread. There is, however, evidence that the sequences of trades in cumulative flow may be important for prices. Hence, it is the direction of trades in sequence, and not the size of a single trade that is informative. This is consistent with informed dealers breaking up large trades. We find no inventory effect through prices. However, dealer inventories exhibit strong mean reversion showing that inventory control is important to our dealers. We also document differences in trading style among the dealers.

The rest of the paper is organized as follows. Section 2.2 describes important market characteristics relevant for our study. Here, we describe the different trading options available to dealers. We also discuss what may motivate a dealer's choice of trading system, and how the introduction of electronic broker systems may affect pricing and dealer behavior. Our data set is presented in section 2.3. Section 2.4 outlines the Madhavan and Smidt (1991) model that is similar to the model used by Lyons (1995) and Yao (1998). Section 2.5 presents estimation method and results for the Madhavan and Smidt model. In section 2.6, we explore inventory and information effects under the new trading environment. The paper ends with conclusions and some directions of future research (section 2.7).

2.2 Important Market Characteristics

This section briefly describes the different trading options available to FX dealers (section 2.2.1). We also discuss features of the trading systems that may affect dealers choice of where to conduct interdealer trades in section 2.2.2. Finally, in section 2.2.3 we relate the increasing popularity of electronic brokers to FX market transparency.

2.2.1 Trading systems in the interbank FX spot market

There are two main channels for trading in the interbank FX spot market. First, dealers can trade directly with another dealer. Negotiations between two dealers take place over the electronic system Reuters D2000-1 (or less commonly by phone). D2000-1 reveals the identity of the initiating dealer. 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.

The second main channel for trading is through brokers. In addition to traditional voice-brokers, there are two popular electronic broker systems (Reuters D2000-2 and EBS). The dealers use brokers either to post limit orders or hit posted limit orders (market order). When a trade is executed on one of the electronic broker systems, the order flashes on the screen of all dealers connected to the system. Only a subset of the trades executed by traditional voice-brokers are communicated to the dealers via intercoms. Another difference between electronic brokers and voice-brokers is that the former offers higher execution speed. All broker trades are anonymous, so dealer identities are kept secret by the brokers until settlement.

The different trading options let dealers manage their inventory positions in several different ways. Dealers can move their bid and ask quotes to induce a trade in a certain direction in an incoming trade (quote shading). Alternatively, dealers can manage their inventory positions by trading at other dealers' quotes. In an incoming trade, the dealer trades at the most favorable side of the bid or ask. However, outgoing trades offer higher execution speed. The trading options available to FX dealers can be summarized in a 2×2 matrix, as shown in figure 2.1.

Figure 2.1: Interbank trading options

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

As noted by Reiss and Werner (1999), for different trading channels to coexist, prices must be the same, or each system must offer different combinations of attributes that are not directly related to price. When testing the Madhavan and Smidt model we assume that prices are the same (section 2.5). In section 2.6, we examine differences between the trading channels.

There are four significant differences between direct and broker trading that may be of importance. First, direct trading is nonanonymous, while broker trades are anonymous. Second, in direct trades the dealer gives quotes on request, while broker trades are based on flexible limit orders. In a direct trade it is the initiator who decides when to trade, the quantity traded and the direction of the trade. Limit orders are flexible because the dealer decides when to post a limit order and the maximum quantity traded if the limit order is hit. Typically, in direct trades the dealer is requested to give two-way quotes, while in a broker trade the dealer decides whether to give one-way or two-way quotes. Third, dealers in the direct market are expected to honor all direct trades, while participating in broker trading is voluntary and thus liquidity may be limited. The direct market is based on informal agreements among dealers. Such informal agreements may, for instance, determine the "normal" spread for a certain amount. Typically, such arrangements are established among homogenous groups of FX dealers (for instance large FX banks). Fourth, the post-trade transparency is much higher for broker trades than direct trades since all electronic broker trades (and a subset of voice-broker trades) are communicated to the market, while a direct trade is known only by the two counterparts involved in the trade.

2.2.2 The choice of trading channel and private information

We are not aware of any model that can simultaneously explain how these differences between trading systems affect where dealers choose to trade. According to Reiss and Werner (1999), adverse selection plays an important role. Dealers claim that the most important source of private information in the FX market is knowledge of customer order flows.[3] Hence, banks with a large customer base may be better informed. We also argue that the potential for quote shading may differ between the two main trading channels.

In the absence of more than one trading channel, Röell (1990) shows that informed traders are worse off in nonanonymous markets if dealers can detect and punish informed dealers. In FX markets, dealers can distinguish informed and uninformed dealers based on the size of the bank's customer base (Bjønnes and Rime, 2000). This limits the possibility of informed dealers to take advantage of their private information.

If dealers have more than one trading channel available, the above argument suggests that informed dealers should trade at the anonymous trade channel. However, unless uniformed dealers also find it optimal to trade with brokers, prices will fully reveal the private information of informed dealers. Uninformed dealers will migrate to brokers if spreads are lower than those observed in the direct market. Reiss and Werner (1999) show that the higher the probability that informed dealers will be detected in the direct market, the lower the (relative) amount of adverse selection among dealers has to be for broker trading to be viable. Hence, a larger amount of price discrimination in direct trading reduces adverse selection and improves prices in the remaining order flow. This makes it more difficult for broker trading to be attractive to uninformed dealers.

Saporta (1997) provides another explanation for why dealers might prefer a trading channel to another. In her model a dealer can unload a customer trade through (i) direct dealing at other dealers quotes, or (ii) posting limit orders or hitting limit orders with a broker. The model predicts that broker markets are more attractive the greater is the number of market makers. The explanation is that an increase in dealer competition tends to flatten dealers' price schedules and increase potential benefits from risk sharing. Similar effects will not arise in the direct market since trading is bilateral.

Another prediction of the model is that when a dealer receives more private information (e.g. from customer trades), the dealer tends to trade in the direct market. The explanation is rather subtle. An increase in private information would lead less informed dealers to widen their quotes in the direct market, while they would submit smaller market orders in the brokered market. Although these changes reduce the attractiveness of both markets, the impact is greatest in the brokered market because dealers behave more strategically there.

The arguments above may be strengthened if post-trade transparency is important. Post-trade transparency is much higher for broker trades than direct trades. This may be important for an informed dealer engaged in a dynamic trading strategy. Hence, the dealer has an incentive to trade direct.

[3] A customer is a non-bank firm, for instance a multinational company.

To summarize dealers will use broker systems if quoted prices are within the bid and ask spread offered in the direct market. Also, broker trading is more attractive when there is little asymmetric information among dealers. Note that since both direct and broker trading coexist, execution costs and subsequent price impacts of the two channels must balance such that a hitting dealer is indifferent.

Market microstructure models typically assume that it is the initiator of a trade that may have private information. However, a dealer may also have private information when setting quotes. By shading quotes, he would signal his inventory position and thus his private information (Lyons, 1995). From the above arguments, we would expect that quote shading is more likely in the direct market. Also, dealers face a trade-off between revealing their private information when setting quotes or trading at other dealers quotes when they want to adjust their inventories.

2.2.3 The introduction of electronic brokers and transparency

An important feature of the foreign exchange market, distinguishing it from stock markets, is the decentralized multiple dealership structure, and the low transparency of trading (Lyons, 2001). Transparency is usually defined as the ability to observe the information in the trading process (O'Hara, 1995). Direct trades are unknown except to the two parties in a trade. Only a small subset of voice-brokers trades is communicated to the market via intercoms. On electronic broker systems, all trades are communicated to the dealers in a "trade window." This suggests that the growing popularity of the electronic brokers have led to increased transparency.

Recent surveys suggest that the interbank market share of electronic brokers is 50% at the time of our study (Cheung and Chinn, 1999; Cheung, Chinn, and Marsh, 2000). Since the introduction of electronic brokers at the end of 1992 the share of direct trading is reduced from 50% to 35%, while the share of traditional voice-broker trading is reduced from 50% to only 15%.

The reduction in the share of direct trades suggests that the electronic brokers facilitate risk sharing in a way that was not previously available. From the discussion above, the reduction in direct trades may also come from less importance of private information or an increase in the number of dealers. The rapidly declining market share of voice-brokers suggests that the difference between voice-brokers and electronic brokers is important. Perhaps the most important difference between voice-brokers and electronic brokers is that electronic brokers offer much higher execution speed. In fact, execution speed is higher than in direct trades were a conversation must be initiated. Since post-trade transparency is much higher for electronic brokers than voice-brokers, there is much more price and order flow information available today than earlier. Before the growing importance of electronic brokers, a close relationship with voice-brokers was important for seeking price information. Today, voice-brokers have lost this competitive advantage.

2.3 Data

The data set employed in this study consists of complete trading records for four spot dealers over the week March 2–6, 1998. All dealers work in the same Scandinavian commercial bank.

The bank is a major player in foreign exchange markets with a long history of foreign exchange trading.

The four dealers trade in different currency pairs and represent different trading styles. Dealer 1 is a medium-sized Market Maker in DEM/USD. Dealer 2 is described as a “Nintendo-dealer”; that is, he takes open positions only for a very short time in DEM/USD using electronic broker systems as “Nintendo”-game machines. Dealer 3 is the largest Market Maker in NOK/DEM. While the other dealers have only limited customer order flows, Dealer 3 has large customer order flows. Dealer 4 has much in common with Dealer 2, and trades mainly in DEM/USD. Dealers 2, 3 and 4 trade in several other exchange rates as well, while Dealer 1 only trades in DEM/USD.

The data set includes transaction prices, quantities and dealer inventories. The advantages of such a data set over other foreign exchange data alternatives (mostly indicative quotes), are that transaction prices better reflects market activity, and for a thorough analysis of dealer behavior one need inventory observations (Lyons, 1995). Using transaction prices instead of indicative quotes is especially important when trading intensity is high (Daníelsson and Payne, 1999). Compared with new data sets with transaction prices from electronic trading systems, e.g. Payne (1999) and Evans (1998) and Evans (1998), 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 consists of two components: (i) the dealers’ record from an internal system used for controlling inventory positions, and (ii) information from electronic trading systems. The first part of the data set consists of all trades. From this information we are able to calculate the dealers inventory positions (section 2.3.1). The second part of the data set provides detailed information on trades executed on electronic systems (section 2.3.2). Finally, we present our final data set (section 2.3.3).

2.3.1 Inventory positions

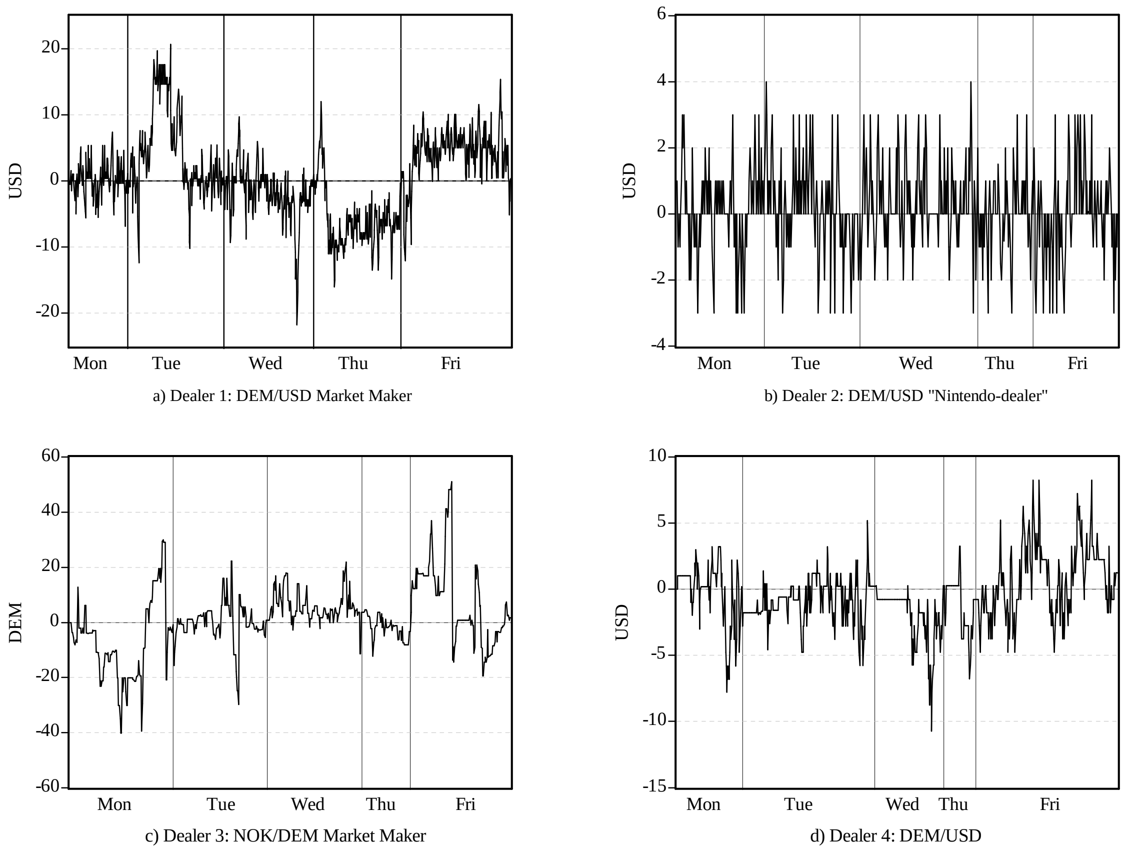
The first component of the data set consists of all trades, including trades with voice-brokers, direct trades completed by telephone, internal trades and customer trades. Trades executed by electronic systems, Reuters D2000-1 and D2000-2, and EBS, are electronically entered into the record. Other trades must be entered manually.

A dealer starts the day with his overnight position, and enters his trades during the day. We can therefore track the dealers’ inventory position. The record gives the dealers’ information on their inventories and accumulated profits during the day and during the last month. In this part of the data set, we have information on transaction time, transaction price, volume, counterpart and which currency the dealer bought and which he sold.

Figure 2.2 presents inventory positions measured in USD for the three DEM/USD dealers and in DEM for the NOK/DEM dealer. There are pronounced differences in the development of dealer inventories during the week. Dealer 1’s maximum long dollar position was USD 21 million, while the maximum short dollar position was USD 22 million. Dealer 2 has only small open positions.

During the week, he never had positions for more than USD 4 million. Compared with Dealer 1, the inventory of Dealer 2 shows much less persistence. After initiating an open position, Dealer 2 closes the position in the next trade. Dealer 3 has a maximum long DEM position of DEM 51 million and a maximum short position of DEM 40 million. Dealer 4 has a maximum USD position of USD 8 million and a maximum short position of USD 11 million. All dealers ends the day with a position close to zero.[4] This finding is consistent with Lyons (1995) and Yao (1998).

Figure 2.2: Dealer Inventory



The evolution of dealers inventory over the week. Dealer 1 (panel a), 2 (panel b) and 4s (panel d) inventory are in USD million, while Dealer 3s inventory is in DEM million. The horizontal axis is in“transaction”-time. Vertical lines indicate end of day. The numbers are in USD million.

2.3.2 Information from electronic trading systems

The second component of the data set consists of all trades executed on the three electronic trading systems, Reuters D2000-1, Reuters D2000-2 and EBS.

[4] The dealers informed us that Dealer 1 and Dealer 2 always end the day with a position close to zero. However, Dealer 3 and Dealer 4 may have overnight positions. The most likely explanation for this is that (i) the volatility in European currency crosses is low and (ii) it is expensive to square the position at the end of the day in less traded currency pairs.

Reuters Dealing 2000-1

The Reuters D2000-1 allows dealers to communicate quotes and trades bilaterally via computer rather than verbally over the telephone. 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 inter-bank trades are executed using D2000-1.

From the Reuters D2000-1 system, we have 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 just bid or ask); and if the conversation results in a trade, (vi) the quantity traded; and (vii) the transaction price.

Figure 2.3 provides an example of a D2000-1 conversation when a trade takes place. A conversation starts by a dealer contacting another dealer. The contacting dealer usually asks for bid and ask quotes for a certain amount, for instance USD one million.[5] When seeing the quotes, the contacting dealer states whether he wants to buy or sell. Sometimes he asks for better quotes, or end the conversation without trading. However, most conversations result in a trade (70%). All D2000-1 transactions in the data set take place at quoted bids or asks.

Electronic broker systems

Electronic broker systems fill the same functions as voice-brokers, but are more efficient. A bank dealer with access to one of the electronic broker systems can enter his buy and/or sell price into the system as a market maker. D2000-2 and EBS show only the highest bid and the lowest ask, thereby minimizing the spread. These will normally be entered by different banks, but the identity of the inputting bank is not shown. The total quantity entered for trade on these quotes is also shown. This means that when more than one bank input the same best bid (ask) price, the quantity shown is the sum of that offered by these banks. This quantity is shown as integers of USD one million, and in some bilateral cases DEM one million. When the quantity is at least ten million, "R" is entered on the D2000-2 screen. EBS shows two set of bid and ask quotes, for amounts up to ten million USD or DEM, and for amounts of at least ten millions. This information is optional on the D2000-2 screen. The limit orders below the best bid and above the best ask, and the respective quantities, are entered and stored in the systems, but not revealed over D2000-2 and EBS. Another bank dealer, possibly in the same bank, can hit the bid or the ask, by typing instructions on his own machine.

In our data set, trades executed by electronic broker systems provide almost exactly the same information as the D2000-1 records. The exception is that only the transaction price can be observed, that is, we cannot see the bid and ask spread.[6] However, the spread is tight — often only

[5]In some rare cases, the contacting dealer also tells whether he wants to buy or sell.

[6]Another slight difference is that EBS deals are only time stamped in minutes while D2000-1 deals and D2000-2 deals are time stamped in seconds.

Figure 2.3: D2000-1 conversation

```
From ''CODE'' ''FULL NAME HERE'' *0728GMT ????98 */7576
Our Terminal:  ''CODE''       Our user:  ''FULL NAME HERE''
    DEM 1
#   45.47
    BA> I BUY
#   TO CONFIRM AT 1,8147 I SELL 1 MIO USD
#   VAL ??(+2)??98
#   MY DEM TO ''FULL NAME HERE''
#   THANKS AND BYE
    TO CONFIRM AT 1,8147 I BUY 1 MIO USD
    VAL ??(+2)??98
    MY USD TO ''FULL NAME HERE''
    THANKS FOR DEAL FRDS. CHEERS
#
    # END REMOTE #

ˆ   ## TKT EDIT OF CNV 7576 BY ''CODE'' 0728GMT ????98
ˆ   STATUS CONFIRMED
ˆ   ##ENDED AT 07:27 GMT#

(   293 CHARS)
```

An example of a D2000-1 conversation when a trade takes place. The first word means that the call came “From” another dealer. There are information regarding the institution code and the name of the counterpart, and the time (Greenwich Mean), the date, and the number assigned to the communication. DEM 1 means that this is a request for a spot DEM/USD quote for up to USD 1 million, since it is implicitly understood that it is DEM against USD. At line 4, we find the quoted bid and ask price. Only the last two digits of the four decimals are quoted. In this case, the bid quote is 1.8145 and the ask quote is 1.8147. When confirming the transaction, the communication record provides the first three digits. In this case, the calling dealer buys USD 1 million at the price 1.8147. The record confirms the exact price and quantity. The transaction price always equals the bid or the ask. There is also information regarding the settlement bank. “My DEM to “Settlement bank” identifies the settlement bank of “our bank”, while “My USD to “Settlement bank” identifies the settlement bank of the other bank. It is usual to end a conversation with standard phrases, such as “thanks and bye,” “thanks for deals friends.”

one pip (that is, 0.0001 DEM).

2.3.3 The final data set

Table 2.1 reports statistics on the dealers' daily activity during the sample period. Dealer 1 has an average daily trading volume of USD 443 million. This is a small number compared with the daily trading volume in DEM/USD of USD 150 billion (BIS, 1998). However, there are hundreds of dealers working in the DEM/USD market. He characterizes himself as a medium-sized Market Maker in this market. Dealer 2 averages USD 142 million in DEM/USD. He also has some trading in European currency crosses. Dealer 3's average daily trading volume in NOK/DEM is DEM 270 million. He also trades in other currency pairs. Dealer 3 is one of the major players in the Norwegian market, with 25% of the daily NOK/DEM trading volume in the Norwegian market (BIS, 1998).[7] Dealer 4 also trades in several currency pairs. Her trading in DEM/USD averages USD 145 million. Trading in SEK/DEM is also important for this dealer. From table 2.1 we can see that there is considerable daily variation in turnover.

Table 2.1: Trading volumes and number of trades for each dealer

			Mon.	Tue.	Wed.	Thu.	Fri.	Total
Dealer 1	DEM/USD	Volume	302	491	464	395	562	2214
		Number	133	221	192	206	240	992
		% of all trades	100	100	100	100	100	100
Dealer 2	DEM/USD	Volume	138	164	178	82	150	712
		Number	95	99	111	56	91	452
		% of all trades	91	89	83	84	92	88
Dealer 3	NOK/DEM	Volume	354	281	314	62	337	1348
		Number	63	61	83	25	60	292
		% of all trades	50	54	67	42	48	53
Dealer 4	DEM/USD	Volume	115	201	82	31	298	727
		Number	64	126	47	18	180	435
		% of all trades	56	53	36	30	73	55

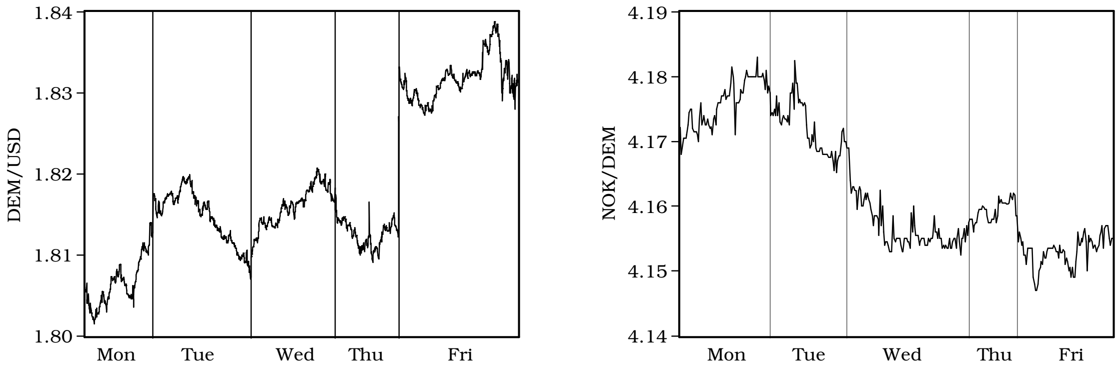
"Volume" is the total trading volume in USD for Dealer 1, Dealer 2 and Dealer 4, and the total trading volume in DEM for Dealer 3. "Number" is the number of trades in DEM/USD or NOK/DEM. "is the number of trades in DEM/USD for Dealers 1, 2 and 4, and the number of trades in NOK/DEM for Dealer 3, divided by the total number of trades.

The transaction prices for DEM/USD is presented in the left section of figure 2.4, while transaction prices for NOK/DEM is presented in the right section. Vertical lines indicate end of day.

Table 2.2 presents some statistics about the different types of trades. Statistics on the dealers are presented in four panels, a-d. Dealer 2 and Dealer 4 rely almost exclusively on electronic broker systems when trading DEM/USD. Electronic broker systems are also important for Dealer 1, and account for 77% of his total volume. Note that most of the outgoing trades are executed by D2000-2, while most of the incoming trades are executed by EBS. The dealers told us that their choice of trading incoming or outgoing at electronic trading systems is related to the fee structure. Dealer 3 also uses electronic broker systems to some extent, but only for 31% of total volume. The

[7] This number reflects NOK/DEM trading with at least one Norwegian bank as counterpart. Taking account of some NOK/DEM trading executed outside of Norway the share will be somewhat lower. The daily NOK/DEM volume in Norway is USD 0.7 billion, according to BIS (1998).

Figure 2.4: Transaction prices



a) DEM/USD transaction price

b) NOK/DEM transaction price

Transaction prices during the week. The source is all the spot transactions conducted electronically by the whole FX department of the bank. The horizontal axis is in "transaction"-time. Vertical lines indicate end of day.

majority of these trades are executed by D2000-2 because there is no active trading in NOK/DEM at EBS. Dealer 1 and Dealer 3 also use traditional voice brokers. For Dealer 1 voice-broker trades account for 11% of total volume, while for Dealer 3 the number is 9%.

Dealer 1 and Dealer 3 use direct trading to some extent, that is, they give quotes on request. They do not use outgoing direct trades since these were regarded as expensive. Dealer 3 also claimed to be concerned about not signaling his inventory position. For Dealer 1 direct trading accounts for less than 10% of total volume, while for Dealer 3 direct trading accounts for 25% of total volume.

Dealer 2 and Dealer 4 have some customer trading, but not in DEM/USD. For Dealer 1 customer trades account for only 3% of total trading. Customer trading is very important for Dealer 3. About 17% of his trading in NOK/DEM are with customers. In addition, he has considerable customer trading in other currency crosses. Most important is NOK/USD.

Dealers use internal trades to adjust their inventory position. Instead of trading in the market, they can trade with another dealer in the same bank. All dealers have some internal trades.

Table 2.3 compares our dealers with the market average and the dealer in Lyons' (1995) study. The interbank trading is split into three categories: Direct trades, traditional broker trades and electronic broker trades. The "Nature of Business" refers to banks' trading. Customer trading is the main source of demand for currency. The two columns with "Survey Data" are calculated from Cheung and Chinn (1999) and Cheung et al. (2000). These surveys favor customer orders somewhat compared with previous studies which have estimated customer orders at around 20% of turnover (see BIS, 1998). We calculate similar numbers for our dealers and Lyons' (1995) dealer.

From table 2.3 we see that direct trading and traditional voice-brokers have lost market shares to electronic broker systems.[8] Except Dealer 3, our dealers rely more heavily on electronic broker

[8]Since voice-brokers have no access to the electronic brokers, there is also the problem of knowing the prices they compete against. Furthermore, their information advantage from seeing much flow has also decreased making it even harder to give competitive quotes. Dealers have also told us that the market share of the electronic systems is increasing

Table 2.2: Descriptive statistics

Panel *a* Dealer 1	Direct trading D2000-1 Inc.	Teleph.	Electronic brokers D2000-2 Inc.	D2000-2 Out.	EBS Inc.	EBS Out.	Voice broker	Customer	Internal trades	Total
No. of trades	78	1	109	276	250	177	57	23	21	992
– % total	7.9	0.1	11.0	27.8	25.2	17.8	5.7	2.3	2.1	100
Volume	125	5	203	606	456	447	242	72	58.9	2214
– % total	5.6	0.2	9.2	27.4	20.6	20.2	10.9	3.2	2.7	100
Average size	1.6	NA	1.9	2.2	1.8	2.5	4.2	3.1	2.8	
Median size	1.0	NA	1.0	2.0	1.0	2.0	5.0	1.0	2.5	
Stdev.	1.7	NA	1.1	1.3	1.2	1.5	2.0	4.2	2.9	
Min	0.3	NA	1.0	1.0	1.0	1.0	1.5	0.1	0.1	
Max	10.0	NA	5.0	8.0	10.0	9.0	10.0	15.0	10.5	

Panel *b* Dealer 2	Direct trading D2000-1 Inc.	Teleph.	Electronic brokers D2000-2 Inc.	D2000-2 Out.	EBS Inc.	EBS Out.	Voice broker	Customer	Internal trades	Total
No. of trades	5	0	35	191	151	65	0	0	5	452
– % total	1.1	0.0	7.7	42.3	33.4	14.4	0.0	0.0	1.1	100
Volume	5	0	63	316	215	106	0	0	7	712
– % total	0.7	0.0	8.8	44.4	30.2	14.9	0.0	0.0	1.0	100
Average size	1.0	NA	1.8	1.7	1.4	1.6	NA	NA	1.4	
Median size	1.0	NA	2.0	1.0	1.0	1.0	NA	NA	1.0	
Stdev.	0.4	NA	0.8	0.9	0.7	0.8	NA	NA	1.1	
Min	0.5	NA	1.0	1.0	1.0	1.0	NA	NA	0.1	
Max	1.5	NA	3.0	5.0	3.0	3.0	NA	NA	3.0	

Panel *c* Dealer 3	Direct trading D2000-1 Inc.	Teleph.	Electronic brokers D2000-2 Inc.	D2000-2 Out.	EBS Inc.	EBS Out.	Voice broker	Customer	Internal trades	Total
No. of trades	90	3	59	46	0	2	16	50	26	292
– % total	30.8	1.0	20.2	15.8	0.0	0.7	5.5	17.1	8.9	100
Volume	337	4	223	176	0	20	114	246	227.9	1348
– % total	25.0	0.3	16.5	13.1	0.0	1.5	8.5	18.3	16.9	100
Average size	3.7	1.4	3.8	3.8	NA	10.0	7.1	4.9	8.8	
Median size	0.6	1.5	3.0	3.0	NA	10.0	5.0	3.0	5	
Stdev.	4.9	0.3	2.5	2.5	NA	0.0	2.4	7.7	13.3	
Min	0.0	0.8	1.0	1.0	NA	10.0	4.0	0.0	0.1	
Max	40.0	2.0	20.0	14.0	NA	10.0	15.0	50.0	65	

Panel *d* Dealer 4	Direct trading D2000-1 Inc.	Teleph.	Electronic brokers D2000-2 Inc.	D2000-2 Out.	EBS Inc.	EBS Out.	Voice broker	Customer	Internal trades	Total
No. of trades	0	1	110	109	168	35	0	0	12	435
– % total	0.0	0.2	25.3	25.1	38.6	8.0	0.0	0.0	2.8	100
Volume	0	1	196	235	227	58	0	0	10	727
– % total	0.0	0.1	27.0	32.3	31.2	8.0	0.0	0.0	1.4	100
Average size	NA	1	1.8	2.2	1.4	1.7	NA	NA	0.8	
Median size	NA	1	2.0	2.0	1.0	2.0	NA	NA	0.5	
Stdev.	NA	NA	0.7	1.0	0.6	0.7	NA	NA	0.4	
Min	NA	1	1.0	1.0	1.0	1.0	NA	NA	0.1	
Max	NA	1	5.0	8.0	5.0	3.0	NA	NA	3.0	

The table lists different types of trades over the sample period, one week in March 1998. If possible, the trades are separated as incoming (inc.) or outgoing (out.). All dealers use D2000-1 only for incoming trades. Volume numbers are measured in USD for Dealer 1, Dealer 2 and Dealer 4 and in DEM for Dealer 3.

Table 2.3: FX transaction types

	Survey Data 1997/98	1992/93	Dealer 1	Dealer 2	Dealer 3	Dealer 4	Lyons' Dealer
				Transactions Interbank:			
Direct	34.6%	47.7%	6.2%	0.7%	39.0%	0.1%	66.7%
Trad. Brokers	16.5%	48.5%	11.6%	0.0%	13.0%	0.0%	33.3%
El. Brokers	48.8%	3.9%	82.2%	99.3%	47.9%	99.9%	0.0%
				Nature of Business:			
Interbank	65.7%	66.9%	96.7%	100%	78.0%	100%	100%
Customer	34.3%	33.1%	3.3%	0.0%	22.0%	0.0%	0.0%

The survey data are from Cheung and Chinn (1999) (USA) and Cheung et al. (2000) (UK). The numbers are not remarkably different in the two surveys, and the reported numbers are calculated as simple averages. The surveys were conducted during 1997 and 1998, respectively. The dealers were asked about their current trading, and their trading "5 years ago", which then becomes 1992 or 1993. Numbers for our dealers are calculated from table 2. "Lyons' Dealer" is from Lyons (1995). His data is from 1992, while our data is from March 1998.

systems than the average. Dealer 3's trading is close to the average. Lyons' (1995) dealer is not only very different from our dealers, but is also different from the average dealer in 1992/1993. First, he relies more heavily on direct trading and less heavily on traditional voice brokers than the average. Second, he has no customer orders. This dealer earns money from the bid and ask spread in the inter-dealer market. This means that the majority of his trades are direct and incoming. To adjust his inventory position he uses quote shading instead of outgoing trades.

2.4 The Madhavan and Smidt model

This section presents the model that we test empirically. We use the model of Madhavan and Smidt (1991), which is the same model as in Lyons (1995) and Yao (1998).

Consider a pure exchange economy with a risk free (the numeraire) and a risky asset with a stochastic liquidation value. The risky asset is traded at times $t = 1, 2, ..., T$. The model focuses on the pricing decision of a representative dealer i (market maker). Each period is characterized by one incoming order at dealer i's quote. Incoming means that the bilateral contact was initiated by dealer i's counterpart, denoted j (aggressor). Dealer j may have private information when he contacts dealer i, while dealer i does not have access to private information when he quotes prices. To take account of this asymmetry, dealer i quotes prices that can be contingent on order size. Hence, dealer i provides dealer j with a price schedule. Given the quoted prices, dealer j decides whether and how much to trade. After the trade, dealer i can revise the quotes for the next trade based on new public information.

The full information price of the risky asset (currency) at time T is denoted by $\tilde{V}$. It is composed of a series of increments (e.g. interest differentials), such that $\tilde{V} = \sum_{i=0}^{T} \tilde{r}_i$, where r_0 is a known constant. The increments are $i.i.d.$ with a mean of zero. The increment r_t is realized immediately after trading in period t. Announcements of the increments represent the flow of public information over time. The currency value is thus $V_t = \sum_{i=0}^{t} r_i$. At the time of quoting and trading

very fast. In DEM/USD (or USD/EUR), the winning electronic broker system seems to be EBS. The liquidity is very high. Sometimes it is possible to trade for amounts of EUR 100 million.

in period t, which is before $\widetilde{r}_t$ is realized, V_t is a random variable. In a market without transaction costs or further information, the quoted currency price would equal V_{t-1}, the expected value of the asset conditional on public information at t.

In reality, prices will deviate from expected values because of microstructure elements. The Madhavan and Smidt model incorporates information and inventory effects through two postulated behavioral equations. The first is a typical inventory model. In this model, price (P_{it}) is linearly related to the dealer's current inventory (I_{it}):

$$P_{it} = \mu_{it} - \alpha(I_{it} - I_i^*) + \gamma D_t, \tag{2.1}$$

where μ_{it} is the expectation of V_t conditional on information available to dealer i at t, and I_i^* is the desired inventory position. The inventory response effect (α) is negative because the dealer may want to "shade" (reduce) his price to induce a sale if the inventory is above the preferred level. It is a function of interest rates, firm capital, and inventory carrying costs. The term D_t is a direction-dummy that takes the value 1 if it is a sale (trade at the ask) and -1 if it is a buy (trade at the bid), as seen by dealer i. Since the quoted spread is expected to widen with quantity to protect against adverse selection, we may think of γD_t as half of the spread for quantities close to zero.

The second behavioral equation (2.2) defines the quantity Q_{jt} dealer j wants to trade in period t:

$$Q_{jt} = \theta(\mu_{jt} - P_{it}) + X_{jt}, \tag{2.2}$$

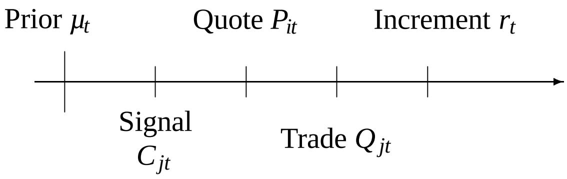
where μ_{jt} is the expectation of V_t conditional on information available to dealer j at time t, and X_{jt} is an idiosyncratic shock that represents inventory-adjustment trading. The demand of the contacting dealer j, (2.2), is optimal when dealers maximize exponential utility over end-of-period wealth. Thus, the quantity dealer j chooses to trade is linearly related to the deviation between dealer j's expectation and dealer i's price quote (P_{it}), plus a term representing inventory-adjustment trading. Since X_{jt} is only known to trader j, Q_{jt} only provides a noisy signal to dealer i of V_t. Note that Q_{jt} will be positive for sales to dealer j and negative for purchases.

Dealer i will set 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 conditional on observing the size and the direction of the order, dealer i does not want to change his quote. In the foreign exchange market, dealer j will typically request quotes for a particular quantity (and not for the entire price schedule). If the contacting dealer buys, the bid price reflects the expectation conditional on a buy.

Dealer i's price schedule is a function of his expectation of V_t at the time of quoting (μ_{it}) (see (2.2)). The expectation is conditioned on the signals described in figure 2.5. Although this information structure describes a trade between two dealers in a dealership market, this set-up may also be relevant in broker trades. The analogy is that dealer i submits a limit order to a broker. In this case it is dealer i that decides quantity. However, dealer i must still consider the case where another dealer trade at his quotes.

Both dealers' prior belief (μ_t) on the full information value V_t are each period based on public

Figure 2.5: Information structure within period t



At the beginning of each period all information is public and each dealer holds the same prior belief. Before trading in the period dealer j observes a private signal. Then dealer j requests for a quote P_{it} from dealer i. The trade Q_{jt} is then realized. At the end of the period all information is made public, hence private information is only short-lived.

information, such as public news and information on market-wide order flows from brokers, and is given by

$$\mu_t = V_t + \tilde{\eta}_t. \tag{2.3}$$

The noise term, $\tilde{\eta}_t$, is independently normally distributed around zero with variance σ^2_η. Also at the beginning of each period t, dealer j receives a private signal C_{jt} of V_t,

$$\tilde{C}_{jt} = V_t + \tilde{\omega}_{jt}, \tag{2.4}$$

where the noise term, $\tilde{\omega}_{jt}$, is independently normally distributed around zero with σ^2_ω.[9] An important source of private information is a customer deal.[10] For dealer i the quantity actually traded with dealer j gives a signal of C_{jt}.

To derive the price-schedule we need to insert for the expectations in (2.1) and (2.2). After observing the private signal C_{jt}, dealer j's posterior (μ_{jt}) can be expressed as

$$\mu_{jt} = \lambda\mu_t + (1-\lambda)C_{jt}, \tag{2.5}$$

where $\lambda = \sigma^2_\omega/(\sigma^2_\eta + \sigma^2_\omega)$ since $\tilde{\eta}_t$ and $\tilde{\omega}_{jt}$ are independent of one another. Dealer i conditions on various possible Q_{jt}'s when setting his prices. More specifically, dealer i forms the sufficient statistic Z_{jt} given by

$$Z_{jt} = \frac{Q_{jt}/\theta + P_{it} - \lambda\mu_t}{1-\lambda} = V_t + \omega_{jt} + \frac{1}{\theta(1-\lambda)}X_{jt}. \tag{2.6}$$

Equations (2.2) and (2.5) are used to derive the second equality. Z_{jt} is normally distributed with mean V_t and variance σ^2_{Zj} (equal to the variance of the two last terms). Furthermore, Z_{jt} is statisti-

[9] In the model, only dealer j observes a private signal, while the quoting dealer i does not. However, most interbank dealers receive some private signals from customer order flows. A dealer cannot choose when information arrives. Therefore, dealer i may have private information while he gives quotes. Bjønnes and Rime (2000) extends the Madhavan and Smidt (1991) model to a situation where both dealer j and dealer i observe a private signal.

[10] Notice, although C_{jt} is a private signal, it is drawn from a common distribution. This is necessary to posit the demand equation in (2.2) where the θ-parameter is common for all dealers.

cally independent of μ_t. Dealer i's posterior belief (μ_{it}) is a weighted average of μ_t and Z_{jt},

$$\mu_{it} = \kappa\mu_t + (1-\kappa) Z_{jt}, \tag{2.7}$$

where $\kappa = \sigma^2_{Zj}/(\sigma^2_\eta + \sigma^2_{Zj})$. Using the first equality in (2.6), we see that dealer i's posterior belief is expressed as a function of any Q_{jt},

$$\mu_{it} = \phi\mu_t + (1-\phi)\left(\frac{Q_{jt}}{\theta} + P_{it}\right), \tag{2.8}$$

where $\phi = \kappa - \lambda(1-\kappa)/(1-\lambda)$.[11] Inserting (2.8) into (2.1) gives

$$P_{it} = \mu_t + \frac{1-\phi}{\phi\theta} Q_{jt} - \frac{\alpha}{\phi}(I_{it} - I_i^*) + \frac{\gamma}{\phi} D_t. \tag{2.9}$$

To test this equation, we need to replace μ_t which is unobservable to the econometrician. The usual way to do this (e.g. Madhavan and Smidt, 1991; Lyons, 1995) is to express the period t prior belief as equal to the period $t-1$ posterior, plus an expectational error term ε_{it}. The error term represents public information that arrives between trades. Hence,

$$\mu_t = \mu_{it-1} + \varepsilon_{it} = P_{it-1} + \alpha(I_{it-1} - I_i^*) - \gamma D_{t-1} + \varepsilon_{it}. \tag{2.10}$$

Substituting this expression for μ_t into (2.9), gives

$$\Delta P_{it} = \left(\frac{\alpha}{\phi} - \alpha\right) I_i^* + \left(\frac{1-\phi}{\phi\theta}\right) Q_{jt} - \left(\frac{\alpha}{\phi}\right) I_{it} + \alpha I_{it-1} + \left(\frac{\gamma}{\phi}\right) D_t - \gamma D_{t-1} + \varepsilon_{it}. \tag{2.11}$$

Thus, the baseline model to test is

$$\Delta P_{it} = \beta_0 + \beta_1 Q_{jt} + \beta_2 I_{it} + \beta_3 I_{it-1} + \beta_4 D_t + \beta_5 D_{t-1} + \varepsilon_{it}, \tag{2.12}$$

This baseline model corresponds to the model in Lyons (1995), excluding his variable on market wide order flows. Since we are computing the price change between two successive incoming trades, the perfect collinearity between inventory and trade quantity breaks down. The coefficients β_1 and β_3 measure the information effect and inventory effect, respectively, while β_4 measures the transaction costs for small quantities. The model predicts that $\{\beta_1, \beta_3, \beta_4\} > 0$, $\{\beta_2, \beta_5\} < 0$, $|\beta_2| > \beta_3$, $\beta_4 > |\beta_5|$. The latter inequalities derive from the fact that $0 < \phi < 1$.

[11] In the model it is assumed that the precision of a signal reflected in θ is the same for all dealers. However, larger banks see more customer order flow. Thus, the assumption of equal precision may not hold. Since dealers know the identity of the counterpart in a bilateral trade, one can argue that they also have some knowledge of their precision. In broker trades the counterpart is anonymous when quoting. With information on counterparts, it is possible to construct variables that captures this by interviewing the dealers in question about whether a specific bank are better or worse informed than him (Bjønnes and Rime (2000)).

The error term in this model is MA(1):

$$\varepsilon_{it} = \beta_6 \nu_{it-1} + \nu_t, \nu_t \sim IID\left(0, \sigma_\nu^2\right). \tag{2.13}$$

where $\beta_6 < 0$ due to the use of former incoming trade as an proxy for this periods prior belief (See Madhavan and Smidt (1991)).

2.5 The Madhavan and Smidt model: Estimation results

In section 2.5.1 we present some descriptive statistics on the regression variables. Estimation results for the baseline model are presented in section 2.5.2. Here, our results are directly comparable to similar studies, for instance Lyons (1995) and Madhavan and Smidt (1991). Finally, we discuss the results in section 2.5.3.

2.5.1 Descriptive statistics

Descriptive statistics for relevant variables used in estimation, plus inter-transaction times, are reported in table 2.4. The baseline model considers only incoming trades. For our dealers, more than 90% of all trades are signed as incoming or outgoing. Dealer 2 has the lowest share of incoming trades (43%), while Dealer 3 has the highest share (76%).

We focus on DEM/USD trading for Dealer 1, Dealer 2 and Dealer 4, and NOK/DEM trading for Dealer 3. Inventories are measured in USD for the DEM/USD dealers and in DEM for the NOK/DEM dealer. Since Dealer 2 and Dealer 4 trade in several currency pairs, their DEM inventory need not mirror their USD inventory exactly. Similarly, the NOK inventory of Dealer 3 may not mirror his DEM inventory exactly. We believe that a DEM/USD dealer located in Europe face higher risks with a USD inventory than a DEM inventory. Similarly, a dealer in NOK/DEM working out of Norway will most likely be more concerned about his DEM inventory than his NOK inventory. The correlation between USD and DEM inventories is -0.98 for Dealer 2 and -0.53 for Dealer 4. The correlation between Dealer 3's DEM and NOK inventories is -0.79. Our results are not very sensitive to whether inventories are measured in DEM or USD for our DEM/USD dealers or in NOK or DEM for our NOK/DEM dealer.

2.5.2 Baseline model

Table 2.5 presents the results for the four dealers over the five-day sample. The results of Lyons (1995) are also reported for comparison. We have deleted the overnight price changes since it is the pricing decision intra day 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 heteroscedastisty and autocorrelation of unknown form. We have also estimated the model with the Hildreth-Lu procedure, which is a linear estimation procedure for autoregressive error terms (results not shown here). Whether we use GMM or

Table 2.4: Descriptive statistics on regression variables: Sample moments for incoming trades

		ΔP_{it}	Abs(ΔP_{it})	Q_{jt}	Abs(Q_{jt})	I_{it}	Abs(I_{it})	Δt
	Mean	0.1	4.5	0.25	1.80	-0.05	4.25	5.22
Dealer	Median	0.0	3.0	1.00	1.00	0.00	3.82	2.33
1	Maximum	46.0	82.0	10.00	10.00	18.38	21.82	62.57
DEM/	Minimum	-82.0	0.0	-5.00	0.25	-21.82	0.00	0.00
USD	Std. Dev.	7.7	6.3	2.22	1.32	5.72	3.81	8.14
	Mean	-0.3	6.9	0.18	1.48	0.06	0.67	13.46
Dealer	Median	0.0	4.0	1.00	1.00	0.00	0.00	4.88
2	Maximum	51.0	51.0	3.00	3.00	4.00	4.00	69.75
DEM/	Minimum	-50.0	0.0	-3.00	0.50	-3.00	0.00	0.02
USD	Std. Dev.	11.0	8.6	1.64	0.71	1.16	0.95	17.47
	Mean	0.4	12.1	-0.85	3.77	1.17	9.50	15.69
Dealer	Median	0.0	10.0	-0.28	2.00	1.72	6.10	7.64
3	Maximum	50.0	55.0	20.00	40.00	48.13	48.13	102.60
NOK/	Minimum	-55.0	0.0	-40.00	0.02	-40.17	0.15	0.02
DEM	Std. Dev.	16.8	11.7	6.40	5.24	13.25	9.27	20.03
	Mean	-0.1	4.5	-0.20	1.53	-0.50	2.07	7.34
Dealer	Median	-0.1	2.0	-1.00	1.00	-0.76	1.76	0.55
4	Maximum	40.0	41.0	5.00	5.00	8.24	10.76	373.42
DEM/	Minimum	-41.0	0.0	-5.00	1.00	-10.76	0.00	0.00
USD	Std. Dev.	8.0	6.7	1.73	0.83	2.64	1.71	30.71

ΔP_{it} is the change in price between to 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.

Hildreth-Lu does not affect any of our conclusions. Madhavan and Smidt (1991) and Yao (1998) use GMM, while Lyons (1995) uses the Hildreth-Lu procedure. 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 heteroscedastisty 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.

The model receives very little support for our data set. The "+" and "-" in parentheses in the first row 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}, which measure the effective spread for Q_{jt} close to zero. For DEM/USD, the estimated baseline spread, $(2 \times D_t)$, varies between 3.3 (2×1.65) to 10.5 (2×5.24) pips. These estimates are implausible high. For NOK/DEM the estimated spread is 10.8 (2×5.38). There is no evidence that dealers increase the quoted spread to protect against private information when volume (Q_{jt}) increases. Similarly, there is no evidence that dealers control inventory by adjusting their quotes to induce a trade in a certain direction.

In search for information and inventory effects, we did several experiments. First, we excluded small trades (less than one million). Second, we tried to exclude extreme observations (large price changes). Third, we included customer orders in the sample. Fourth, we addressed the potential importance of transaction time. The Madhavan and Smidt model does not imply any relation between inter-transaction time and the information content of order flow. However, other modeling approaches suggest such a relationship. In Easley and O'Hara (1992) order flow is

Table 2.5: Results for the baseline model, equation (2.12). Regression of ΔP_{it} between incoming trades

	Dealer 1 DEM/USD	Dealer 2 DEM/USD	Dealer 3 NOK/DEM	Dealer 4 DEM/USD	Lyons DEM/USD
Constant	0.01	-0.86	-1.24	0.92	-0.13
	(0.04)	(-1.05)	(-1.14)	(1.24)	(-0.99)
Trade Q_{jt} (+)	-0.13	-0.96	0.13	-1.41	0.14
	(-0.50)	(-1.11)	(0.50)	(-0.89)	***(3.03)
Inventory I_t (-)	0.06	2.52	-0.07	-0.80	-0.10
	(0.55)	***(3.19)	(-0.37)	(-0.75)	***(-3.56)
Inventory I_{t-1} (+)	-0.03	-0.98	-0.13	0.36	0.08
	(-0.30)	(-0.79)	(-0.67)	(0.37)	***(2.95)
Direction D_t (+)	1.65	5.24	5.38	3.62	1.04
	***(2.47)	***(3.03)	***(3.59)	**(1.96)	***(4.86)
Direction D_{t-1} (-)	-0.25	-1.07	-7.26	-0.23	-0.92
	(-0.71)	(-1.65)	***(-5.31)	(-0.29)	***(-6.28)
AR(1)	-0.06	-0.09	0.03	0.04	-0.01
	(-1.02)	(-0.91)	(0.49)	(1.02)	***(-2.61)
Adjusted R^2	0.02	0.08	0.23	0.01	0.22
Observations	432	186	144	272	839

Estimated by GMM and variable Newey-West correction. t-values in parenthesis, and "***", "**" and "*" indicate significance at the 1%, 5% and 10%-level, respectively. All coefficients multiplied by 10^4, except the AR(1) term. "Lyons DEM/USD" is from Lyons' (1995). He uses the Hildreth-Lu procedure. The dependent variable is ΔP_{it}, and is the change in price between to 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 end 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 row indicate the expected sign of the coefficient. We use all incoming trades at the D2000-1 (direct trading), D2000-2 and EBS (indirect trading).

more informative when trading intensity is high, while Admati and Pfleiderer (1988) suggest the opposite. None of the experiments changed the results presented in table 2.5 significantly.

Next, consider the results for Lyons' dealer. Here, all coefficients have 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.

2.5.3 Discussion

The two most obvious explanations for these different results are (i) difference in trading styles and (ii) changes in trading environment. Lyons' dealer is a typical "jobber." He makes money from the bid-ask spread in the interbank market. To earn money he must be at the favorable side of the bid and ask most of the time. This means that the majority of trades must be incoming. Of total 952 signed trades, 843 are incoming (89%). All these trades are executed using D2000-1. Since the dealer earns money from the bid-ask spread, he controls his inventory position mainly through quote shading. By shading quotes he makes one price particularly attractive to induce a trade in a certain direction. Since the dealer does not have any customer order flow, i.e. private information signals, he is less concerned about signalling his inventory position through prices. To protect against private information the dealer widens his bid-ask spread with quantity requested. As discussed in section 2.2, direct trading is probably the most informative trading channel. The dealer also had agreements to trade with several large dealers, making it important to protect against private information. This may explain the information effect.

The results of Lyons's must be evaluated with regard to the existing market structure in 1992. At that time, trading opportunities were limited to direct trading through D2000-1 (or telephone), or indirect trading through voice-brokers. Electronic brokers have introduced a new channel for inventory control, and most likely lead to increased transparency. The new market environments may thus decrease the importance of private information, while inventory control has become easier.

Like Lyons' dealer, Dealer 2 and Dealer 4 have only limited customer order flows. However, these dealers do not make money from the bid and ask spread since their share of incoming and outgoing trades are roughly similar. Hence, these dealers make money from exchange rate movements. Both dealers take limited positions for a short time using electronic broker systems. Most pronounced is this trading strategy for Dealer 2. The dealers have told us that the size of position taking depends on the liquidity of the electronic broker systems. When liquidity is good they take larger open positions than if liquidity is poor. Hence, their trading style may explain the insignificant coefficients in table 2.5. Dealer 1 shares some of the trading characteristics of Dealer 2 and Dealer 4. However, he also trades direct using D2000-1 and he has some customer orders.

Dealer 3 has large customer order flows. He told us that he does not want to use quote shading because he was concerned about signaling his inventory position to other dealers. The lack of any information effect is harder to explain, but note that the number of observations is limited. We explore this closer in the next section.

There are several reasons to believe that the model is better suited for "jobbers" like Lyons' dealer than for other types of dealers. In a survey by Cheung et al. (2000), dealers in UK were asked which best characterized their dealing method. The answers were equally shared between the four categories: "Technical trading-based", "Customer orders-based", "Fundamentals-based" and "Jobbing." Our dealers belong to the three first mentioned categories. Further, between 1992/1993 and 1997/1998, the share of dealers that said they belonged to the "Jobber" category decreased remarkably. The introduction of electronic brokers is a likely explanation of this finding.

2.6 Microstructure effects under the new market structure

This section focuses on inventory control (section 2.6.1) and information effects (section 2.6.2) under the new trading environment.[12] The Madhavan and Smidt model incorporates inventory

[12]In the appendix, we extend the Madhavan and Smidt model by letting the information effect and the degree of quote shading depend on the trading system used. Tests are only conducted for Dealer 1 and Dealer 3 because they are the only dealers with sufficient number of transactions at the direct trading system D2000-1. For Dealer 1 there is weak evidence of an information effect in direct trading, while for Dealer 3 there is evidence of an information effect in trades executed by electronic brokers. The small numbers of direct trades makes it difficult to examine whether the dealers increase their spread to protect against adverse selection or use quote shading to control their inventory position

control only through quote shading in incoming trades. However, dealers can also adjust their inventory positions through outgoing trades. Instead of only focusing on quote shading as a tool for inventory control, which is common in microstructural models, we will explore how dealers use all their trading options.

This section starts by showing that inventory control is important for the dealers we study (2.6.1). We proceed by examining inventory control through quote shading in incoming direct trades more closely (2.6.1). Next, we study inventory control through broker trades (2.6.1). Finally, we examine whether private information is important when setting bid and ask quotes in direct trades (2.6.2), and if order flow from electronic broker trades carry private information (2.6.2).

2.6.1 Inventory control

Mean reversion

Consider a simple model of inventory time series consistent with inventory control models:

$$I_{it} - I_{it-1} = \alpha + \beta I_{it-1} + \varepsilon_t, \tag{2.14}$$

where $I_t - I_{it-1}$ is the change in inventory from the previous trade, incoming or outgoing. Inventory control implies that dealers adjust inventories toward a desired level. This behavior leads to mean reversion. Figure 2.2 suggests that inventory control is important to our dealers. We formally test for inventory control by examining whether a given inventory series follows a random walk. Inventory is random walk if $\beta = 0$, while mean reversion predicts that $\beta < 0$.

Table 2.6 presents the results. The null hypothesis of a unit root is strongly rejected (1% level) by the Phillips-Perron test (Perron, 1988). Since the mean reversion parameter (β) varies between -0.11 and -0.81, this means that our dealers reduce inventory by 11 to 81% during the next trade. This suggests that 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 Dealer 1 and Dealer 3, while mean reversion is very strong for Dealer 2. The implied half-life is calculated from β and mean or median intertransaction time. It varies between 6.6 minutes (6 minutes and 36 seconds) and 33.9 minutes (33 minutes and 54 seconds). Since the dealers have some breaks during the trading day (for instance lunch), median transaction time is more relevant when characterizing trading style. Note that the implied half-life calculated using the median intertransaction time is less than one minute for Dealer 2 and less than 2 minutes for Dealer 4.

Lyons (1997) estimates the implied half-life, using mean intertransaction 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 in table 2.6. Typically, dealers reduce the inventory by roughly 50% in the next trade. Results from

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in these trades. We will therefore use the observed spread from direct trades to examine quote shading and adverse selection in direct trades.

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, also this estimate is much slower than what we observe for our dealers.

Table 2.6: Results for equation (2.14). Mean reversion in dealer inventory (I_{it})

	Dealer 1 DEM/USD	Dealer 2 DEM/USD	Dealer 3 NOK/DEM	Dealer 4 DEM/USD
β	-0.11	-0.81	-0.18	-0.24
Test statistic	***(-6.39)	***(-17.76)	***(-5.24)	***(-7.46)
Implied half-life (mean)	15.8 min	6.6 min	33.9 min	17.5 min
Impled half-life (median)	3.7 min	0.7 min	12.3 min	1.45 min
Observations	987	447	287	430

The dependent variable is the change in dealer inventories from the previous trade (in USD for Dealer 1, Dealer 2 and Dealer 4 and in DEM for Dealer 3), incoming or outgoing. The explanatory variable is lagged inventory. The first row reports the mean reversion coefficient β. The second row reports the test statistic from a Phillips-Perron (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). Six lags are included for Dealer 1, while five lags are included for the other dealers. "***" indicate that the null hypothesis of one unit root can be rejected at the 1significance level. The implied half-life is calculated as mean or median intertransaction time times ln(2)/ln(1+β).

Inventory control in direct trades

D2000-1 conversations let us examine whether quote shading is important or not in a very simple manner. In a D2000-1 conversation, the initiator typically requests bid and ask quotes for a certain amount. Of conversations, which ended with a trade, this was the case for 61 out of 78 conversations for Dealer 1 and 67 out of 90 conversations for Dealer 3. In the remaining trades, the initiator requests only one-sided quotes (bid or ask). In these trades, the initiator typically (but not always) asked for only a small amount.

We construct a simple test for quote shading. The intuition behind the test is also simple. When Dealer 1 realizes that his USD inventory is large, he may reduce his USD inventory position by selling USD at the ask in an incoming direct trade. He may thus have an incentive to reduce his ask price to induce a purchase by the initiator. Similarly, if his USD inventory is small (short in USD), he may have an incentive to increase the bid price to induce a sale by the initiator. Exactly the same arguments apply to Dealer 3 and his DEM inventory. Hence, it is most likely to observe a buy at the ask by the initiator (or sell at the bid) when dealer inventory is large (small).

Table 2.7 presents our results. In the probit regressions, the dependent variable takes the value one if the trade is executed at the ask and zero if the trade is executed at the bid. The explanatory variable is the lagged inventory position. If quote shading is present, we expect that the coefficient on lagged inventory is significantly larger than zero. Results in table 2.7 are strong evidence against quote shading as a tool for inventory control. Hence, this supports the results in table 2.5.

Table 2.7: Probit-regression of quote shading in incoming direct trades

	Dealer 1 DEM/USD	Dealer 3 NOK/DEM
Constant	-0.045	-0.311
	(-0.28)	*(-1.96)
Lagged inventory (I_{it-1})	0.048	-0.016
	(1.38)	(-1.08)
McFadden's R^2	0.02	0.01
Observations	62	67

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 lagged one period. z-values are in parenthesis, and "*" indicates significance at the 10%-level. R^2 is McFadden's analog to ordinary R^2-measures.

Inventory control through broker trades

Dealers can control their inventory position by submitting limit orders (incoming) or market orders (outgoing) to a broker. When submitting a limit order, a dealer has to wait for other dealers to trade at his quotes, while a market order is executed immediately. An advantage of a limit order is that the trade is executed at the bid when buying and at the ask when selling. Table 2.8 studies dealers' choice between submitting a limit order or a market order to an electronic broker. In the probit regressions, 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, a dummy which takes the value one if the previous trade was an incoming direct trade and zero otherwise, a dummy which takes the value one if previous trade was with a customer and zero otherwise, absolute lagged inventory and the dependent variable lagged.

Table 2.8: Probit-regression of incoming/outgoing trade

	Dealer 1	Dealer 2	Dealer 3	Dealer 4
Constant	-0.096	0.247	-0.334	-0.768
	(-0.88)	(1.56)	(-1.11)	***(-5.03)
Absolute trade size $(Abs(Q_{jt}))$	0.152	0.290	0.014	0.340
	***(4.69)	***(3.43)	(0.32)	***(4.97)
Previous trade was direct (incoming)	-0.393	0.600	0.369	
	**(-2.31)	(0.87)	(1.15)	
Previous trade was with customer	-0.420		0.447	
	(-1.24)		(1.21)	
Absolute inventory, lagged $(Abs(I_{it-1}))$	0.018	-0.407	0.001	-0.099
	(1.61)	***(-6.33)	(0.07)	***(-2.70)
Incoming/Outgoing last trade	-0.229	-0.177	-0.445	-0.026
	**(-2.38)	(-1.35)	(-1.17)	(-0.19)
McFadden's R^2	0.03	0.09	0.05	0.06
Observations	811	441	106	421

Probit regression of Incoming/Outgoing trade decision. Incoming trades are 0, while outgoing trades are coded 1. The dummy "Previous trade was direct" (incoming) equals one if previous trade was executed using D2000-1. The dummy "Previous trade was with customer" equals 1 if previous trade was with a customer. R^2 is McFadden's analog to ordinary R^2-measures.

For Dealer 3, we find no significant coefficients. The DEM/USD dealers tend to trade outgoing when trade size is large. When hitting other dealers' limit orders (outgoing trade), the dealer can have several counterparts. Execution is immediate, and we thus record this as a single trade. On the other hand, when the dealer submit a limit order (incoming trade) the dealer may not be hit by another dealer for the entire order. Hence, it may take some time before the entire order is fulfilled. The dealer can also choose to withdraw his limit order. This difference may explain the significant coefficient on absolute trade size. There is evidence that Dealer 1 submits limit orders on electronic broker systems (incoming trades) to adjust his inventory position after an incoming direct trade. Dealer 1 also tends to trade outgoing if the previous trade was incoming. Both Dealer 2 and Dealer 4 tend to submit limit orders when their absolute inventory position is large. However, in table 2.5 we find no evidence that these dealers shade quotes to control their inventory position. Moreover, our findings are consistent with those of Manaster and Mann (1996). Similar to futures scalpers, the inventories of Dealer 2 and Dealer 4 show strong mean reversion, while there is no sign of quote shading in incoming trades. As noted by Manaster and Mann (1996) for futures scalpers, our FX dealers are not merely passive order fillers, but are profit-seeking individuals with heterogeneous levels of information and/or trading skills.

Table 2.9 outlines the different options available for dealers through broker trades. Trades that increase the absolute size of the inventory are accumulating, while trades that decrease the absolute size of the inventory are decumulating. The dealers use outgoing trades both to reduce and to increase their absolute inventory position. This clearly illustrates that their target inventory position varies. The target inventory position can vary for two reasons: (i) in anticipation of a customer order or (ii) for speculative reasons. While both motives are relevant for Dealer 1 and Dealer 3, only the last motive is relevant for Dealer 2 and Dealer 4. For Dealer 2 and Dealer 4 there is a tendency for outgoing trades through D2000-2 to increase the absolute inventory position, while incoming trades through EBS decrease the absolute inventory position. To some extent, a similar trading pattern applies to Dealer 1. For Dealer 3, there is no similar pattern. Most of his electronic broker trades are executed using D2000-2. During the week of our study, only a very small number of NOK/DEM trades were executed through EBS.

Table 2.9: Accumulating and decumulating broker trades

	Incoming Electronic broker trades		Outgoing Electronic broker trades			
	D2000-2	EBS	D2000-2	EBS	Voice-broker	Sum
Dealer 1:						
Decumulating trades	39	154	113	98	36	440
Accumulating trades	70	96	163	79	21	429
Dealer 2:						
Decumulating trades	7	131	44	52	NA	234
Accumulating trades	28	20	147	12	NA	207
Dealer 3:						
Decumulating trades	24	0	20	2	9	55
Accumulating trades	35	0	20	2	7	64
Dealer 4:						
Decumulating trades	66	122	35	15	NA	238
Accumulating trades	44	46	73	20	NA	183

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 are not signed.

2.6.2 Information effect

The size of quantity demanded and bid and ask spread in direct trades

Microstructural models suggest that, in absence of an inventory effect, a positive relationship between spread and absolute trade size would be evidence of an information effect. We use the D2000-1 conversations which ended with a trade to examine this. Roughly 70% of all D2000-1 conversations ended with a trade. This indicates that the quotes are highly competitive. Transactions are always executed at the bid or the ask price. The advantage of using the bid and ask quotes from the conversations is that all noise between transactions are excluded.

Table 2.10 presents descriptive statistics of the observed bid and ask spread from D2000-1 conversations which ended with a trade. The average spread quoted by Dealer 1 is 1.985 pips (or 0.0001985 DEM). The DEM/USD spread varies between 1 and 4 pips. The average spread quoted by Dealer 3 is 15.515 pips (or 0.0015515 NOK). The NOK/DEM spread varies between 5 and 35 pips. Measured in percent the average DEM/USD spread is 0.011. The average NOK/DEM spread is more than three times higher and equals 0.037%. Note that both the DEM/USD spread and the NOK/DEM spread are positively correlated with absolute quantity traded.

Table 2.10: Descriptive statistics: Bid and ask spread in direct trades

	Dealer 1 DEM/USD	Dealer 3 NOK/DEM
Average	1.985	15.515
Median	2	12.5
Stdev	0.507	8.601
Min	1	5
Max	4	35
Correlation between spread and absolute size	0.455	0.760
Observations	62	67

The numbers are in pips. Average is the average spread observed from D2000-1 conversations which ended with a trade. Similarly, we calculate the median, standard deviation, minimum and maximum values. Correlation between spread and absolute size is the simple correlation between the spread and absolute trade size.

To test whether the quoted spread increases with quantity, we run the following regression for Dealer 1 and Dealer 3:

$$Spread_t = \beta_0 + \beta_1 \cdot abs(Q_{jt}) + \varepsilon_{it}, \tag{2.15}$$

where $abs(Q_{jt})$ is the absolute quantity. The results in table 2.11 show that the bid and ask spread increases with quantity demanded by the initiator of the trade. First, consider the results for Dealer 1. Typically, the spread for a USD one million request (DEM/USD) is 1.90 pips $(1.747 + 0.138)$. He tends to increase the spread to 3.13 pips $(1.747 + 10 \cdot 0.138)$ when the quantity requested increases to USD ten million. The dealer increases the spread with 1.4 pips per USD 10 million $(10 \cdot 0.138)$. Note that this increase in quoted spread is much smaller than estimated by Lyons (1995) for the effective spread (see table 2.5). Lyons finds that the effective spread increases with 2.8 pips per USD ten million traded. Hence, Lyons dealer increases his spread twice as much as

Table 2.11: Results for equation (2.15). Regression of observed spread from D2000-1 trades on absolute quantity traded

	Dealer 1 DEM/USD	Dealer 3 NOK/DEM
Constant	1.747	10.326
	***(20.73)	***(14.20)
Abs(Q_{jt})	0.138	1.513
	***(4.00)	***(11.48)
R^2	0.20	0.66
Observations	62	67

Estimated by OLS. t-values in parenthesis, and "***", "**" and "*" indicate significance at the 1%, 5% and 10%-level respectively. All coefficients multiplied by 10^4. The dependent variable is the observed spread in pips. $Abs(Q_{jt})$ is the trade (absolute) quantity measured in millions.

our Dealer 1 when quantity requested increases. Yao (1998) finds that his dealer increases spread by 0.9 pips per USD 10 million. His estimate is thus close to ours.

Second, consider the results for Dealer 3. On average, the spread for a DEM one million request is 11.84 pips $(10.326+1.513)$. He tends to increase the spread to 25.46 pips $(10.326+10\cdot 1.513)$ when the quantity requested is DEM 10 million. Note that the increase in spread with quantity requested is much larger for NOK/DEM than for DEM/USD.

Information effect and electronic broker trades

In trades executed by electronic brokers, we are not able to observe the spread. Here, we want to test whether the effective spread increases with quantity in the electronic broker market. In table 2.5 there is no evidence of information or inventory effects. To examine whether the spread increases with quantity in electronic broker trades, we start with the Madhavan and Smidt model and assume that there is no inventory effect. Thus, we set $\alpha = 0$. The resulting model is

$$\Delta P_{it} = \left(\frac{1-\phi}{\phi\theta}\right) Q_{jt} + \left(\frac{\gamma}{\phi}\right) D_t - \gamma D_{t-1} + \varepsilon_{it}. \tag{2.16}$$

This model is very close to the Glosten and Harris (1988) model. The only exception is that in their model the coefficients on D_t and D_{t-1} are restricted to be identical.[13]

We use the following regression equation to estimate possible information effects and effective bid and ask spread in the electronic broker market:

$$\Delta P_{it} = \beta_1 Q_{jt} + \beta_4 D_t + \beta_5 D_{t-1} + \varepsilon_{it}. \tag{2.17}$$

To increase estimation power, we pool all the incoming trades for the different dealers. The estimated baseline bid-ask spread for DEM/USD is 2.8 pips, and 16.6 pips for NOK/DEM. We find no evidence of any information effect (table 2.12). These results suggest that the size of the trade is not informative.

[13] If we assume that there is neither any information effect ($\phi = 1$) nor any inventory effect ($\alpha = 0$), the Madhavan and Smith model becomes $\Delta P_{it} = \gamma D_t - \gamma D_{t-1} + \varepsilon_{it}$, which is the Roll (1984) model, with the assumption that D_t and ε_{it} are independently distributed with zero means.

Table 2.12: Results for equation (2.17). Regression of ΔP_{it} between incoming, electronic brokered, trades.

	DEM/USD	NOK/DEM
Trade Q_{jt}	0.105	-0.413
	(0.60)	(-1.02)
Direction D_t	1.400	8.302
	***(3.68)	***(5.56)
Direction lagged D_{t-1}	-0.336	-2.294
	*(-1.95)	**(-2.08)
AR(1)	-0.045	-0.045
	(-0.98)	(-0.58)
Observations	891	145

Estimated by GMM and variable Newey-West correction. t-values in parenthesis, and "***", "**" and "*" indicate significance at the 1%, 5% and 10%-level respectively. All coefficients are multiplied by 10^4, except the AR(1) term. The dependent variable ΔP_{it} is the change in price between two incoming (electronic brokered) trades. Q_{jt} is signed incoming trade measured in millions, positive for a purchase from dealer j, and negative for a sale. 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). We pool data for all dealers. Adjusted R^2 is not reported because the regressions do not include a constant.

Although the size of a trade is not informative, there can be information in the direction of order flows. This is consistent with informed dealers breaking up large trades. For instance, Evans and Lyons (1999) develop a model where the price depends on cumulated signed flow.[14] A large positive cumulative flow means that some has to hold less currency (sell to initiators). To make them willing to hold less, the price must increase sufficiently to induce the sale.

Cumulative order flow is created by using the direction and size of all electronic broker trades executed by the FX department. If cumulative order flow is informative, we expect that cumulative order flow and price are cointegrated. Unit root tests (not shown here) confirm that both price and cumulative order flow have one unit root.

Table 2.13 presents the results. We find cointegration between price and cumulative order flow for both DEM/USD and NOK/DEM. Thus, a buying pressure of USD goes together with a high price of USD measured in DEM. Similarly a buying pressure of DEM goes together with a high price of DEM measured in NOK. This is evidence that cumulative order flow carry private information.

2.7 Conclusion and future work

This paper studies the behavior of four interbank foreign exchange dealers using a detailed data set from one week in March 1998, with transaction prices, trading quantities, dealer inventories, exact timing, and which trading system were used for the transactions. The four dealers trade in different exchange rates and have different trading styles. In particular, we study whether dealers set prices to protect against private information (information effects), and whether they control inventory to adjust their risk exposure.

In a widely cited paper, Lyons (1995), using data from 1992, found support for both informa-

[14] Evans and Lyons (1999) find that price changes depend significantly on unexpected period flow, for daily data. This is further confirmed in Rime (2000a,b), for weekly data from Norway and USA.

Table 2.13: Tests of cointegration between price and cumulative order flow

	DEM/USD	NOK/DEM
Constant	1.810	4.18
Cumulative flow	0.33	0.88
Trend	-0.11	-1.06
ADF-test	**(-2.49)	***(-2.59)
PP-test	**(-2.40)	***(-3.57)
Observations	2104	377

The parameters are estimated using ordinary least square. Since the variables have one unit root, t-values are not reported because they are unreliable. The dependent variable is price. Cumulative flow is created using the direction and size of the electronic broker trades. ADF-test is a standard augmented Dickey-Fuller test on the regression residual. PP-test is a Phillips-Perron test (Perron, 1988) on the regression residual. The Phillips-Perron test incorporates the Newey and West (1987) modification procedure. The number of lags included is calculated from the sample size (Newey-West automatic truncation lag selection). The tests do not include a constant since a constant is included in the original regression equation. "***", "**" and "*" indicate significance at the 1%, 5% and 10% level respectively. The flow and trend coefficients are multiplied by 10^4.

tion and inventory effects in the pricing of a market maker. The market maker of Lyons increased his spread to protect against private information, and adjusted the midpoint in the spread (quote shading) to induce trade in a preferred direction to adjust inventory. Using the same model as Lyons, we find no support for such information or inventory effects.

We believe this to be primarily due to the change in structure of the foreign exchange market. The introduction of electronic brokers, Reuters D2000-2 and EBS, may have increased transparency. Through these systems, dealers can see a larger share of the trading in the market than earlier. Hence, individual trades may be less important for information updating. The electronic brokers also offer attractive options for inventory control. This may explain why we are not able to find any inventory effects in our study.

When we examine the quoted bid ask spreads in direct trades, we find that spreads indeed widen with the size of transaction. In the absence of any inventory effect, this leads us to conclude that there is an information effect in direct trading. Lyons' data were solely from direct trading, and the Madhavan and Smidt model is probably best suited to this kind of trading. However, the information effect found in direct trades in this study is only half the size of the information effect found by Lyons.

When it comes to the electronic brokers, the conjecture that sequences of trades may be more informative than single trades is supported. We find that the cumulative order flow on the electronic brokers and exchange rates are cointegrated, with a higher price when the cumulative flow is high and positive. If there is a buying pressure of USD for DEM in the market, the price of USD measured in DEM will be higher.

It seems that the dealer Lyons studied had a trading style particularly well suited for analysis using the Madhavan and Smidt model. Lyons' dealer had a high share of incoming direct trades, and hence had to control inventory partly through quote shading. Furthermore, the dealer worked in an investment bank, and did not see any customer order flow. The risk of revealing inventory was therefore not that crucial. In comparison, our dealers have a higher share of outgoing trades than Lyons' dealer does. While two of the dealers in this study act as market makers in interbank direct trades, they also trade with customers and take speculative positions. Thus, the variety of trading styles among dealers may also be important in understanding the results presented in this study.

Our results indicate that the Madhavan and Smidt model is not as applicable to foreign exchange trading as first believed. The Madhavan and Smidt model focuses on the pricing decision of a market maker in incoming trades. We think it is important to also explore other characteristics of interbank trading. First, there is a need to better understand the use of outgoing trades (the aggressor's decision). Second, it is important to understand the dealer's choice between different trading channels. New theories that address risk management and information updating in a trading environment with both direct and indirect trading are thus in great demand.

2.A Direct and indirect trading

The information effect and the degree of quote shading may depend on the trading system used. As mentioned in section 2.2, there are at least four important differences between direct and indirect trading. These four characteristics suggest that broker trades may be less informative than trades executed directly. It is also likely that dealers shade quotes differently depending on whether they trade direct or indirect. Below, we suggest an extension of the Madhavan and Smidt model where the dealer's conditional expectation (μ_{it}) and quote shading depend on the trading channel used (direct trade or electronic broker).

We model the information content in the different trading systems such that the updated belief depends on which system is used, hence,

$$\mu_{it} = d_t\left[\kappa^{\mathrm{D}}\mu_t + \left(1-\kappa^{\mathrm{D}}\right)Z_{jt}\right] + (1-d_t)\left[\kappa^{\mathrm{I}}\mu_t + \left(1-\kappa^{\mathrm{I}}\right)Z_{jt}\right], \tag{2.A.1}$$

where d_t is a dummy that equals 1 if the trade is direct, and 0 if the trade is indirect. Z_{jt} is defined as in equation (2.6). The superscript "D" means direct, while the superscript "I" means indirect, so κ^{D} and κ^{I} are the weights on prior belief when the trade is direct and indirect, respectively. The hypothesis is that Z_{jt} is a more precise signal in direct trades, that is, $\kappa^{\mathrm{D}} < \kappa^{\mathrm{I}}$. This implies that $\phi^{\mathrm{D}} < \phi^{\mathrm{I}}$, which means that the information effect is smaller for indirect trade. We see this from differentiating the coefficient on Q_{jt} with respect to ϕ, which gives

$$\frac{-\phi\theta-(1-\phi)\theta}{(\phi\theta)^2} = \frac{-1}{\phi^2\theta} < 0$$

Updated beliefs can be written as

$$\begin{aligned}
\mu_{it} &= \left[d_t\kappa^{\mathrm{D}} + (1-d_t)\kappa^{\mathrm{I}}\right]\mu_t + \left[d_t\left(1-\kappa^{\mathrm{D}}\right) + (1-d_t)\left(1-\kappa^{\mathrm{I}}\right)\right]Z_{jt} \\
&= \left[d_t\kappa^{\mathrm{D}} + (1-d_t)\kappa^{\mathrm{I}}\right]\mu_t + \frac{d_t\left(1-\kappa^{\mathrm{D}}\right) + (1-d_t)\left(1-\kappa^{\mathrm{I}}\right)}{1-\lambda}\left(\frac{Q_{jt}}{\theta} + P_{it} - \lambda\mu_t\right) \\
&= \left\{d_t\left[\kappa^{\mathrm{D}} - \frac{\left(1-\kappa^{\mathrm{D}}\right)\lambda}{1-\lambda}\right] + (1-d_t)\left[\kappa^{\mathrm{I}} - \frac{\left(1-\kappa^{\mathrm{I}}\right)\lambda}{1-\lambda}\right]\right\}\mu_t \\
&\quad + \left\{d_t\frac{1-\kappa^{\mathrm{D}}}{1-\lambda} + (1-d_t)\frac{1-\kappa^{\mathrm{I}}}{1-\lambda}\right\}\left(\frac{Q_{jt}}{\theta} + P_{it}\right) \\
&= \left[d_t\phi^{\mathrm{D}} + (1-d_t)\phi^{\mathrm{I}}\right]\mu_t + \left[d_t\left(1-\phi^{\mathrm{D}}\right) + (1-d_t)\left(1-\phi^{\mathrm{I}}\right)\right]\left(\frac{Q_{jt}}{\theta} + P_{it}\right)
\end{aligned} \tag{2.A.2}$$

ϕ^{D} and ϕ^{I} are defined similar as in the benchmark case.

We also open for the possibility that dealers' inventory control behavior differ on different systems, such that

$$P_{it} = \mu_{it} - \left[\alpha^{\mathrm{D}}d_t + \alpha^{\mathrm{I}}(1-d_t)\right](I_{it} - I_i^*) + \gamma D_t. \tag{2.A.3}$$

The relative size of α^{D} and α^{I} is not obvious.

Given that there already exist different trading systems with very different characteristics in the market, and has done so for several years, we believe such a description of information content and dealer behavior as above may be part of an equilibrium. We do not pretend however that this is derived from first principles.

We now combine the two mechanisms, differences both in information and inventory control across the two systems. This imply using the following equations:

$$\begin{aligned}
\mu_{it} &= d_t\left[\kappa^{\mathrm{D}}\mu_t + \left(1-\kappa^{\mathrm{D}}\right)Z_{jt}\right] + (1-d_t)\left[\kappa^{\mathrm{I}}\mu_t + \left(1-\kappa^{\mathrm{I}}\right)Z_{jt}\right] \\
P_{it} &= \mu_{it} - \left[\alpha^{\mathrm{D}}d_t + \alpha^{\mathrm{I}}(1-d_t)\right](I_{it} - I_i^*) + \gamma D_t. \\
\mu_t &= P_{it-1} + \left[\alpha^{\mathrm{D}}d_{t-1} + \alpha^{\mathrm{I}}(1-d_{t-1})\right](I_{it-1} - I_i^*) - \gamma D_{t-1} + \varepsilon_{it}
\end{aligned}$$

The pricing schedule then becomes:

$$P_{it} = \mu_t + \frac{1-\left[d_t\phi^{\mathrm{D}} + (1-d_t)\,\phi^{\mathrm{I}}\right]}{\left[d_t\phi^{\mathrm{D}} + (1-d_t)\,\phi^{\mathrm{I}}\right]\theta} Q_{jt} - \frac{\alpha^{\mathrm{D}} d_t + \alpha^{\mathrm{I}}(1-d_t)}{d_t\phi^{\mathrm{D}} + (1-d_t)\,\phi^{\mathrm{I}}}(I_{it} - I_i^*) + \frac{\gamma}{d_t\phi^{\mathrm{D}} + (1-d_t)\,\phi^{\mathrm{I}}} D_t$$

It is easier to work with if we rewrite the coefficients containing dummies:

$$\frac{1-\left[d_t\phi^{\mathrm{D}} + (1-d_t)\,\phi^{\mathrm{I}}\right]}{\left[d_t\phi^{\mathrm{D}} + (1-d_t)\,\phi^{\mathrm{I}}\right]\theta} = \begin{cases} \dfrac{1-\phi^{\mathrm{D}}}{\phi^{\mathrm{D}}\theta} & \text{when } d_t = 1 \\ \dfrac{1-\phi^{\mathrm{I}}}{\phi^{\mathrm{I}}\theta} & \text{when } d_t = 0 \end{cases}$$

$$\frac{\alpha^{\mathrm{D}} d_t + \alpha^{\mathrm{I}}(1-d_t)}{d_t\phi^{\mathrm{D}} + (1-d_t)\,\phi^{\mathrm{I}}} = \begin{cases} \dfrac{\alpha^{\mathrm{D}}}{\phi^{\mathrm{D}}} & \text{when } d_t = 1 \\ \dfrac{\alpha^{\mathrm{I}}}{\phi^{\mathrm{I}}} & \text{when } d_t = 0 \end{cases}$$

$$\frac{\gamma}{d_t\phi^{\mathrm{D}} + (1-d_t)\,\phi^{\mathrm{I}}} = \begin{cases} \dfrac{\gamma}{\phi^{\mathrm{D}}} & \text{when } d_t = 1 \\ \dfrac{\gamma}{\phi^{\mathrm{I}}} & \text{when } d_t = 0 \end{cases}$$

This gives us

$$P_{it} = \mu_t + \left[\frac{1-\phi^{\mathrm{D}}}{\phi^{\mathrm{D}}\theta} d_t + \frac{1-\phi^{\mathrm{I}}}{\phi^{\mathrm{I}}\theta}(1-d_t)\right] Q_{jt} - \left[\frac{\alpha^{\mathrm{D}}}{\phi^{\mathrm{D}}} d_t + \frac{\alpha^{\mathrm{I}}}{\phi^{\mathrm{I}}}(1-d_t)\right](I_{it} - I_i^*) + \left[\frac{\gamma}{\phi^{\mathrm{D}}} d_t + \frac{\gamma}{\phi^{\mathrm{I}}}(1-d_t)\right] D_t \quad (2.A.4)$$

To get an estimable equation we insert the expectation:

$$\begin{aligned} P_{it} = P_{it-1} &+ \left[\alpha^{\mathrm{D}} d_{t-1} + \alpha^{\mathrm{I}}(1-d_{t-1})\right](I_{it-1} - I_i^*) - \gamma D_{t-1} \\ &+ \left[\frac{1-\phi^{\mathrm{D}}}{\phi^{\mathrm{D}}\theta} d_t + \frac{1-\phi^{\mathrm{I}}}{\phi^{\mathrm{I}}\theta}(1-d_t)\right] Q_{jt} - \left[\frac{\alpha^{\mathrm{D}}}{\phi^{\mathrm{D}}} d_t + \frac{\alpha^{\mathrm{I}}}{\phi^{\mathrm{I}}}(1-d_t)\right](I_{it} - I_i^*) \\ &+ \left[\frac{\gamma}{\phi^{\mathrm{D}}} d_t + \frac{\gamma}{\phi^{\mathrm{I}}}(1-d_t)\right] D_t + \varepsilon_{it} \end{aligned}$$

Collecting terms:

$$\begin{aligned} \Delta P_{it} = &\left[\frac{\alpha^{\mathrm{D}}}{\phi^{\mathrm{D}}} d_t + \frac{\alpha^{\mathrm{I}}}{\phi^{\mathrm{I}}}(1-d_t)\right] I_i^* - \left[\alpha^{\mathrm{D}} d_{t-1} + \alpha^{\mathrm{I}}(1-d_{t-1})\right] I_i^* \\ &+ \left[\frac{1-\phi^{\mathrm{D}}}{\phi^{\mathrm{D}}\theta} d_t + \frac{1-\phi^{\mathrm{I}}}{\phi^{\mathrm{I}}\theta}(1-d_t)\right] Q_{jt} - \left[\frac{\alpha^{\mathrm{D}}}{\phi^{\mathrm{D}}} d_t + \frac{\alpha^{\mathrm{I}}}{\phi^{\mathrm{I}}}(1-d_t)\right] I_{it} \\ &+ \left[\alpha^{\mathrm{D}} d_{t-1} + \alpha^{\mathrm{I}}(1-d_{t-1})\right] I_{it-1} + \left[\frac{\gamma}{\phi^{\mathrm{D}}} d_t + \frac{\gamma}{\phi^{\mathrm{I}}}(1-d_t)\right] D_t - \gamma D_{t-1} + \varepsilon_{it} \quad (2.A.5) \end{aligned}$$

Econometric equation:

$$\Delta P_{it} = \beta_0 + \beta_0' d_t + \beta_0'' d_{t-1} + \beta_1^{\mathrm{D}} d_t Q_{jt} + \beta_1^{\mathrm{I}} (1-d_t) Q_{jt} + \beta_2^{\mathrm{D}} d_t I_{it} + \beta_2^{\mathrm{I}} (1-d_t) I_{it} + \beta_3^{\mathrm{D}} d_{t-1} I_{it-1} + \beta_3^{\mathrm{I}} (1-d_{t-1}) I_{it-1} + \beta_4^{\mathrm{D}} d_t D_t + \beta_4^{\mathrm{I}} (1-d_t) D_t + \beta_5 D_{t-1} + \varepsilon_{it} \quad (2.A.6)$$

Regression coefficients and predicted signs:

$$\begin{array}{ll}
\beta_0 = \alpha^{\mathrm{I}} \left(\frac{1}{\phi^{\mathrm{I}}} - 1 \right) I_i^* \approx 0 & \beta_0' = \left(\frac{\alpha^{\mathrm{D}}}{\phi^{\mathrm{D}}} - \frac{\alpha^{\mathrm{I}}}{\phi^{\mathrm{I}}} \right) I_i^* \approx 0 \\
\beta_0'' = -\left(\alpha^{\mathrm{D}} - \alpha^{\mathrm{I}} \right) I_i^* \approx 0 & \beta_1^{\mathrm{D}} = \frac{1-\phi^{\mathrm{D}}}{\phi^{\mathrm{D}}\theta} > 0 \\
\beta_1^{\mathrm{I}} = \frac{1-\phi^{\mathrm{I}}}{\phi^{\mathrm{I}}\theta} > 0 & \beta_2^{\mathrm{D}} = -\frac{\alpha^{\mathrm{D}}}{\phi^{\mathrm{D}}} < 0 \\
\beta_2^{\mathrm{I}} = -\frac{\alpha^{\mathrm{I}}}{\phi^{\mathrm{I}}} < 0 & \beta_3^{\mathrm{D}} = \alpha^{\mathrm{D}} > 0 \\
\beta_3^{\mathrm{I}} = \alpha^{\mathrm{I}} > 0 & \beta_4^{\mathrm{D}} = \frac{\gamma}{\phi^{\mathrm{D}}} > 0 \\
\beta_4^{\mathrm{I}} = \frac{\gamma}{\phi^{\mathrm{I}}} > 0 & \beta_5 = -\gamma < 0
\end{array} \quad (2.A.7)$$

The coefficients β_1^{D} and β_1^{I} capture information effect, while β_3^{D} and β_3^{I} capture inventory control. The coefficient β_5 is the same as in the benchmark model, β_1^{D}. If the information effect is more important when trading direct, we expect that β_1^{D} is significantly greater than β_1^{I}. Predictions on inventory control effect is uncertain. The error term will be MA(1) of the same reasons as above.

In table 2.14 we test this model. This test is only conducted for Dealer 1 and Dealer 3 since they are the only dealers with sufficient transactions at the direct trading system D2000-1. Again the baseline spread variables enter with correct sign. This formulation however shows that for DEM/USD (Dealer 1) the direct trading channel seems to be more informative with an significant information effect coefficient on Q_{jt}. Dealer 1 increases his spread with 2 pips for a USD 1 million trade. This number is implausible large. However, the coefficient is only significantly different from zero at the ten percent level. Somewhat surprising is that for Dealer 1 the indirect baseline spread $(1-d_t)D_t$ is larger than the direct baseline spread $d_t D_t$. For Dealer 3, there is evidence that the indirect channel is more informative than the direct channel.

Table 2.14: Results for the system model, equation (2.A.6). Regression of ΔP_{it}

	Dealer 1 DEM/USD	Dealer 3 NOK/DEM
Constant	-0.25	-1.20
	(-0.59)	(-0.55)
Direct dummy d_t	-0.02	0.71
	(-0.02)	(0.21)
Direct dummy d_{t-1}	0.99	3.10
	(1.05)	(1.19)
Direct trade $d_t Q_{jt}$ (+)	1.07	-0.07
	*(1.86)	(-0.20)
Indirect trade $(1-d_t)Q_{jt}$ (+)	-0.37	1.10
	(-1.16)	**(2.11)
Inventory $d_t I_{it}$ (-)	0.37	-0.22
	(1.48)	(-1.02)
Inventory $(1-d_t)I_{it}$ (-)	0.09	0.10
	(0.72)	(0.56)
Inventory $d_{t-1}I_{it-1}$ (+)	0.03	0.09
	(0.14)	(0.52)
Inventory $(1-d_{t-1})I_{it-1}$ (+)	-0.11	-0.17
	(-1.07)	(-0.72)
Direct $d_t D_t$ (+)	1.42	6.55
	(1.42)	***(5.14)
Indirect $(1-d_t)D_t$ (+)	1.91	2.30
	**(2.39)	(0.71)
D_{t-1} (-)	-0.37	-2.46
	(-1.02)	(-1.53)
AR(1)	-0.04	-0.16
	(-0.63)	***(-2.79)
Adjusted R^2	0.04	0.20
Observations	432	143

Estimated by GMM and variable Newey-West correction. t-values in parenthesis, and "***", "**" and "*" indicate significance at the 1%, 5% and 10%-level respectively. All coefficients multiplied by 10^4, except the AR(1) term. The dependent variable is ΔP_{it} is the change in price between to 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 end 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). d_t is a dummy variable taking the value 1 if the trade is direct and 0 otherwise. The "+" and "-" in parentheses in the first row indicate the expected sign of the coefficient.

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CHAPTER 3

Customer Trading and Information in Foreign Exchange Markets[1]

3.1 Introduction

There has recently been several papers addressing the possibility of private information in the foreign exchange market(e.g. Lyons, 1995; Yao, 1998a; Bjønnes and Rime, 2000). Dealers operating in the interbank foreign exchange market regard trading with customers of the bank to be their most important source of private information (Lyons, 1995). Hence, banks with access to a large customer pool are also expected to have better information about exchange rate movements (see several recent surveys, Cheung and Chinn (2000, 1999b,a), Cheung et al. (2000), and Cheung and Wong (2000)).

We empirically study two related questions concerning the importance of private information in the foreign exchange market: First, we study how customer trades influence the dealer's trading strategy. Second, we examine how direct (bilateral) interbank trades with (nonanonymous) counterparts perceived to be well-informed affect the dealer's trading strategy. With trading strategy we mean the dealer's pricing decisions (i.e. market making), and the placement of orders. It is important to analyze both decisions because a foreign exchange dealer will not only give quotes on request, but also place orders at other dealers quotes or at brokers.

The previous studies by Lyons (1995), Yao (1998a), and Bjønnes and Rime (2000) consider the dealer's pricing decision using the Madhavan and Smidt (1991) model, which incorporates inventory control and adverse selection through two postulated equations.[2] In the Madhavan and

[1] Co-authored with Geir H. Bjønnes. *Memorandum 30/2000, Department of Economics, University of Oslo*. We like to thank Steinar Holden, Ylva Søvik and Kristian Rydqvist for helpful comments. Any errors are entirely our own.

[2] Inventory control models (e.g. Garman, 1976; Amihud and Mendelson, 1980; Ho and Stoll, 1981) suggest that dealers adjust price to control their inventories, while information-based models (e.g. Kyle, 1985; Glosten and Milgrom, 1985; Admati and Pfleiderer, 1988) predict that dealers will adjust price to protect themselves against informed traders.

Smidt (1991) the pricing decision is studied under the assumptions that only the initiating dealer may have private information and that knowledge of the identity of the counterpart is unimportant when setting prices. Within the same empirical framework, we relax both assumptions. First, a dealer may have private information when setting prices. Second, a dealer may regard trades with particular counterparts as more informative than with others. We also develop a framework for analyzing the dealer's order placement strategy. When a dealer receives private information from trades with customers or well-informed dealers, he can use this information in his position taking. The order placement decision was not analyzed by the above mentioned studies.

The data set we use to study dealers pricing and trading decisions consists of two parts. The first part contains the complete trading records of two foreign exchange dealers during one week in March 1998. It includes all relevant information about each trade such as transaction time, transaction prices and quantities, and who initiated the trade. The second part of the data set is collected through interviews. In addition to the two market makers, three other spot dealers in the FX department were interviewed. The dealers were asked whether they perceived a specific counterpart in direct interbank trades as worse, equally or better informed than themselves. Consistent with previous surveys, the answers suggest that the dealers regard large banks with a large customer pool as better informed than smaller banks with only limited customer trading.

Since customer orders are claimed to be the most important source of private information in foreign exchange, studying the effect of customer trades can be viewed as studying the behavior of an informed dealer. Most models of dealer behavior only consider that the initiating dealer has private information, not the Market Maker (e.g. Kyle, 1985). However, since a dealer in foreign exchange not only give quotes on request, but also place orders at other dealers quotes or with brokers, there is an artificial asymmetry between the market making decision and the order placement decision. Most interbank dealers receive some private signals from customer order flows. A dealer cannot choose when this information arrives. Therefore, a dealer may have private information when he gives quotes. Furthermore, a dealer with private information does not wait for other dealers to initiate trades. If the information is sufficiently precise, he acts upon it and places his own orders with other dealers or brokers.

In the theoretical literature it is common to assume that the Market Maker only knows the distribution of informed dealers, not whether he is actually trading with an informed dealer. In the foreign exchange market, dealers see the identity of their counterpart in direct trades, and through experience learn whether it is an informed dealer or not. Through interviews the dealers ranked their counterparts in direct trades as worse, equally or better informed compared to themselves. This information let us test how dealers protect themselves against the possibility of trading with better-informed dealers.

We find that customer trades do not seem to influence the dealers' interbank pricing decisions. The dealers do not utilize their private information to price differently from the rest of the market. This may be due to a strategy of not revealing the private information, since there is high price transparency in the interbank foreign exchange market. The dealers do, however, price discriminate against customers. We find that the spreads quoted to customers are significantly wider than interbank spreads. This is possible because the customers have no access to the interbank market.

Customer trades influence the dealer's order-placing strategy such that a customer purchase leads to subsequent purchases by the dealer in excess of inventory control. Instead of using the private information in the pricing strategy, which is very transparent, they use their private information in their order placement strategy, which is much less transparent.

The identity of counterparts and their perceived level of informativeness do not influence pricing strategy. This is somewhat surprising given the weight in the literature on protection against better-informed dealers (e.g. Röell, 1990). Spreads do widen with the size of the trade, but whether the counterpart is perceived to be well informed or not does not matter for spreads. Consequently, the dealers do not seem to price discriminate in interbank trading. A possible explanation for this finding is that dealers learn from trading with informed counterparts and is able to use this information profitably. In the foreign exchange market, it may be possible to exploit this information since transparency is low. To attract informative trades, dealers may thus have an incentive to give informed dealers attractive bid and ask quotes. In this sense, dealers buy information from informed dealers. However, we do not find evidence that trading with informed counterparts affect order placement strategy. The dealers do not take the same positions as their informed counterparts. The finding that spreads do not depend on the identity of the counterpart, is in line with surveys showing that spreads are determined by market norms.

The rest of the paper is organized as follows. Section 3.2 describes the foreign exchange market in relation to customer trading and private information, drawing on some recent surveys. In section 3.3 we adapt the Madhavan and Smidt (1991) model to incorporate customer trading and different precision of information. Section 3.4 provide a description of our data set. Section 3.5 presents the results, while section 3.6 concludes.

3.2 Customer orders and private information in foreign exchange

We first describe the role of customer trades in foreign exchange markets in more detail (section 3.2.1). In section 3.2.2 we then describe the trading environment of dealers in the interbank foreign exchange market. The trading environment has implications both for identification of counterpart and for trading strategy.

3.2.1 The importance of customer orders

A customer is an industrial corporation, a non-dealer financial institution or a professional speculator that demands the dealer's services in the foreign exchange market. Banks function as intermediaries for customers, and executes the customers' orders in the interbank market.

The spot market has about 40% of the average daily total turnover of USD 1.5 trillion in the foreign exchange market. Customer trading accounts for only 20–30% of total spot trading, while the interbank market account for the remaining 70–80% (see BIS, 1993, 1996, 1998). In this paper we study a DEM/USD dealer and a NOK/DEM dealer operating out of Norway. The

DEM/USD dealer has only limited customer orders, while customer orders are very important for the NOK/DEM dealer.

The importance that dealers attach to customer trading may seem at odds with customer orders' low share of total volume. However, the trading of customers is the underlying source of demand for currency. The "hot-potato-trading" story of Lyons (1997) may shed some light on why interbank trading is so much larger than customer trading. Imagine that a dealer initially is holding his preferred inventory position when a large customer order arrives at his desk. Since customer orders usually are larger than ordinary interbank trades, the dealer split the order into several smaller orders, which are passed on to other interbank dealers. These dealers will also adjust their inventory position after the trade, and the initial customer trade is passed on further to other dealers as a "hot potato." The resulting interbank trading volume ends up being much larger than the initial customer order.

There are two reasons for why customer trading is important in the foreign exchange market. First, dealers can quote a wider spread on these trades than what is normal in interbank trading. In a study of a large DEM/USD dealer, Yao (1998b) finds that 75% of the dealer's total profits came from trading with customers although customer trading represented only 13% of total trading volume. Dealers are able to quote wider spreads to customers since customers do not have access to the interbank market. Furthermore, the customers are in a bad bargaining position versus the banks due to the low transparency of the foreign exchange market. Customers can not see interbank prices or order flow.

Second, customer order flows are the most important source of private information in the foreign exchange market. In what sense are customer trades informative? Order flow may be seen as expectations backed by money: the "voting" of the market (e.g. Lyons, 2001). By observing customer order flows, the dealers obtain a signal of the customers' expectations. Customer order flow may be informative about fundamental values through three channels: (i) Customers may have private information (see different signals) on fundamental value; (ii) customers may use different "models" to evaluate new information; or (iii) customers may use different probability distributions to evaluate new information.

All three may be a valid description of the foreign exchange market. Some customers may have better capabilities for collecting, analyzing, and interpreting information. Furthermore, new public information of a given kind may be interpreted differently by the customer sector at different points in time. Customer trading may then give a dealer information on how the customer sector evaluate a new piece of public information, or in the words of the dealers — information on the "market sentiment".

An empirical result supporting the importance of customer trades is found in Rime (2000). Rime studies how trading by different sectors in the Norwegian market affect weekly exchange rate changes. He finds that the strongest effect comes from the trading of customers, and that this effect is permanent. The interviews with London based dealers reported in Heere (1999) confirm that large customers' views on the market is valuable information.

However, even if we take the extreme view that customer trades are completely unrelated to any fundamental value of the currency, these trades may still be useful for the dealer in forecasting prices. In Cao and Lyons (1998), dealers speculate based on customer order flow that is uncorrelated with the fundamentals by using the customer order to predict whether there will be a buyer-pressure or seller-pressure in interbank trading later on. A buyer-pressure, in this model, will push interim prices up. In the model, demand is not perfectly elastic due to risk aversion. The risk aversion, together with an assumption that the customer trade is sufficiently large and not observed by the rest of the market, drives the result.

Table 3.1: The most important sources for competitive advantage for the large players in the Foreign exchange market? (In %)

	UK	US	Hong Kong	Tokyo	Singapore
Large customer base	33	33	27	27	30
Better information	22	23	22	21	22
Can deal in large volumes	16	15	17	15	12
Can influence exchange rates	14	9	12	12	9
Access to global trading network	4	5	8	9	11

Source: Cheung and Wong (2000); Cheung and Chinn (1999b); Cheung et al. (2000). The table reports the answers that dealers gave to the question “Select the 3 (or fewer) most important sources of competitive advantage for the large players in the FX market?” The table shows percentages of all answers within each country.

Table 3.1 presents perceived sources of competitive advantage for the large players in the foreign exchange market, as reported in a series of surveys (Cheung and Wong, 2000; Cheung and Chinn, 1999b; Cheung, Chinn, and Marsh, 2000). At the top, we find “Large customer base.” However, also the second and third most important advantage may be related to customer trading. Since customer trades are regarded as private information, banks with larger customer base may also be better informed. Furthermore, since customer orders typically are larger than the ordinary inter-bank trade, it also enables them to trade more and in larger volumes. In fact, many dealers base their trading strategy on customer orders. According to Cheung et al.’s surveys of dealers, between 22% (US) and 37% (UK) base their trading on customer orders. Trading based on customer orders is equally popular as using technical or fundamental analysis.

3.2.2 Trading channels in the interbank market

When dealers turn to the interbank market, they have four trading options available, as shown in figure 3.1. Dealers can trade directly with another dealer using the bilateral electronic system Reuters D2000-1, or indirectly with a broker, either a traditional voice-broker or the electronic brokers Reuters D2000-2 and EBS (rows). In each trade the dealer can either set a price (quote) at which other dealers can trade (incoming trade), or the dealer can trade at other dealers’ quotes (outgoing trade) (columns). The advantage with incoming trades is that the (quoting) dealer trade at the most favorable side of the bid-ask spread. In case the initiating dealer wants to buy, the quoting dealer sells at the ask, the highest price. Alternatively, if the initiating dealer wants to sell, the quoting dealer buys at the bid, the lowest price. The advantage with outgoing trades is more control with time of execution.

Figure 3.1: Interbank trading options

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

The direct trading channel D2000-1 allows a dealer to contact a specific dealer, at the cost of identifying oneself and revealing information to the other dealer. However, for larger trades this system may be more suitable than the electronic brokers since a dealer only contacts other dealers that he knows are willing to trade these volumes at reasonable prices. Market Makers are expected to give competitive two-way quotes to another dealer at request.

In general, the three most important aspects of any kind of foreign exchange broker are that (i) the initiating part stay anonymous, (ii) dealers can enter one-way prices (bid or ask) without being worried about revealing their position, and (iii) the quoting party chooses when to place a quote, opposed to direct trading. The execution is still decided by the "hitting" dealer, of course. A difference between electronic brokers and voice brokers, is that the former offers higher execution speed.

An important feature of the foreign exchange market, distinguishing it from stock markets, is the decentralized multiple dealership structure, and the low transparency of trading. Transparency has implications for how fast new information dissipates in the market. Customer trades are only observed by the dealer, so customer trades are private information. All direct trades are unknown except to the two parties in a trade. In indirect trades with voice-brokers, a small subset of the trades is communicated to the market via intercoms. On electronic broker systems, all trades are shown in a "trade window."[3]

Traditionally, direct trading through D2000-1 and indirect trading through voice-brokers have been the most popular trading channels. Lately, the new electronic brokers, D2000-2 and EBS, have increased their shares of the market, while the share of voice-brokers has decreased.

3.3 A theoretical framework

There exists no coherent model which can be used to analyze the effects of customer trades and counterpart identity together. We will instead use the Madhavan and Smidt (1991) model as an empirical framework. In section 3.3.1 we address the effects of customer trades on pricing strategy (section 3.3.1) and order placement strategy (section 3.3.1). Then, in section 3.3.2, we address the effects of counterpart identity. First however, we introduce the framework that is common to the analysis of both problems.

A Market Maker must be willing to offer both sell and buy quotes to any other dealer interested in trading a particular currency pair. The Market Maker has two particular considerations: First,

[3] To be precise, they observe the time, the price, and the direction of all trades. Most trades on electronic brokers are between 1 and 5 million.

he utilizes all available information to set bid and ask quotes. This is his information aggregation problem, which in the context of asymmetric information was first studied by Kyle (1985) and Glosten and Milgrom (1985). Secondly, since a Market Makers' inventory rarely will be equal to his desired due to the obligation to accept any trade on his quoted price, he has to manage his inventory so that he does not carry excessive risk. This is his inventory control problem (see Ho and Stoll, 1981).

To handle the information problem the Market Maker will try to learn the motives for trade from the initiative of another dealer. If the contacting dealer buys, the Market Maker interprets this as a signal that the true value can be (if informed) higher than the current price.

The Market Maker has four options available for inventory control. He can trade at other dealers' quotes (outgoing trades) or by giving quotes to induce a trade in his preferred direction (incoming trades). Both alternatives can be used in either direct trades (Reuter D2000-1), or in indirect trades (voice-brokers, D2000-2 or EBS).

The information and inventory problem have not yet been satisfactory integrated in one model. We use the model developed in Madhavan and Smidt (1991) as a framework, where the two effects are incorporated through postulated behavioral equations. We extend the model so that both dealers observe private signals, and address how differences in precision of these signals may influence pricing decisions.

Consider a pure exchange economy with a risk free and a risky asset. The risky asset represents currency. There are n dealers, and T periods (the whole trading day). The basic model focus on the pricing decision of a representative Market Maker, dealer i. Hence, each period is characterized by one incoming order at dealer i's quote. Incoming means that the bilateral contact was initiated by dealer i's counterpart, denoted j (aggressor). At time T the true value of the currency, $\tilde{V}$, is revealed. The value in period 0 is known and equal to r_0. After trading in period t, there arrives some new public information $r_t \sim IID\left(0, \sigma_r^2\right)$ informative about the increment to currency value. Private information is short-lived in the sense that when r_t arrives at time t agents know that the true value is described as $V_t = \sum_{\iota=0}^{t} r_\iota$. In other words, private information is a signal about r_t.

Information and inventory effects are incorporated through two postulated behavioral equations

$$Q_{jt} = \theta\left(V_{t-1} + \mu_{jt} - P_{it}\right) + X_{jt}, \tag{3.1}$$

$$P_{it} = V_{t-1} + \mu_{it} - \alpha\left(I_{it} - I_i^*\right) + \gamma D_t, \tag{3.2}$$

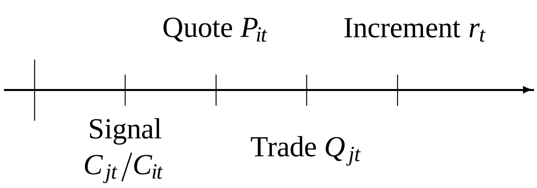
where $\mu_{\ell t}$ $(\ell = i, j)$ are the dealers' conditional expectation of this period's increment. Hence, $(V_{t-1} + \mu_{\ell t})$ is the conditional expectation of V_t. Dealer j decides on his demand Q_{jt} conditional on the quoted price P_{it}, while the Market Maker, dealer i, decides on a price P_{it}.

The demand of the contacting dealer j, (3.1), is optimal when dealers maximize exponential utility over end-of-period wealth, added a stochastic element X_{jt} for inventory shocks which is unobservable for dealer i. The coefficient θ is equal to the inverse of the absolute risk aversion parameter and the variance of dealer j's conditional expectation. The inventory adjustment trading

X_{jt} is assumed to be uncorrelated with r_t. If dealer j's conditional expectation of V_t is above (below) dealer i's price P_{it}, he will tend to buy (sell) dollars. As a convention, Q_{jt} is positive for sales of dealer i to dealer j and negative for purchases. Since X_{jt} is only known to trader j, Q_{jt} will only provide a noisy signal to dealer i of dealer j's information on V_t.

Equation (3.2) is typical for inventory models, where price P_{it} is linearly related to the dealer's current inventory (I_{it}). I_i^* is i's desired inventory position, and α (> 0) measures the inventory response effect. The inventory effect is negative because the dealer may want to "shade" (reduce) his price to induce a sale if the inventory is above the preferred level. D_t is a direction-dummy that takes the value 1 if it is a sale and -1 if it is a buy.[4] Since the quoted spread is expected to widen with quantity to protect against adverse selection, captured by the conditional expectation, we can think of γD_t as half of the spread for quantities close to zero. The price is set such that it is ex post regret-free, in the sense of Glosten and Milgrom (1985), after observing the trade Q_{jt}.

Figure 3.2: Information structure within period t



At the beginning of each period all information is public. Before trading in the period both dealers observe a private signal through a customer trade. Then dealer j "asks" dealer i for a quote P_{it}. The trade Q_{jt} is then realized. In the end of the period all information is made public, hence private information is only short-lived.

Figure 3.2 summarizes the information structure, as seen from the perspective of the market making dealer i. Without any new information, the dealers' expectation of V_t equals V_{t-1}. At the beginning of each period t, the dealers receive a customer trade $C_{\ell t}$ ($\ell = i, j$) which is their private signal of r_t. This signal is given by

$$\tilde{C}_{\ell t} = r_t + \tilde{\omega}_{\ell t}, \tag{3.3}$$

where the noise term, $\tilde{\omega}_{\ell t}$, is independently normally distributed around zero with variance $\sigma^2_{\omega \ell}$.For dealer i, the quantity actually traded with dealer j, Q_{jt}, gives dealer i a signal of dealer j's private information C_{jt}. Similarly, for dealer j the price he receives may give him a signal of C_{it}.[5] We derive the price-schedule by inserting for the expectations in (3.2) and (3.1).

To address the two issues at hand, Customer trading and Counterpart informativeness, we will consider two different formulations of the basis of dealer i's formation of expectations: The first is a simple extension of the standard Madhavan-Smidt framework where we include customer trading as a private signal in the posterior expectation. In the second, we let the Market Maker consider that his counterparts have different precision in their private signals when he gives quotes. The first one will be used to discuss the importance of customer trading as part of the dealers' information

[4] Buy and sell are from the perspective of the Market Maker, that is, the Market Maker sells at the high price (ask), and buys at the low price (bid).

[5] We do not pursue the learning problem of dealer j any further. See below.

set, while in the other we address the importance of counterpart identity.

Since the Market Maker receives a private signal, and gives quotes based on his conditional expectation, the contacting dealer might use the quoted price to learn about the Market Maker's private information. This was the argument used by Lyons (1995) to argue for why the dealer did not shade prices at the end of the day, namely that initiating dealer might learn from the price. Therefore, when both dealers have private information, both dealers may use the action of their counterpart to learn about the other's private signal.

We will however not consider this problem here. Our main reason is to simplify the discussion. We also believe that the present framework is not very useful in this respect because it is a postulated model, not the result of full optimization. The model therefore does not allow the strategic consideration that would be natural to model if both dealers learn from each other. The simplification may be valid if the Market Maker (myopically) does not take into account that the contacting dealer may learn about the Market Maker's private information through his pricing behavior. Alternatively, one may take the view that the initiating dealer, aware of the informativeness of the dealer he contacts, already has conditioned on the possible signal from alternative quotes. This is more in line with rational expectations, and there is nothing that the Market Maker can do to influence this.

3.3.1 Customer trading as part of dealers' information set

We let the customer trade of dealer i enter his conditional expectation as a private signal, and model the implication for the two parts of his trading strategy: Pricing and order placement. In section 3.3.1, we extend the Madhavan and Smidt framework described above, so that the Market Maker uses the customer trade to update his conditional expectation. In other words, we derive a pricing strategy were both dealers may have private information. Next, in section 3.3.1, we show how private information influences the order placement strategy, using an analog to equation (3.1).

Customer trading and pricing strategy

The modelling implication of a private signal to dealer i, when dealer i does not take account of dealer j's possible learning from dealer i's action, is that dealer i will receive two private signals. These signals will be the trade with the customer, and the trade with dealer j, which is a signal on dealer j's private signal. Dealer j, seen from dealer i's perspective, only observes his own customer trade as private information. Of course, the demand of dealer j is still described by equation (3.1), hence he conditions on the price in his demand. To simplify we abstract from different precision of private signals, which is considered in section 3.3.2.

After observing the customer trade C_{jt}, dealer j's posterior (μ_{jt}) can be expressed as

$$\mu_{jt} = (1-\lambda)C_{jt} \tag{3.4}$$

where $\lambda = \sigma_\omega^2/(\sigma_r^2+\sigma_\omega^2)$. Similarly, dealer i will have the following expectation after observing his customer trade:

$$\mu'_{it} = (1-\lambda)C_{it}, \tag{3.5}$$

The weight on private signals $C_{\ell t}$ is the same for the two dealers since the signals have the same precision. Upon observing Q_{jt} dealer i extracts as much information about C_{jt} as possible to include in his expectation for his quote decision. More specifically, dealer i forms the sufficient statistic Z_{jt} given by

$$Z_{jt} = \frac{Q_{jt}/\theta + P_{it} - V_{t-1}}{1-\lambda} \equiv C_{jt} + \frac{1}{\theta(1-\lambda)}X_{jt}. \tag{3.6}$$

Equations (3.1) and (3.4) are used to derive the second equality. Z_{jt} is normally distributed with mean V_t and variance σ^2_{Zj} (equal to the variance of C_{jt} and X_{jt}). Furthermore, Z_{jt} is statistically independent of V_{t-1}. Dealer i's posterior belief (μ_{it}) is a weighted average of μ'_{it} and Z_{jt},

$$\mu_{it} = \kappa\mu'_{it} + (1-\kappa)Z_{jt}, \tag{3.7}$$

where $\kappa = \sigma^2_{Zj}/(\sigma^2_{\mu'} + \sigma^2_{Zj})$. Using the first equality in (3.6), we see that dealer i's posterior belief can be expressed as a function of Q_{jt},

$$\mu_{it} = \kappa(1-\lambda)C_{it} + (1-\phi)\left(\frac{Q_{jt}}{\theta} + P_{it} - V_{t-1}\right), \tag{3.8}$$

where $\phi = (\kappa-\lambda)/(1-\lambda) \in (0,1)$ since $\kappa > \lambda > 0$.

Inserting (3.8) into (3.2) gives

$$P_{it} = V_{t-1} + \kappa(1-\lambda)C_{it} + (1-\phi)\left(\frac{Q_{jt}}{\theta} + P_{it} - V_{t-1}\right) - \alpha(I_{it} - I_i^*) + \gamma D_t.$$

Collecting all terms containing P_{it} on the left hand side gives

$$P_{it} = V_{t-1} + \frac{\kappa(1-\lambda)}{\phi}C_{it} + \frac{1-\phi}{\phi\theta}Q_{jt} - \frac{\alpha}{\phi}(I_{it} - I_i^*) + \frac{\gamma}{\phi}D_t. \tag{3.9}$$

To test this equation we need to replace V_{t-1}, which is unobservable to the econometrician. We replace V_{t-1} with last periods conditional expectation of currency value, and add an expectational error term ε_{it} that represents public information which arrives between trades. Hence,

$$V_{t-1} = V_{t-2} + \mu_{it-1} + \varepsilon_{it} = P_{it-1} + \alpha(I_{it-1} - I_i^*) - \gamma D_{t-1} + \varepsilon_{it}. \tag{3.10}$$

Substituting this expression for V_{t-1} into (3.9), gives

$$\begin{aligned}\Delta P_{it} = \left(\frac{\alpha}{\phi} - \alpha\right)I_i^* + \left(\frac{\kappa(1-\lambda)}{\phi}\right)C_{it} + \left(\frac{1-\phi}{\phi\theta}\right)Q_{jt} \\ - \left(\frac{\alpha}{\phi}\right)I_{it} + \alpha I_{it-1} + \left(\frac{\gamma}{\phi}\right)D_t - \gamma D_{t-1} + \varepsilon_{it}.\end{aligned} \tag{3.11}$$

The model we use to test for effects from customer trades on pricing strategy is then given by

$$\Delta P_{it} = \beta_0 + f\left(C_{it};\boldsymbol{\beta}_C\right) + \beta_1 Q_{jt} + \beta_2 I_{it} + \beta_3 I_{it-1} + \beta_4 D_t + \beta_5 D_{t-1} + \varepsilon_{it}. \tag{3.12}$$

The coefficients β_1 and β_3 measure the information effect and inventory effect, respectively, while β_4 measures the transaction costs for small quantities. The model predicts that $\{\beta_1,\beta_3,\beta_4\} > 0, \{\beta_2,\beta_5\} < 0, \mid \beta_2 \mid > \beta_3, \beta_4 > \mid \beta_5 \mid$. The latter inequalities derive from the fact that $0 < \phi < 1$. We let the function $f\left(C_{it};\boldsymbol{\beta}_C\right)$, with coefficient vector $\boldsymbol{\beta}_C$, capture the effect from customer trades, since we in the empirical implementation do not only consider one-period effects. In the model of Madhavan and Smidt, this part falls out since they do not allow for private signals to the Market Maker. The model predicts that the effect from customer trades will be positive for customer purchases and negative for customer sales.

Customer trading and order placement strategy

If a dealer has good information due to customer trades, it will be natural to utilize this information in his own position taking. After receiving a customer trade, the dealer may choose to place his own orders with other dealers or brokers, rather than to wait for others to contact him. This is important in the foreign exchange market, where the multiple dealership structure allows the dealers to trade actively in addition to function as market makers. If private information may live longer than only one period (trade), the dealer may use the information from the customer trade in subsequent order placements as well.

We use ideas from Lyons (1997) to incorporate customer trading's effect on order placement strategy. A trade τ_{it} can be decomposed into three parts,

$$\tau_{it} = I_{it}^* - I_{it-1} + E\left[\tau_{it}'|\Omega_{it}\right]. \tag{3.13}$$

The dealer wants to have an inventory of I_{it}^*, and prior to the period t trade he already has I_{it-1} of this preferred inventory. In addition he buys a hedge against the expected inventory shocks that the dealer may receive from other dealers, $E\left[\tau_{it}'|\Omega_{it}\right]$. We will assume that this expectation is zero (see Lyons, 1997). This trading strategy can be used to analyze informed demand through the preferred inventory I_{it}^*.

Following Lyons (1997), the preferred inventory can be determined from an optimization of a negative exponential utility over final wealth. It is well known from Grossman and Stiglitz (1980) that this gives us

$$I_{it}^* = \theta\left(V_{t-1} + \mu_{it} - P_t\right), \tag{3.14}$$

where $V_{t-1} + \mu_{it}$ represent the conditional expectation of currency value (μ_{it} is the expectation for increment in currency value), and θ equals the inverse of the coefficient of risk aversion and the variance of the conditional expectation.

Similar to the treatment in section 3.3.1 there is a customer trade C_{it} which gives dealer i

a private signal on this periods increment to currency value, r_t. Conditionally on observing the customer trade, the expected increment μ_{it} is

$$\mu_{it} = (1-\lambda)C_{it}, \tag{3.15}$$

where $\lambda = \sigma_\omega^2 / \left(\sigma_\omega^2 + \sigma_r^2\right)$ and σ_ω^2 and σ_r^2 as before. We proxy for the unobservable currency value from previous trade, V_{t-1} in equation 3.14, in a very simple way: We simply subtract the half-spread from the prices in last trade, $P_{t-1} - \gamma D_{t-1}$, and add a noise term for new information that may have arrived in the meantime. The conditional expectation of V_t can then be expressed as

$$V_{t-1} + \mu_{it} = P_{t-1} - \gamma D_{t-1} + (1-\lambda)C_{it} + \varepsilon_{it}.$$

When we insert this into (3.14), let $(1-\lambda)C_{it}$ be represented by the more general $f(C_{it};\boldsymbol{\beta}_C)$, and insert for I_{it}^* into (3.13), the testable equation becomes

$$\tau_{it} = \beta_0 + f(C_{it};\boldsymbol{\beta}_C) + \beta_2 P_{t-1} + \beta_3 D_{t-1} + \beta_4 P_t + \beta_5 I_{t-1} + \varepsilon_{it} \tag{3.16}$$

where $f(C_{it};\boldsymbol{\beta}_C) + \beta_2 P_{t-1} + \beta_3 D_{t-1}$ represent $V_{t-1} + \mu_{it}$. Notice that the customer trade also will be included in I_{t-1} so that the effect from C_{it} is net of inventory control after a customer trade. The expected sign on the coefficients are $\beta_2 > 0$, $(\beta_3, \beta_4, \beta_5) < 0$, and positive effects from customer trades. We use the function $f(C_{it};\boldsymbol{\beta}_C)$ to represent the information from a customer trade since we do not want to be constrained to a linear static implementation as $(1-\lambda)C_{it}$.

3.3.2 Different precision of dealers' private signals

We have so far assumed that the precision of the private signal is the same for all dealers. However, larger banks see more customer order flow. Thus, the assumption of equal precision may not hold. Since dealers know the identity of the counterpart in a bilateral trade, they may also have some knowledge of their precision. In broker trades, the counterpart is anonymous when trading, so counterpart identity is only relevant for direct bilateral trading through the Reuters D2000-1 system.

In this section we consider how different precision of dealers' private signals can influence the pricing strategy in (3.9). The effect of a trade with an informed counterpart on subsequent order placement strategy is completely analogous to the case described in section 3.3.1, we will therefore not go further into that here. It is enough to observe that any trade with an initiator is a signal of his private information, and can be treated similar to a signal through own customer orders. If information is long-lived (more than one trade), it can be useful for subsequent order placement. The only difference from the order placement strategy derived in section 3.3.1 is that the weight the dealer gives information from a direct trade will be higher for trades with informed counterparts.

To address the issue of different counterparts we allow for different precision of their private signal, so that their conditional expectation of period increment to currency value after observing the customer trade is

$$\mu_{jt} = (1-\lambda_j)\,C_{jt}, \tag{3.17}$$
$$\mu'_{it} = (1-\lambda_i)\,C_{it}, \tag{3.18}$$

where $\lambda_\ell = \sigma^2_{\omega\ell}/\left(\sigma^2_r + \sigma^2_{\omega\ell}\right)$, $\ell = i, j$. We continue to abstract from the contacting dealer's learning problem, hence it is only dealer i that learn from the trade. Dealer j does condition his demand on the quoted price, but does not update his expectation after observing the quote. The change in price will be as in (3.11), except that the weight on new information in the conditional expectation μ_{it} expressed in (3.8) now have a subscript j, where $\phi_j = (\kappa - \lambda_j)/(1-\lambda_j)$. Note that λ_j depends on $\sigma^2_{\omega j}$, while κ depends on both $\sigma^2_{\omega i}$ and $\sigma^2_{\omega j}$.

We are particularly interested in how the coefficient on the trade Q_{jt} depends on the precision of the private information. All coefficients to present period variables are inversely related to ϕ_j, while the coefficient on the trade Q_{jt} itself, cf. equation (3.9), now becomes

$$\frac{1}{\theta}\frac{1-\phi_j}{\phi_j} = \frac{1}{\theta}\frac{1-\kappa}{\kappa-\lambda_j}.$$

The effect of $(1-\phi_j)/\theta\phi_j$ of a change in dealer j's precision $\sigma^2_{\omega j}$ is

$$\frac{\partial\left[(1-\phi_j)/\theta\phi_j\right]}{\partial\sigma^2_{\omega j}} = \frac{\partial(1/\theta)}{\partial\sigma^2_{\omega j}}\frac{1-\phi_j}{\phi_j} + \frac{1}{\theta}\frac{\partial\left[(1-\phi_j)/\phi_j\right]}{\partial\sigma^2_{\omega j}}. \tag{3.19}$$

We can not derive a unambiguous result for the effect of $\sigma^2_{\omega j}$ on this coefficient. In the appendix we argue that for reasonable values on the variances, the second derivative term in the expression above, $\partial\left[(1-\phi_j)/\phi_j\right]/\partial\sigma^2_{\omega j}$, is negative. In other words, $(1-\phi_j)/\phi_j$ will increase as the counterpart becomes better informed (lower $\sigma^2_{\omega j}$). A buy order from a counterpart perceived to be better informed will receive a larger weight in the updating of expectations, and lead to a larger price increase (for a given θ, see below) to protect against private information. This is also the most intuitive case.

The parameter θ is the parameter in the demand function of the contacting dealer,

$$Q_{jt} = \theta\left(V_{t-1} + \mu_{jt} - P_{it}\right) + X_{jt}.$$

This parameter equals

$$\theta = \frac{1}{\rho\sigma^2_{\mu j}}, \tag{3.20}$$

where

$$\sigma^2_{\mu j} = \lambda^2_j\sigma^2_r + (1-\lambda_j)^2\,\sigma^2_{\omega j} = \frac{\sigma^2_r\sigma^2_{\omega j}}{\sigma^2_r + \sigma^2_{\omega j}}, \tag{3.21}$$

and ρ is the coefficient of risk aversion. When $\sigma^2_{\omega j}$ decreases there is a direct negative effect on the variance $\sigma^2_{\mu j}$ through lower $\sigma^2_{\omega j}$, an indirect positive effect through the weight $(1-\lambda_j)$ on the noisy signal C_{jt}, and an indirect negative effect through the weight λ_j on the prior information. It turns out that the two indirect effects cancel out, so when dealer j receives signals that are more precise the θ-parameter increases and he trades more aggressively. The expression is given by

$$\frac{\partial (1/\theta)}{\partial \sigma^2_{\omega j}} = \rho (1-\lambda_j)^2.$$

Since $\sigma^2_{\mu j}$ is concave in $\sigma^2_{\omega j}$, $1/\theta$ will also be concave in $\sigma^2_{\omega j}$. This implies that for a relatively well informed dealer (low $\sigma^2_{\mu j}$, and high θ), changes in $\sigma^2_{\omega j}$ will only lead to small changes in θ. Furthermore, since $(1-\lambda_j)$ is between 0 and 1, and in cases where dealer i gives higher weight to his own information than to the signal from trading with dealer j $(\phi_j > 1-\phi_j)$, the first term in (3.19) will most likely be small and positive.

If the private information signal is more precise than the public information signal, which most likely will be the case for well informed dealers, then we can feel rather confident that (3.19) will be decreasing in $\sigma^2_{\omega j}$ since the second term in (3.19) is negative. This means that the Market Maker puts more weight on a trade with a well informed dealer than on a trade with a uninformed.

We cannot observe the precision of other dealers' signals, but we can observe how well informed the market makers perceive their counterparts to be. We have interviewed the dealers about how well informed they perceive their counterparts in direct trading are compared to themselves, using a scale from 1 to 5, where 3 was equally well informed and 5 was superiorly informed. The results from the interviews are presented below.

3.4 Data

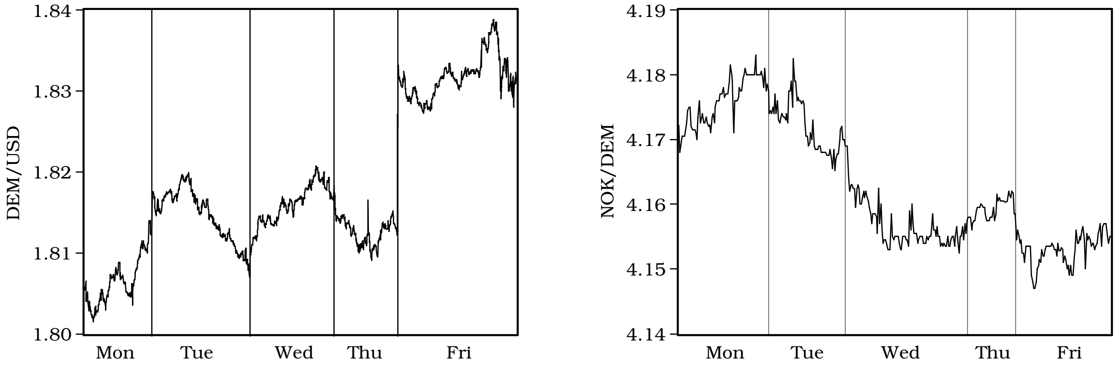
The data set employed in this study consists of the complete trading records for two spot dealers over the week March 2–6, 1998.[6] Both dealers work in the same Scandinavian commercial bank. The dealers trade in different currency pairs and represent different trading styles. Both are experienced dealers. The first dealer is a medium-sized Market Maker in DEM/USD, while the other dealer is the largest Market Maker in NOK/DEM. The DEM/USD Market Maker has some customer order flows, while the NOK/DEM Market Maker has large customer order flows. In figure 3.3 transaction prices for the two exchange rates are presented, based on the trading of the whole Foreign Exchange Department in the bank.

The data set consists of two components: (*i*) the dealers' record from an internal system used for controlling inventory positions and dealer profits, and (*ii*) information from electronic trading systems. Our data allows a direct test of inventory models and the investigation of trading strategies, since it contains the complete records of the dealers' trading actions.

The first component of the data set consists of all trades, including trades with "voice" bro-

[6]This is the same data set as in Bjønnes and Rime (2000). Here, we focus on the two dealers called Dealer 1 and Dealer 3 in Bjønnes and Rime (2000).

Figure 3.3: Transaction prices



a) DEM/USD transaction price

b) NOK/DEM transaction price

Transaction prices during the week. The source is all the spot transactions conducted electronically by the whole Foreign Exchange department of the bank, a total of 2108 DEM/USD transactions and 377 NOK/DEM transactions. The horizontal axis is in "transaction"-time. Vertical lines indicate end of day.

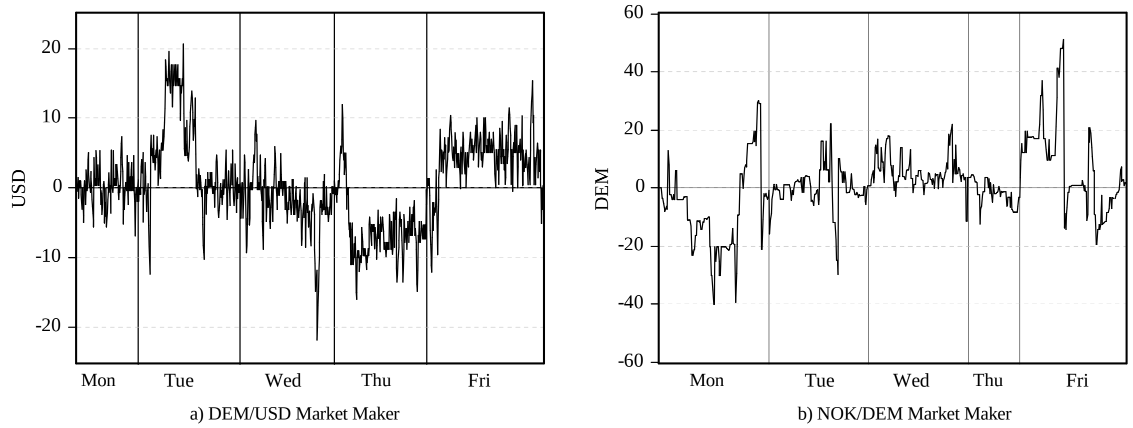
kers, direct trades completed by telephone, internal trades and customer trades. Trades executed by electronic systems, the bilateral system Reuters D2000-1 and the two electronic brokers Reuters D2000-2, and EBS, are electronically entered into the record. Other trades must be entered manually. This part contains all trades, so we can track the dealers' inventory position.

The second part of the data set consists of all trades executed on the three electronic trading systems, Reuters D2000-1, Reuters D2000-2 and EBS. When we match the two parts, we obtain a data set with information on (*i*) the type of transaction (D2000-1, D2000-2, EBS, voice broker, customer trade, or internal transfer); (*ii*) time of transaction; (*iii*) exact inventories in all currencies; (*iv*) transaction price; (*v*) whether the dealer bought or sold; and in the case of electronic transactions, we have information on (*vi*) initiator of the trade; and (*vii*) counterpart to the trade.

Figure 3.4 presents inventory positions of the two dealers. The inventories follow similar patterns. The DEM/USD Market Maker trades only in DEM/USD. The maximum long position in dollar was USD 21 million, while the maximum short dollar position was USD 22 million. He ends each day with a position close to zero. The NOK/DEM Market Maker has a maximum long DEM position of DEM 51 million and a maximum short position of DEM 40 million. He has significant trading in several currency crosses, most important is customer trading in NOK/USD. The NOK/DEM Market Maker ends his day with a slightly higher average absolute value of inventory, DEM 2.43 million against the DEM/USD Market Maker's USD 0.2 million.

Table 3.2 reports statistics on the dealers' daily activity during the sample period. The DEM/USD Market Maker has an average daily trading volume of USD 443 million, and average trade size of USD 2.2 million. This characterizes him as a medium-sized Market Maker in a market with hundreds of market makers and an average daily trading volume of USD 150 billion (BIS, 1998). The NOK/DEM Market Maker's average daily trading volume in NOK/DEM is DEM 270 million, with an average trade size of DEM 4.4 million. The total daily average NOK/DEM trading in the Norwegian market in April 1998 was USD 656 million (BIS, 1998). With a market share of 25%,

Figure 3.4: Dealer inventory



The evolution of the inventory of the two dealers over the week. The horizontal axis is in "transaction"-time. Vertical lines indicate end of day. Panel *a* shows the USD-inventory of the DEM/USD Market Maker, while panel *b* shows the DEM-inventory of the NOK/DEM Market Maker.

the NOK/DEM Market Maker is certainly a major player in this market.[7] From table 3.2 we can see that there is considerable daily variations in volume. For the NOK/DEM Market Maker the busiest day in NOK/DEM has as much as five times the volume compared with the slowest day.

Table 3.2: Trading volumes and number of trades for both dealers

			Mon.	Tue.	Wed.	Thu.	Fri.	Total
DEM/USD	All DEM/USD	Volume	302	491	464	395	562	2214
Market		Number	133	221	192	206	240	992
Maker	Customer trades	Volume	23	17	18	2	12	72
		Number	6	4	6	3	4	23
NOK/DEM	All NOK/DEM	Volume	354	281	314	62	337	1348
Market		Number	63	61	83	25	60	292
Maker	Customer trades	Volume	102	49	59	10	26	246
	in NOK/DEM	Number	13	12	17	2	6	50
	All customer trades	Number	40	26	29	16	36	147
	All trades	Number	125	113	123	60	124	546

"Volume" is the total trading volume in DEM/USD for the DEM/USD Market Maker (measured in USD), and the total trading volume in NOK/DEM for the NOK/DEM Market Maker (measured in DEM). "Number" is the number of trades. The DEM/USD Market Maker trades only in DEM/USD, while the NOK/DEM Market Maker trades in several exchange rates where NOK/DEM is the most important one. "All trades" represent all trades executed by the dealer. "Customer trades" and "All customer trades" refer to trades with customers.

Table 3.2 also presents numbers on customer trades. The DEM/USD Market Maker has only a limited number of customer trades. Customer trading is very important for the NOK/DEM Market Maker. In addition, he has considerable customer trading in other currency crosses. Most important of these other crosses is trading in NOK/USD.

The distribution of signed customer order flow, positive for a customer purchase and negative for a sale, is shown in table 3.3. The DEM/USD Market Maker has a few medium sized customer trades of USD 10 and 15 million, but most are small. Most of the customers bought DEM when trading with the NOK/DEM Market Maker. Although the two Market Makers have different access

[7] This number reflects NOK/DEM trading with at least one Norwegian bank as counterpart. Taking account of some NOK/DEM trading executed outside of Norway the share will be somewhat lower.

to customer trades, both regard their customer trades as important.

Table 3.3: Distribution of customers trading

	DEM/USD Market Maker		NOK/DEM Market Maker	
$[-15,-10)$	1	(4%)		
$[-10,-5)$	2	(9%)	2	(4%)
$[-5,0)$	13	(57%)	4	(8%)
$[0,5)$	4	(17%)	26	(52%)
$[5,10)$	2	(9%)	11	(22%)
$[10,15)$	1	(4%)	4	(8%)
$[15,20)$			1	(2%)
$[20,25)$			1	(2%)
$[50,55)$			1	(2%)
Total	23	(100%)	50	(100%)
Aver(Q_t^{CUS})	-1.07		3.98	
Aver(abs(Q_t^{CUS}))	3.12		4.93	

Distribution of the dealers customer transactions. Negative numbers indicate that the customers sold to the market maker, while positive indicate a customer purchase. The intervals measure USD-amounts for the DEM/USD Market Maker, and DEM-amounts for the NOK/DEM Market Maker.

The relevant trading channel for the testing of pricing behavior when the counterpart is known is direct trading through D2000-1. This is the traditional channel for market making, i.e. giving quotes on request. Both dealers use direct trading, but to a smaller extent than what they used to before the introduction of electronic brokers. They never use outgoing direct trades. This was regarded as expensive. The NOK/DEM Market Maker was also concerned by not signalling his inventory position. For the DEM/USD Market Maker direct trading account for 6% of total volume, while for the NOK/DEM Market Maker direct trading account for 25% of total volume (30% of interbank trading in case of the NOK/DEM Market Maker). Both dealers regard direct trading as an obligation due to being a “Market Maker.” They also see their presence on this system as a way to attract trades from other dealers. As we see below, they generally trade with counterparts that in their own views are less informed than themselves.

Since none of the Market Makers use direct trading for outgoing trades, the order placement strategies are related to the electronic brokers. The DEM/USD Market Maker primarily uses electronic broker systems. These account for 77% of his total volume. The NOK/DEM Market Maker also uses electronic broker systems, but only for 28% of total volume.[8]

To study the importance of counterpart identity in direct trading, without revealing the actual identity of the counterpart, we made a questionnaire to each of the most active spot dealers in the department. Each dealer was asked to give scores with respect to informativeness, from 1 to 5, to the banks they had been trading directly with during the week. A score of 3 indicated that the dealer expected the bank to be equally well informed as him, while 5 indicated superiorly informed and 1 were for those banks the dealer regarded as very badly informed compared to him.

[8]Both dealers also use traditional voice brokers. For the DEM/USD Market Maker voice-broker trades account for 11% of total volume, while for the NOK/DEM Market Maker the number is 8% (10% of interbank trades in case of the NOK/DEM Market Maker).

Table 3.4: Dealer perceptions of counterpart's information

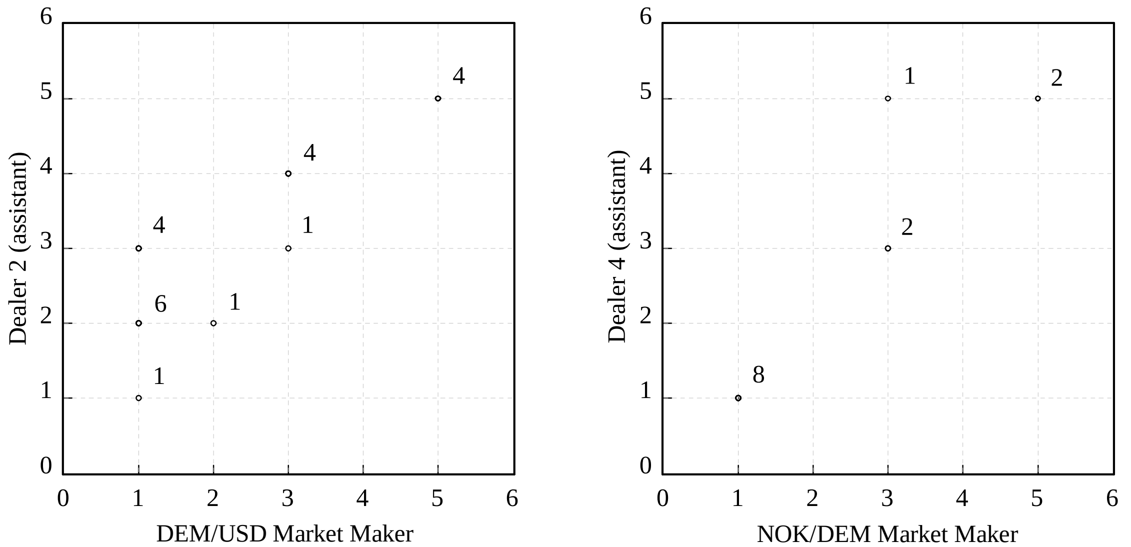
	DEM/USD Market Maker	NOK/DEM Market Maker	Dealer 2	Dealer4	Dealer 5
(1) Inferiorly	12	26	1	36	
(2) Worse	3		7		3
(3) Equally	5	8	5	7	2
(4) Better			4		3
(5) Superiorly	4	5	4	13	1
Total	24	39	21	56	9
Average	2.2	1.9	3.1	2.2	3.2

The table reports the number of replies in each category in the questionnaire.

The results of the questionnaire are reported in table 3.4, where the two dealers in the present study are presented together the other dealers answering the questionnaire. The other dealers in the table are as follows: Dealer 2 and 4 are the same dealers as in Bjønnes and Rime (2000). Dealer 2 is a DEM/USD dealer working as assistant for the DEM/USD Market Maker, and Dealer 4 is a DEM/USD and SEK/DEM dealer that was also working as an assistant for the NOK/DEM Market Maker. Dealer 5 is a JPY-dealer that was not very active this particular week.

The DEM/USD Market Maker and the NOK/DEM Market Maker traded directly with 24 and 39 different banks respectively. We can see that they traded mainly with banks they regarded as being less informed than themselves. Figure 3.5 presents scatter plots of the cases where the Market Makers and their assistants, Dealer 2 and 4 respectively, traded with the same bank, and how they regarded the bank's informativeness. We can see that the assistants' entries are either on or above the 45-degree line, showing that they were somewhat less confident than the Market Makers.

Figure 3.5: Bank counterpart informativeness



Scatter plot of how the dealers agree on counterpart informativeness. Each dot represents a bank that both dealers had traded with, and the position of the dot reflects how they regarded this bank. The number next to each dot gives the numbers of banks in each combination.

Table 3.5 confirms the picture in figure 3.5. The table shows the correlation between the dealers in the cases where they both had traded with the same bank. We see that they seem to agree to a large extent, which may be taken as a sign of reliability of the results. However, in some cases there are very few banks they share, as can be seen from the numbers in parenthesis.

Table 3.5: Correlation matrix of dealer perceptions

	DEM/USD Market Maker	NOK/DEM Market Maker	Dealer 2	Dealer 4	Dealer 5
DEM/USD Market Maker	1				
NOK/DEM Market Maker	(4)	1			
Dealer 2	0.90 (21)	(3)	1		
Dealer 4	0.92 (7)	0.95 (13)	0.94 (7)	1	
Dealer 5	0.94 (4)	1 (2)	1 (4)	(1)	1

Correlations between the dealers' replies in cases where they have traded with the same bank. Numbers in parenthesis indicate the number of banks. In some cells it was not possible to calculate a correlation coefficient.

3.5 Results

In section 3.5.1 we test the importance of customer trades, and in section 3.5.2 we test the importance of counterpart identity. In both cases we test the effect on both pricing strategy (sections 3.5.1 and 3.5.2), and order placement strategy (sections 3.5.1 and 3.5.2). In all regressions, except the ones testing for effects on the spread, we will use the event study method that is commonly applied in corporate finance (see Thompson, 1995). In short, in corporate finance applications, event studies are used to measure the impact of new information on stock prices. In the present setting, we measure the impact of new information from customer trades and counterpart identity on the dealers trading strategy. Since dealers regard customer trades as private information, we use the event study methodology to study the effect of these trades as new information. We also regard a trade with particularly well informed banks as information events.

In an event study it is important to identify the event itself and define a period ("event window") where the event is allowed to have effect. In our case, the identification of the event is easy since we have an exact timing of the trades with both customers and informed counterparts. In most cases, we let the event window be the event itself and the two or three following trades. With a median intertransaction time for the DEM/USD and NOK/DEM Market Maker in incoming trades of 2.3 and 7.6 minutes, respectively, this should be sufficient to capture the potentially abnormal effect following the new information. We implement the events using dummy variables.

3.5.1 Customer trading

Customer trading and pricing strategy

In equation (3.12) we incorporate customer trades as private information to the Madhavan and Smidt model. The equation we test is the following,

$$\Delta P_{it} = \beta_0 + \sum_{\ell=0}^{3} \beta^{B}_{\ell 1} d_{\ell t} Q^{CUS}_{t-\ell} + \sum_{\ell=0}^{3} \beta^{S}_{\ell 2} d_{\ell t} Q^{CUS}_{t-\ell} + \beta_3 Q_{jt} + \beta_5 I_{it} + \beta_6 I_{it-1} + \beta_5 D_t + \beta_4 D_{t-1} + \varepsilon_t, \quad (3.22)$$

where the dummies $d^{j}_{\ell t}$, $j = \{B, S\}$, takes the value 1 in period ℓ after the customer trade (the event), and zero otherwise. We have implemented the effect from customer trades, the $f(C_{it}; \boldsymbol{\beta}_C)$-function in (3.12), as a linear function with three lags. The results from testing on the pricing strategy are shown in table 3.6.

The results investigating whether the dealers utilize their private information in pricing are somewhat ambiguous. Several of the coefficients are positive, as predicted, and significant. However, we also have cases with negative and significant coefficients. The effect on the change in the price is countered by a opposite sign in the next quote. This may be due to that using private information to give quotes different from the rest of the market may neither be a preferable strategy, due to high transparency of prices, nor a viable strategy for a Market Maker supposed to give competitive quotes.

We do not find any inventory effects through quote shading. This is line with previous results in Bjønnes and Rime (2000). The baseline spread variables D_t are significant and correctly signed.

When we add a specific baseline spread variable (direction-variable, D^{CUS}_t) for the customer trades to take account of the possibility that dealers give wider spreads to customers than in interbank trading, some of the effects disappear. However, the coefficient on the customer baseline spread is significantly larger than the interbank baseline spread. The baseline spread to customers is three to four times larger than the interbank baseline spread. This shows that customers receive wider spreads than interbank dealers do. Wider spreads to customers have been highlighted as one of the main benefits with customer order flow by Yao (1998b). One reason why it is possible to discriminate between customers and interbank dealers is that the customers do not have access to the electronic trading systems in the interbank market.

Customer trading and order placement strategy

To explore the order-placing strategy we take equation (3.16) as our starting point. We implement the effect from customer trades, i.e. the $f(C_{it}; \boldsymbol{\beta}_C)$ function in (3.16), as a linear function with three lags, hence we allow the customer trade to have effect on the three following trades. The

Table 3.6: Customer trade as event in estimation of the pricing strategy ΔP_{it}

	DEM/USD Market Maker		NOK/DEM Market Maker	
Constant	0.147	0.246	1.274	1.066
	(0.49)	(0.82)	(1.11)	(0.95)
Customer purchase: $d^B_{0t}Q^{CUS}_t$ $(+)$	1.447	0.895	0.462	-0.770
	***(2.93)	*(1.79)	*(1.83)	(-1.46)
Customer purchase: $d^B_{1t}Q^{CUS}_{t-1}$ $(+)$	-0.242	0.792	-0.555	0.636
	*(-1.79)	**(2.10)	*(-1.90)	(0.99)
Customer purchase: $d^B_{2t}Q^{CUS}_{t-2}$ $(+)$	4.971	-4.991	-0.087	-0.058
	**(2.11)	**(-2.13)	(-0.36)	(-0.36)
Customer purchase: $d^B_{3t}Q^{CUS}_{t-3}$ $(+)$	1.219	1.375	-0.884	-0.233
	(1.27)	*(1.70)	(-1.32)	(-0.43)
Customer sale: $d^S_{0t}Q^{CUS}_t$ $(+)$	0.277	-0.274	0.962	-3.101
	**(2.21)	(-1.19)	(1.32)	***(-3.69)
Customer sale: $d^S_{1t}Q^{CUS}_{t-1}$ $(+)$	0.021	-0.352	-1.870	2.607
	(0.26)	(-1.44)	***(-3.72)	***(3.41)
Customer sale: $d^S_{2t}Q^{CUS}_{t-2}$ $(+)$	-0.380	-0.360	0.510	0.315
	*(-1.82)	*(-1.71)	(0.24)	(0.13)
Customer sale: $d^S_{3t}Q^{CUS}_{t-3}$ $(+)$	0.011	-0.051	0.872	-0.650
	(0.06)	(-0.40)	(0.63)	(-0.89)
Interbank trade Q_{jt} $(+)$	-0.058	-0.104	0.092	-0.018
	(-0.21)	(-0.39)	(0.25)	(-0.06)
Inventory I_{it} $(-)$	0.158	0.145	0.117	-0.201
	(1.19)	(1.07)	(0.58)	(-1.30)
Lagged inventory, I_{it-1} $(+)$	-0.143	-0.119	-0.252	0.079
	(-1.17)	(-0.96)	(-1.15)	(-0.60)
Direction D_t $(+)$	1.614	1.713	7.081	5.551
	***(3.18)	***(3.42)	***(4.52)	***(4.21)
Direction lagged D_{t-1} $(-)$	-0.567	-0.511	-5.506	-4.014
	*(-1.80)	(-1.62)	***(-3.06)	**(-2.53)
Customer direction D^{CUS}_t $(+)$		5.103		21.931
		**(2.34)		***(7.08)
Customer dir lagged D^{CUS}_{t-1} $(-)$		3.628		-24.717
		(1.44)		***(-5.68)
AR(1) $(-)$	-0.081	-0.078	-0.360	-0.290
	***(-3.46)	***(-3.23)	***(-4.57)	***(-2.99)
Adjusted R^2	0.20	0.22	0.18	0.43
Durbin-Watson stat	1.92	1.92	2.02	2.08

Estimation by GMM and Newey-West correction. t-values are in parenthesis, and ***, ** and * indicate significance at the 1%, 5% and 10%-level respectively. All coefficients except the AR-term are multiplied by 10^4. Number of included observations are 452 and 191 for the DEM/USD Market Maker and the NOK/DEM Market Maker, respectively. Overnight price changes are deleted.

following equation is used to test customer trades effect on order placement strategy:

$$\tau_{it} = \beta_0 + \sum_{\ell=0}^{3} \beta_{\ell 1}^{B} d_{\ell t}^{B} Q_{t-\ell}^{CUS} + \sum_{\ell=0}^{3} \beta_{\ell 2}^{S} d_{\ell t}^{S} Q_{t-\ell}^{CUS} + \beta_3 P_{t-1} + \beta_4 D_{t-1} + \beta_5 P_t + \beta_6 I_{t-1} + \varepsilon_t, \qquad (3.23)$$

with event-dummies d inserted for the new information contained in customer trades. The $\beta_{\ell 1}^{B}$-coefficients measures the abnormal effect on trading strategy in trade ℓ after a customer purchase. The S-superscript indicates coefficients capturing the effect of a customer sale. Note that the customer trade is captured in the lagged inventory. Inventory control related to the customer trade will therefore be picked up by this variable. Hence, the effect through the $\beta_{\ell 1}^{B}$ and $\beta_{\ell 2}^{S}$ coefficients from a customer trade may be interpreted as a speculative demand. We include both current and lagged price variables. Both are non-stationary, but a linear combination of the two is stationary. Replacing the two with the change in price, and thereby constraining the β_3 and β_5 coefficients to be equal, does not alter the results.

We are interested in how the customer trade influences the dealer's subsequent trading. Hence, in τ_{it} we include all deliberate purchases and sales on behalf of the dealer. This means that we include all outgoing trades (irrespective of choice of trading system), and all incoming trades on electronic brokers. Incoming trades on electronic brokers are often placed as a one-way quote so the dealer controls the direction of trade. We let a purchase by dealer i be a positive trade, and a sale be a negative trade. The predicted sign on the coefficients are $\left(\beta_{\ell 1}^{B}, \beta_{\ell 2}^{S}\right) > 0, \beta_3 > 0, (\beta_4, \beta_5, \beta_6) < 0$. Notice that both $\beta_{\ell 1}^{B}$ and $\beta_{\ell 2}^{S}$ will be positive since we weight each event with the customer trade, which will be positive for customer purchases and negative for customer sales. In this way we let the effect of a large customer trade be larger than from a small one, in line with the presumption that a large trade leads to a larger change in conditional expectation.

The results are reported in table 3.7. Since the NOK/DEM Market Maker has so few transactions where the customer sells, it is difficult to evaluate an implementation where these are included. We see that customer purchases of currency tend to make the dealer purchase currency. The effect after customer sales is weaker. The results are most evident for the DEM/USD Market Maker, which probably is in a more favorable position to take advantage of customer trades since he operates in a more liquid sub-market than the NOK/DEM market. We also see that both dealers use several trades to follow up on a customer trade. One should keep in mind that the customer trade also is contained in the inventory, so that the effect measured by the $\beta_{\ell 1}^{B}$ and $\beta_{\ell 2}^{S}$ coefficients are in excess of inventory control. This is in line with the speculation that occurs in the model of Cao and Lyons (1998). An example may clarify: If a customer buys 10 million USD from the DEM/USD Market Maker, he will in the next four deliberate trades buy a total of 6 million USD $(0.14 + 0.28 + 0.18)$. When a customer buys 10 million DEM from the NOK/DEM Market Maker, he will buy almost 8 million DEM during the next four trades $(0.41 + 0.38)$.[9]

The coefficients on lagged price should be positive, since it is part of the dealers' expectations. This is confirmed for the NOK/DEM Market Maker. Impact of current price should be negative

[9]Here we only consider significant coefficients.

Table 3.7: Customer trade as event in estimation of the order placement strategy τ_{it}

	DEM/USD Market Maker	NOK/DEM Market Maker
Constant	-17.322	407.227
	(-0.98)	(1.33)
Customer purchase: $d^B_{0t}Q^{CUS}_t$ $(+)$	0.141	0.409
	**(2.08)	**(2.60)
Customer purchase: $d^B_{1t}Q^{CUS}_{t-1}$ $(+)$	-0.154	0.328
	(-0.96)	(1.02)
Customer purchase: $d^B_{2t}Q^{CUS}_{t-2}$ $(+)$	0.289	0.385
	***(9.05)	**(2.33)
Customer purchase: $d^B_{3t}Q^{CUS}_{t-3}$ $(+)$	0.180	0.017
	***(10.99)	(0.20)
Customer sale: $d^S_{0t}Q^{CUS}_t$ $(+)$	-0.279	
	*(-1.69)	
Customer sale: $d^S_{1t}Q^{CUS}_{t-1}$ $(+)$	0.087	
	(0.68)	
Customer sale: $d^S_{2t}Q^{CUS}_{t-2}$ $(+)$	-0.005	
	(-0.05)	
Customer sale: $d^S_{2t}Q^{CUS}_{t-2}$ $(+)$	0.176	
	*(1.75)	
Lagged price P_{t-1} $(+)$	12.479	653.551
	(0.11)	**(2.03)
Direction lagged D_{t-1} $(-)$	0.033	-0.632
	(0.35)	(-1.51)
Price P_t $(-)$	-2.925	-751.142
	(-0.03)	**(-2.25)
Inventory I_{t-1} $(-)$	-0.034	0.002
	**(-2.27)	(0.05)
AR(1)	-0.213	0.224
	***(-5.04)	(1.32)
Adjusted R^2	0.06	0.18
Durbin-Watson stat	2.08	1.60

Estimation by GMM and Newey-West correction. t-values are in parenthesis, and ***, ** and * indicate significance at the 1%, 5% and 10%-level respectively. Dependent variable is trade τ_{it}. Number of included observations are 808 for the DEM/USD Market Maker and 106 for the NOK/DEM Market Maker. Inventory is USD-inventory in case of the DEM/USD Market Maker, and DEM inventory in case of the NOK/DEM Market Maker.

for a profit maximizing dealer. This coefficient is negative for both dealers, but significantly so only for the NOK/DEM Market Maker. The coefficient on lagged inventory should be negative due inventory control, and this is confirmed for the DEM/USD Market Maker. A large positive inventory in the previous trade, leads the DEM/USD Market Maker to sell currency so to control inventory.

3.5.2 Counterpart informativeness

Counterpart informativeness and pricing strategy

A dealer can relate to trading with potentially better informed dealers in two ways: He can widen his spread to discourage trade, and he can update his beliefs based on the trade and hence influence subsequent trades. In this section we first analyze spread determination, and then regard a trade with an informed dealer as an information event.

Table 3.8 reports the relation between the absolute size of trades in direct trading, and the dealers' perception of their counterparts' informativeness. The picture from earlier that the dealers generally regard their counterparts in direct trading as worse informed than themselves are confirmed. A majority of the trades is small.

Table 3.8: Absolute size of direct trade and informativeness of counterpart

		Inferiorly Informed	Worse Informed	Equally Informed	Superiorly Informed	Total Total
DEM/	[0, 5)	45 (58%)	6 (8%)	19 (24%)	3 (4%)	73 (94%)
USD	[5, 10)			4 (5%)		4 (5%)
Market	[10, 15)				1 (1%)	1 (1%)
Maker	Total	45 (58%)	6 (8%)	23 (29%)	4 (5%)	78 (100%)
NOK/	[0, 5)	47 (52%)		10 (11%)	7 (8%)	64 (71%)
DEM	[5, 10)	1 (1%)			4 (4%)	5 (6%)
Market	[10, 15)	2 (2%)		6 (7%)	8 (9%)	16 (18%)
Maker	[15, 20)	1 (1%)			1 (1%)	2 (2%)
	[20, 25)				2 (2%)	2 (2%)
	[40, 45)				1 (1%)	1 (1%)
	Total	51 (57%)		16 (18%)	23 (26%)	90 (100%)

The table shows the absolute value of direct trade in groups, together with how the two dealers regarded their counterparts in the same trades. We see that a majority of the inferiorly informed banks also trade smaller volumes.

The spread of the dealers in direct trading on D2000-1 is reported in table 3.9. With an exchange rate of 1.8 for DEM/USD and 4.16 for NOK/DEM, the minimum spread of 0.0001 DEM in DEM/USD is worth 0.000416 Kroner. The minimum spread in NOK/DEM is 0.0005 Kroner, only slightly higher.

We test two different formulations for how counterpart information influences the spread. In the first we simply let the slope coefficient of a trade differ for different groups of counterparts, while in the second we also address the possibility that only large trades really add to the spread.

Table 3.9: Spread from D2000-1 trading

DEM/USD Market Maker			NOK/DEM Market Maker		
Spread	Number	Percent	Spread	Number	Percent
1	8	(10.3%)	5	6	(6.7%)
2	48	(61.5%)	10	25	(27.8%)
3	5	(6.4%)	15	15	(16.7%)
4	1	(12.8%)	20	1	(1.1%)
			30	14	(15.6%)
NA	16	(20.5%)	NA	29	(32.2%)
Total	78	(100%)	Total	90	(100%)

The spread is measured "pips," which is the fourth decimal of the exchange rate, e.g. 0.0001 DEM.

The two regressions are

$$Spread_{it} = \alpha_0 + \sum_{\ell \in L} \alpha_\ell d_{\ell t} \text{abs}(Q_{jt}) + \varepsilon_{it}, \tag{3.24}$$

$$Spread_{it} = \alpha_0 + \sum_{k \in K} \sum_{\ell \in L} \alpha_{k\ell} \delta_{kt} d_{\ell t} \text{abs}(Q_{jt}) + \varepsilon_{it}, \tag{3.25}$$

where the two summations differ for the two dealers. In case of the DEM/USD Market Maker, $K = \{\text{abs}(Q_{jt}) < 1, \text{abs}(Q_{jt}) \geq 1\}$ and $L = \{INFO < 3, INFO \geq 3\}$. For the NOK/DEM Market Maker the two sets are $K = \{\text{abs}(Q_{jt}) < 5, \text{abs}(Q_{jt}) \geq 5\}$ and $L = \{INFO < 3, INFO = 3, INFO > 3\}$. We split the counterparts into a "informed" and "uninformed" group in this way in order to have enough observations for estimation in each group.

Table 3.10: DEM/USD Market Maker: Spread in direct trading

Constant	1.722	1.750
	***(17.95)	***(11.94)
Uninformed $d_t^{INFO<3}$abs(Q_{jt})	0.172	
	**(2.00)	
Informed $d_t^{INFO\geq 3}$abs(Q_{jt})	0.132	
	***(3.91)	
Uninformed, small trade $\delta_t^{abs(Q)\leq 1} d_t^{INFO<3}$abs($Q_{jt}$)		0.113
		(0.58)
Uninformed, large trade $\delta_t^{abs(Q)>1} d_t^{INFO<3}$abs($Q_{jt}$)		0.168
		*(1.91)
Informed, small trade $\delta_t^{abs(Q)\leq 1} d_t^{INFO\geq 3}$abs($Q_{jt}$)		0.250
		*(1.71)
Informed, large trade $\delta_t^{abs(Q)>1} d_t^{INFO\geq 3}$abs($Q_{jt}$)		0.125
		***(3.26)
Adjusted R^2	0.19	0.17
Durbin-Watson stat	2.52	2.52

t-values are in parenthesis, and ***, ** and * indicate significance at the 1%, 5% and 10%-level respectively.

In table 3.10 the results for the DEM/USD Market Maker is reported, while the results for the NOK/DEM Market Maker is reported in table 3.11.

From the two tables we can see that the most significant coefficient is the constant term, which may be interpreted as the normal spread. We also see that it is the size of the trade, and not the

Table 3.11: NOK/DEM Market Maker: Spread in direct trading

Constant	10.427	11.976
	***(17.50)	***(16.00)
Uninformed $d_t^{INFO<3}\text{abs}(Q_{jt})$	1.196	
	***(3.07)	
Equally informed $d_t^{INFO=3}\text{abs}(Q_{jt})$	1.913	
	***(29.63)	
Informed $d_t^{INFO>3}\text{abs}(Q_{jt})$	1.500	
	***(3.93)	
Uninformed, small trade $\delta_t^{abs(Q)<5} d_t^{INFO<3}\text{abs}(Q_{jt})$		-1.376
		(-0.90)
Uninformed, large trade $\delta_t^{abs(Q)\geq 5} d_t^{INFO<3}\text{abs}(Q_{jt})$		1.082
		***(2.81)
Equally, small trade $\delta_t^{abs(Q)<5} d_t^{INFO=3}\text{abs}(Q_{jt})$		-1.394
		(-1.49)
Equally, large trade $\delta_t^{abs(Q)\geq 5} d_t^{INFO=3}\text{abs}(Q_{jt})$		1.802
		***(24.08)
Informed, small trade $\delta_t^{abs(Q)<5} d_t^{INFO>3}\text{abs}(Q_{jt})$		-5.380
		**(-2.02)
Informed, large trade $\delta_t^{abs(Q)\geq 5} d_t^{INFO>3}\text{abs}(Q_{jt})$		1.366
		***(3.44)
Adjusted R^2	0.72	0.74
Durbin-Watson stat	2.15	2.23

t-values are in parenthesis, and ***, ** and * indicate significance at the 1%, 5% and 10%-level respectively.

counterpart information, which contributes to the spread. When we distinguish between trade size and counterpart, it is only the large trades that are significant, irrespective of the counterpart. This result is in line with recent survey results by Cheung and collaborators. To a question of what is the main determinant of the bid-ask spread, most dealers replied “Market convention” to an alternative of “Potential cost of quoting.” The shares of the dealers giving this reply ranged from 69% in the US, 70% for U.K. and Tokyo, 71% for Singapore, and 77% for Hong Kong.

That spreads do not widen abnormally when trading with informed counterparts is an indication that the dealers do not price discriminate between each other. The condition for doing price discrimination is not present in a market where the transparency with regard to prices is so high as in the foreign exchange market. A contacting dealer being price discriminated would not be willing to trade, and rather turn to another dealer, e.g. an electronic broker, which were offering better terms.

In table 3.12 we test if trading with an expected well-informed counterpart influences subsequent pricing behavior with the following adaption of the Madhavan and Smidt model:

$$\Delta P_{it} = \beta_0 + \sum_{\ell=0}^{3} \beta_{\ell 1}\delta_{t-\ell} d_{t-\ell} Q_{t-\ell} + \beta_3 Q_{jt} + \beta_5 I_{it} + \beta_6 I_{it-1} + \beta_5 D_t + \beta_4 D_{t-1} + \varepsilon_t, \qquad (3.26)$$

where d_t equals one if the counterpart is perceived to be well informed. This formulation allows us to test whether there is any extra protection against adverse selection, and whether subsequent trading is affected.

Table 3.12: Counterpart information as an event in the pricing strategy ΔP_{it}

	DEM/USD Market Maker	NOK/DEM Market Maker
Constant	-0.043	-0.187
	(-0.13)	(-0.23)
Informed direct trading $\delta_t^{\text{Direct}_t} d_t^{INFO_t \geq 3} Q_{jt}$ $(+)$	0.224	-0.292
	(0.41)	(-0.90)
Informed direct, lagged 1 $\delta_{t-1}^{\text{Direct}_{t-1}} d_{t-1}^{INFO_{t-1} \geq 3} Q_{jt-1}$ $(+)$	-0.415	0.284
	**(-2.47)	(0.81)
Informed direct, lagged 2 $\delta_{t-2}^{\text{Direct}_{t-2}} d_{t-2}^{INFO_{t-2} \geq 3} Q_{jt-2}$ $(+)$	0.719	0.140
	**(2.14)	(0.65)
Informed direct, lagged 3 $\delta_{t-3}^{\text{Direct}_{t-3}} d_{t-3}^{INFO_{t-3} \geq 3} Q_{jt-3}$ $(+)$	0.012	-0.509
	(0.04)	***(-4.04)
Other trades $\left(1 - \delta_t^{\text{Direct}_t} d_t^{INFO_t \geq 3}\right) Q_{jt}$ $(+)$	-0.089	-0.136
	(-0.52)	(-0.49)
Inventory, I_{it} $(-)$	0.060	-0.008
	(0.51)	(-0.04)
Lagged inventory, I_{it-1} $(+)$	-0.024	-0.152
	(-0.22)	(-0.80)
Direction, D_t $(+)$	1.859	9.998
	***(3.67)	***(7.31)
Lagged direction, D_{t-1} $(-)$	-0.207	-8.959
	(-0.63)	***(-4.83)
AR(1)	-0.092	-0.324
	***(-3.35)	***(-3.59)
Adjusted R^2	0.05	0.32
Durbin-Watson stat	1.98	2.04

Estimation by GMM. *t*-values are in parenthesis, and ***, ** and * indicate significance at the 1%, 5% and 10%-level respectively. All coefficient except the AR-term are multiplied by 10^4.

The first and the second lagged informed trade are significant for the DEM/USD Market Maker while the third lag is significant for the NOK/DEM Market Maker. The sign of the coefficients are however not intuitive. The model's prediction is that at least one of the coefficients on the events should be positive, i.e. that a purchase from an informed dealer tends to increase expectations about currency value. The negative coefficients in both equations suggest that we are picking up some other dynamics in pricing strategy.

There is no sign of extra protection in the price quoted to well informed dealers. This confirms the previous result of no price discrimination in interbank trading. With high transparency of prices it is difficult to quote a price different from the rest of the market based on private information. Again, this is in line with the previously mentioned survey result.

Counterpart informativeness and order placement strategy

The dealer may want to use the information that a well informed counterpart traded in a particular direction as a signal of the dealers' information, and thereby influence his own expectations and strategy. Heere (1999) reports that in interviews with dealers in London they say that as important as protecting against adverse selection when trading with a well informed dealer, is to use the trade as a basis for own trading. After a trade with a "trustworthy" informed dealer, the dealers take the same position as the informed dealers.

In table 3.13 we adapt equation (3.16) to the case where the information event is that an informed counterpart bought or sold in the previous transaction. The hypothesis from the interviews by Heere is that a purchase of currency by a dealer perceived to be well informed will lead the dealer to trade in the same directions.

The lack of any conclusive results may be because there are few trades where the dealers perceive the counterpart to be well informed. It may of course also be that these dealers do not follow the positions of informed counterparts. Especially in a less liquid markets such as the Norwegian market, taking the same positions as informed counterparts in previous trades may be difficult.

3.6 Conclusion

We investigate empirically two aspects of private information in spot interbank foreign exchange markets. First, we study how dealers react to customer trades, which is claimed to be their most important source for private information, and second, how they react to trading with dealers they regard to be better informed than themselves. We study how these two aspects of private information influence the two elements of their trading strategy, namely pricing and order placement.

To the best of our knowledge, none of these two aspects of private information in foreign exchange has been studied before. We are able to address these issue through a unique data set covering the complete trading of two market makers during one week in March 1998. Our data includes the trading with customers. We have collected observations on the dealers perceptions

Table 3.13: Informed direct trade as an event in the order placement strategy τ_{it}

	DEM/USD Market Maker	NOK/DEM Market Maker
Constant	-18.410	281.165
	(-1.02)	(1.08)
Informed purchase $(+)$	-0.201	-0.392
	(-0.97)	(-1.57)
Informed purchase $(+)$	0.172	-0.185
	(0.73)	(-0.91)
Informed purchase $(+)$	0.188	-0.382
	(1.15)	***(-3.86)
Informed sale $(+)$	0.392	-0.142
	***(2.67)	(-0.44)
Informed sale $(+)$	0.156	0.009
	(0.57)	(0.06)
Informed sale $(+)$	0.052	-0.010
	(0.24)	(-0.06)
Lagged price P_{t-1} $(+)$	30.880	797.423
	(0.30)	*(1.79)
Direction lagged D_{t-1} $(-)$	0.005	-0.546
	(0.05)	(-1.41)
Price P_t $(-)$	-20.720	-864.519
	(-0.20)	*(-1.93)
Inventory I_{t-1} $(-)$	-0.035	-0.020
	**(-2.34)	(-0.37)
AR(1)	-0.198	-0.056
	***(-4.39)	(-0.73)
Adjusted R-squared	0.05	0.09
Durbin-Watson stat	2.11	1.25

Estimation by GMM and Newey-West correction. t-values are in parenthesis, and ***, ** and * indicate significance at the 1%, 5% and 10%-level respectively. Number of included observations are 808 and 106 for the DEM/USD Market Maker and the NOK/DEM Market Maker, respectively. Inventory is USD-inventory in case of the DEM/USD Market Maker, and DEM inventory in case of the NOK/DEM Market Maker.

of how well informed their counterparts in direct interbank trading are compared to themselves through a questionnaire.

We do not find any consistent effect from customer trades on the pricing strategy of the market makers. This leads us to conclude that dealers do not use their private information from customer trades in pricing. The reason might be that even if they end up giving quotes different from their conditional expectation, they gain from not revealing their private information. In the foreign exchange market the transparency with regard to prices is very high, so prices away from the rest of the market would either not be traded at or would be taken as a signal of new information, which then would be transferred to the market price extremely fast.

Interbank dealers do however price discriminate against the customers. We find that the spreads quoted to customers are three to four times wider than the interbank spreads. The dealers are able to price discriminate the customers since the customers can not participate in the more liquid interbank market. Furthermore, they do not see the prices traded at in the interbank market, only prices directly intended for the customers through the Reuters FXFX system. Larger spreads to customers have been emphasized as a main advantage of large customer order flow by Yao (1998b).

Instead of using their private information in their pricing strategy, dealers use their information in the formation of their order placement strategy. We find that trading with customers influence the dealers' order-placing strategy. After a purchase of currency by the customers, the dealers buy currency in the interbank market. We do control for inventory adjustment in the trading strategy, hence the trading by dealers following customer trades may be interpreted as speculative position taking. The dealers ride herd on the customers.

One might expect that the dealers would let the identity of the counterpart influence their trading strategy, e.g. protecting even stronger against adverse selection when trading with a dealer perceived to be well-informed. When we investigate the spread in direct trading, we find that it is the size of the transaction, and not the identity of the initiator, that explains the spread. Consequently, dealers do not discriminate between well informed and less informed dealers. This is also in line with surveys showing that spreads are determined by "market norms," and not by the actual cost of the specific transaction.

It has been suggested that dealers in foreign exchange markets adopts the position taking of their counterparts when trading with better informed dealers. We do not find this for our dealers. Trading with informed counterparts do not influence their order-placing strategy.

In this paper we have empirically investigated aspects of private information in foreign exchange markets without addressing the strategic issues arising when several dealers have private information and trade with each other. With the structure of multiple dealership markets in mind, such as the foreign exchange market, we believe there is a need for such models to help understanding the issues at hand. Hopefully the results from the present study may prove useful in such an attempt.

3.A Q_{jt}-coefficient when dealers have different precision

We are interested in the effect on the coefficient on Q_{jt} in (3.11) of a change in the precision of the counterparts' private information. We are interested in how

$$\frac{1-\phi_j}{\theta\phi_j} = \frac{1}{\theta}\frac{1-\kappa}{\kappa-\lambda_j} \tag{3.A.1}$$

depends on $\sigma^2_{\omega j}$. We have the following relations:

$$\phi_j = \frac{\kappa-\lambda_j}{1-\lambda_j},\ 1-\phi_j = \frac{1-\kappa}{1-\lambda_j} \tag{3.A.2}$$

$$\kappa = \frac{\sigma^2_{Zj}}{\sigma^2_{\mu'}+\sigma^2_{Zj}},\ 1-\kappa = \frac{\sigma^2_{\mu'}}{\sigma^2_{\mu'}+\sigma^2_{Zj}} \tag{3.A.3}$$

$$\lambda_j = \frac{\sigma^2_{\omega j}}{\sigma^2_r+\sigma^2_{\omega j}},\ 1-\lambda_j = \frac{\sigma^2_r}{\sigma^2_r+\sigma^2_{\omega j}} \tag{3.A.4}$$

$$\sigma^2_{\mu'} = \lambda_i^2\sigma_r^2 + (1-\lambda_i)^2\sigma^2_{\omega i} = \frac{\sigma_r^2\sigma^2_{\omega i}\left(\sigma_r^2+\sigma^2_{\omega i}\right)}{\left(\sigma_r^2+\sigma^2_{\omega i}\right)^2} = \frac{\sigma_r^2\sigma^2_{\omega i}}{\sigma_r^2+\sigma^2_{\omega i}} \tag{3.A.5}$$

$$\sigma^2_{Zj} = \sigma^2_{\omega j} + \left[\frac{1}{\theta(1-\lambda_j)}\right]^2\sigma^2_{Xj} = \sigma^2_{\omega j} + \left[\frac{\sigma_r^2+\sigma^2_{\omega j}}{\theta\sigma_r^2}\right]^2\sigma^2_{Xj} \tag{3.A.6}$$

The ϕ_j, κ and λ_j are weights in the dealer's updating formulas for conditional expectations. θ is the inverse of the absolute risk aversion and the variance of the conditional expectation.

The easiest way to investigate the coefficients dependence on $\sigma^2_{\omega j}$ is to begin with investigating $1-\phi_j$.

$$\frac{\partial(1-\phi_j)}{\partial\sigma^2_{\omega j}} = \frac{(1-\kappa)'(1-\lambda_j)-(1-\kappa)(1-\lambda_j)'}{(1-\lambda_j)^2}$$

where prime indicate the derivative with respect $\sigma^2_{\omega j}$. The derivatives can be written as

$$\begin{aligned}
(1-\kappa)' &= \frac{-\sigma^2_{\mu'}}{\left(\sigma^2_{\mu'}+\sigma^2_{Zj}\right)^2}\left[1+2\sigma^2_{Xj}\left(\frac{\sigma_r^2+\sigma^2_{\omega j}}{\theta\sigma_r^2}\right)\frac{\theta\sigma_r^2-\left(\sigma_r^2+\sigma^2_{\omega j}\right)\sigma_r^2\theta'}{(\theta\sigma_r^2)^2}\right]\\
&= -\frac{(1-\kappa)}{\sigma^2_{\mu'}+\sigma^2_{Zj}}\left[1+2\sigma^2_{Xj}\left(\frac{\sigma_r^2+\sigma^2_{\omega j}}{\theta\sigma_r^2}\right)\frac{\theta\sigma_r^2-\left(\sigma_r^2+\sigma^2_{\omega j}\right)\sigma_r^2\theta'}{(\theta\sigma_r^2)^2}\right]\\
(1-\lambda_j)' &= \frac{-\sigma_r^2}{\left(\sigma_r^2+\sigma^2_{\omega j}\right)^2} = -\frac{1-\lambda_j}{\sigma_r^2+\sigma^2_{\omega j}}
\end{aligned}$$

In the second line we use that $(1-\kappa) = \sigma^2_{\mu'}/\left(\sigma^2_{\mu'}+\sigma^2_{Zj}\right)$. Above θ' represent the derivative of θ with respect $\sigma^2_{\omega j}$, and are more closely investigated below.

We insert these two into the expression above, and switch the sequence of the two to get the positive first, to obtain

$$
\begin{aligned}
\frac{\partial(1-\phi_j)}{\partial\sigma^2_{\omega j}} &= \frac{(1-\kappa)(1-\lambda_j)}{(1-\lambda_j)^2}\left\{\frac{1}{\sigma^2_r+\sigma^2_{\omega j}}\right.\\
&\quad\left.-\frac{1}{\sigma^2_{\mu'}+\sigma^2_{Zj}}\left[1+2\sigma^2_{Xj}\left(\frac{\sigma^2_r+\sigma^2_{\omega j}}{\theta\sigma^2_r}\right)\frac{\theta\sigma^2_r-\left(\sigma^2_r+\sigma^2_{\omega j}\right)\sigma^2_r\theta'}{(\theta\sigma^2_r)^2}\right]\right\}\\
&= \frac{1-\kappa}{(1-\lambda_j)\left(\sigma^2_r+\sigma^2_{\omega j}\right)\left(\sigma^2_{\mu'}+\sigma^2_{Zj}\right)}\left\{\sigma^2_{\mu'}+\sigma^2_{Zj}-\sigma^2_r-\sigma^2_{\omega j}\right.\\
&\quad\left.-2\sigma^2_{Xj}\left(\frac{\left(\sigma^2_r+\sigma^2_{\omega j}\right)^2}{\theta\sigma^2_r}\right)\frac{\theta\sigma^2_r-\left(\sigma^2_r+\sigma^2_{\omega j}\right)\sigma^2_r\theta'}{(\theta\sigma^2_r)^2}\right\}\\
&= \frac{1-\kappa}{\sigma^2_r\left(\sigma^2_{\mu'}+\sigma^2_{Zj}\right)}\left\{\lambda^2_i\sigma^2_r+(1-\lambda_i)^2\sigma^2_{\omega i}+\sigma^2_{\omega j}+\left[\frac{\sigma^2_r+\sigma^2_{\omega j}}{\theta\sigma^2_r}\right]^2\sigma^2_{Xj}-\sigma^2_r-\sigma^2_{\omega j}\right.\\
&\quad\left.-2\sigma^2_{Xj}\left[\frac{\sigma^2_r+\sigma^2_{\omega j}}{\theta\sigma^2_r}\right]^2\frac{\theta\sigma^2_r-\left(\sigma^2_r+\sigma^2_{\omega j}\right)\sigma^2_r\theta'}{\theta\sigma^2_r}\right\}
\end{aligned}
$$

In the second equality we get a common denominator, and resolve the square-bracket. In the third equality we use that $(1-\lambda_j)=\sigma^2_r/\left(\sigma^2_r+\sigma^2_{\omega j}\right)$, $\sigma^2_{\mu'}=\lambda^2_i\sigma^2_r+(1-\lambda_i)^2\sigma^2_{\omega i}$, and $\sigma^2_{Zj}=\sigma^2_{\omega j}+\left[\frac{\sigma^2_r+\sigma^2_{\omega j}}{\theta\sigma^2_r}\right]^2\sigma^2_{Xj}$. Finally we collect terms to obtain,

$$
\begin{aligned}
\frac{\partial(1-\phi_j)}{\partial\sigma^2_{\omega j}} &= \frac{1-\kappa}{\sigma^2_r\left(\sigma^2_{\mu'}+\sigma^2_{Zj}\right)}\left\{(1-\lambda_i)^2\sigma^2_{\omega i}-\left(1-\lambda^2_i\right)\sigma^2_r\right.\\
&\quad\left.+\left[\frac{\sigma^2_r+\sigma^2_{\omega j}}{\theta\sigma^2_r}\right]^2\sigma^2_{Xj}\left(1-2\frac{\theta\sigma^2_r-\left(\sigma^2_r+\sigma^2_{\omega j}\right)\sigma^2_r\theta'}{\theta\sigma^2_r}\right)\right\}
\end{aligned}
\tag{3.A.7}
$$

In order to evaluate the sign of the first two terms in the curly braces, let $\sigma^2_r=\alpha\sigma^2_{\omega i}$. If $\alpha=1$, they are equal to $-\sigma^2_{\omega i}/2$ and if $\alpha=2$ they equal $-2\sigma^2_{\omega i}$, the general expression being

$$\frac{-\sigma^2_{\omega i}}{(1+1/\alpha)^2}(1+\alpha).$$

The last parenthesis in the equation above can be written as

$$1-2\frac{\theta\sigma^2_r-\left(\sigma^2_r+\sigma^2_{\omega j}\right)\sigma^2_r\theta'}{\theta\sigma^2_r}=-1+\frac{2\left(\sigma^2_r+\sigma^2_{\omega j}\right)\theta'}{\theta},$$

which is negative if θ' is small or negative. Below we show that θ' indeed is negative, so then the whole derivative will be negative. If $\partial(1-\phi)/\partial\sigma^2_{\omega j}<0$, then $\partial\phi/\partial\sigma^2_{\omega j}>0$, hence $(1-\phi_j)/\phi_j$ will decrease when $\sigma^2_{\omega j}$ increases. Higher precision, lower $\sigma^2_{\omega j}$, will then increase this part of the coefficient on Q_{jt}.

Now we investigate the effect on θ, given by

$$\theta=\frac{1}{\rho\sigma^2_{\mu j}},$$

where ρ is the coefficient of risk aversion, and

$$\sigma_{\mu j}^2 = \lambda_j^2 \sigma_r^2 + (1-\lambda_j)^2 \sigma_{\omega j}^2 = \frac{\sigma_r^2 \sigma_{\omega j}^2 \left(\sigma_r^2 + \sigma_{\omega j}^2\right)}{\left(\sigma_r^2 + \sigma_{\omega j}^2\right)^2}.$$

The derivative of $1/\theta = \rho \sigma_{\mu j}^2$ with respect to $\sigma_{\omega j}^2$ is

$$\frac{\partial (1/\theta)}{\partial \sigma_{\omega j}^2} = \rho \left[2\lambda_j \lambda_j' \sigma_r^2 + (1-\lambda_j)^2 + 2(1-\lambda_j)(1-\lambda_j)' \sigma_{\omega j}^2\right]$$

where prime indicate the derivative with respect $\sigma_{\omega j}^2$. The derivatives can be written as

$$\lambda_j' = \frac{\sigma_r^2 + \sigma_{\omega j}^2 - \sigma_{\omega j}^2}{\left(\sigma_r^2 + \sigma_{\omega j}^2\right)^2} = \frac{\sigma_r^2}{\left(\sigma_r^2 + \sigma_{\omega j}^2\right)^2}$$

$$(1-\lambda_j)' = -\frac{\sigma_r^2}{\left(\sigma_r^2 + \sigma_{\omega j}^2\right)^2}$$

When inserted into the expression for the derivative above, we get

$$\begin{aligned}
\frac{\partial (1/\theta)}{\partial \sigma_{\omega j}^2} &= \rho \left[2\lambda_j \lambda_j' \sigma_r^2 + (1-\lambda_j)^2 + 2(1-\lambda_j)(1-\lambda_j)' \sigma_{\omega j}^2\right] \\
&= \rho \left[2\lambda_j \sigma_r^2 \frac{\sigma_r^2}{\left(\sigma_r^2 + \sigma_{\omega j}^2\right)^2} + (1-\lambda_j)^2 - 2(1-\lambda_j) \sigma_{\omega j}^2 \frac{\sigma_r^2}{\left(\sigma_r^2 + \sigma_{\omega j}^2\right)^2}\right] \\
&= \rho \left[2\lambda_j (1-\lambda_j)^2 + (1-\lambda_j)^2 - 2(1-\lambda_j)^2 \frac{\sigma_{\omega j}^2}{\sigma_r^2 + \sigma_{\omega j}^2}\right] \\
\frac{\partial (1/\theta)}{\partial \sigma_{\omega j}^2} &= \rho (1-\lambda_j)^2 > 0
\end{aligned} \tag{3.A.8}$$

In the third equality we use that $(1-\lambda_j) = \frac{\sigma_r^2}{\left(\sigma_r^2 + \sigma_{\omega j}^2\right)}$ and $(1-\lambda_j)^2 = \frac{\sigma_r^4}{\left(\sigma_r^2 + \sigma_{\omega j}^2\right)^2}$. This is intuitive; when dealer j receives more precise signals (lower $\sigma_{\omega j}^2$), he will trade more aggressively (θ increases).

Notice that this implies that

$$\frac{\partial \theta}{\partial \sigma_{\omega j}^2} = -\frac{1}{\rho \sigma_{\mu j}^2} \frac{(1-\lambda_j)^2}{\sigma_{\mu j}^2} = -\theta \frac{(1-\lambda_j)^2}{\sigma_{\mu j}^2} < 0.$$

The change of $(1-\phi_j)/\theta\phi_j$ from change in $\sigma_{\omega j}^2$ is equal to

$$\frac{\partial \left[(1-\phi_j)/\theta\phi_j\right]}{\partial \sigma_{\omega j}^2} = \frac{\partial (1/\theta)}{\partial \sigma_{\omega j}^2} \frac{1-\phi_j}{\phi_j} + \frac{1}{\theta} \frac{\partial \left[(1-\phi_j)/\phi_j\right]}{\partial \sigma_{\omega j}^2}. \tag{3.A.9}$$

The term $\partial (1/\theta)/\partial \sigma_{\omega j}^2$ is likely to be less than one since $1-\lambda_j$ is between zero and one. If $\rho = 2$ then the weight on the private signal C_{jt} has to be above 0.7 for the whole derivative to be above 1. The multiplicative term $(1-\phi_j)/\phi_j$ will be less than 1 if dealer i puts higher weight on his own information than the signal from the interbank trade, making the first term even smaller. We know that the second term is negative. We will proceed with assuming that (3.A.9) is negative.

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CHAPTER 4

Private or Public Information in Foreign Exchange Markets? An Empirical Analysis[1]

4.1 Introduction

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

In this paper, I test a model for determining exchange rates including both public and private information variables. The model, based on a model by Evans and Lyons (1999), integrates public macroeconomic information in a microstructural trading model where, in equilibrium, the order flow aggregates private information. The model is tested for four exchange rates on 3 years of weekly data, from the beginning of 1996 and onwards (the Norwegian Krone (NOK) against US Dollar (USD), Deutsche Mark (DEM), Swedish Krona (SEK) and Pound Sterling (GBP)). The key to this kind of analysis is a recent data set on weekly order flow from the Norwegian market; hence my choice of the Norwegian Krone as the common currency and the weekly frequency. As will be shown below, the microstructure of the foreign exchange market and, in particular, the low transparency of trade, give both private information and macroeconomic information a role, even

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at the weekly horizon. The models receive considerable support, with significant and correctly signed effects from order flow. The regression fit, given by adjusted R^2, is 33% for NOK/DEM, which is high given the weekly frequency.

Until recently, the predominant way of analyzing exchange rates was to search for new possible macroeconomic variables that might explain the swings in exchange rates (Flood and Rose, 1995). The three mainstream macroeconomic models — the classical flexible price monetary model, the sticky price monetary model (the "overshooting model") and the portfolio balance model — rely solely on public macroeconomic information. However, these models have received little empirical support[2], in particular at a short horizon, as shown in the seminal papers by Meese and Rogoff (1983a,b), for example. Meese and Rogoff demonstrated that monthly and biennial forecasts based on macroeconomic information performed even worse than a random walk. Since the papers by Meese and Rogoff, there has been a huge amount of research on explaining the lack of support of the macro models, to little avail (for surveys, see Frankel and Rose, 1995; Taylor, 1995).[3] de Vries (1994) claims the lack of effect of most macroeconomic variables to be a stylized fact of exchange rate economics. The time has come to search for models of exchange rate determination outside the field of macroeconomics.

Empirical studies of other asset markets, such as the stock market, have also been plagued by lack of empirical support. This has led to the theory of market microstructure of financial markets, with a focus on market institutions, existence of private information, agent heterogeneity, and short-term phenomena. This approach seems well suited for the foreign exchange market. Phenomena such as huge trading volumes and high volatility that are difficult to explain within the macroeconomic approach, are addressed in this approach (see Lyons, 2001). To account for trading, there must be some heterogeneity among agents, and volatility draws the attention to speculation and private information.

The lack of empirical support for the macroeconomic models may be related to heterogeneous expectations (Frankel and Rose, 1995; Lewis, 1995) which, again, may be due to private information. A questionnaire study of London-based foreign exchange analysts by Allen and Taylor (1989) showed considerable heterogeneity of expectations. Several recent survey studies confirm the view of agent heterogeneity.[4] The data in Bjønnes and Rime (2000a) reveal that dealers expect other dealers to have different information than themselves.

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

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

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

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

important, trading has no effect on prices, since all available information will be impounded into prices prior to trading. In such a setting, trading will only occur to the extent that dealers require exchange, for well-known reasons, e.g. trade in goods or liquidity needs. Such trade will have no effect on prices, since it does not reveal any new information by assumption.

It is important to note that order flow is fundamentally different from volume[5] or just “supply and demand”. In financial markets, it can be determined who takes the initiative to a trade, thereby “signing” the trade. Therefore, it is also possible to determine buyer pressure or seller pressure, even in equilibrium (i.e. the direction of flow). Order flow, the signed flow of trades, serves the traditional role of affecting the price to balance supply and demand. In addition, changing beliefs may affect the price. In a market with private information, dealers utilize the additional information in the direction of the flow of trading (buyer pressure/seller pressure) to infer the motives for trade. Hence, buyer pressure leads dealers to infer that some agents have received positive private signals about asset value. Lyons (2001) offers an interesting discussion of what might constitute private information in foreign exchange markets.

For trading to create price effects, we need more than asymmetric information however, due to the famous no-trade result of Milgrom and Stokey (1982). In a fully transparent[6] competitive market with asymmetric information and no ex ante gains from trade that are common knowledge, all available information will be contained in the prices. Any attempt to trade will lead to revisions of expectations such that, in the end, the market price reflects all information and no trade takes place. The existence and importance of private information and trading are hence closely related to the transparency of the market.

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

In the models of Kyle (1985) and Glosten and Milgrom (1985) the price-setters, i.e. Market Makers, face other dealers that might have private information. From trading with potentially better informed players, the Market Makers adjust their beliefs about the uncertain asset value, increasing their expectations of the value of the asset in case of a buy order and reducing it in case of a sell order. Effects of private information will therefore be related to an effect of currency trading on spot exchange rates.

This approach has recently been applied to the foreign exchange market, indicating evidence of private information. With observations on dealers’ intraday trading in the inter bank spot market, Lyons (1995), Yao (1998a) and Bjønnes and Rime (2000b) find evidence of an effect of trading flow on prices associated with private information.

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

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

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

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

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

The results are surprisingly strong. Order flow has a strong and correctly signed effect on price changes, where a buying pressure (positive flow) pushes prices upwards and a selling pressure pushes prices downwards. The effect on exchange rates from order flow is permanent, indicating that order flows carry important information. Changes in interest rate differentials are the single most important variable, while the most important flow variable seems to be the spot trading of Norwegian customers. This results is in line with the importance that dealers attach to customer trades, and that customer trades is the primary source of demand in the foreign exchange market. What might be most surprising is the fact that order flow also has an effect over a week, implying that private information may live longer in foreign exchange markets than previously considered. The results are however in accordance with the results of Evans (1999).

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

The remainder of the paper is organized as follows: In section 4.2, I discuss some important characteristics of currency markets. The model is presented in section 4.3. Section 4.4 presents the data. Results are presented and discussed in section 4.5, while section 4.6 concludes.

4.2 Currency markets

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

Globally, the average daily turnover in April 1998 was USD 1.5 trillion; increasing from USD 820 billion in 1992 and USD 1.2 trillion in 1995 (BIS, 1998). The spot market share is about 40% of the market, while the interbank-share of spot trading is slightly above 80% as reported in table 4.1. Trading in DEM/USD accounts for almost half (49%) of all global spot trading. Small currencies, like the NOK, constitute 30% altogether, or 431 billion USD of the total volume of 1,442 billion USD.[7] It seems warranted to study this part of the foreign exchange market in order to complete the picture.

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

Trading in the foreign exchange market occurs in two separate sub markets; first, customers trading with a bank, and second, the interbank market where banks trade with each other. Although customer orders only account for about 20% of the total volume, they are important for they generate the majority of trading profits for most foreign exchange dealers, (Yao, 1998b). Trading with customers is also regarded as an important source of private information.[8] This information is private since only the dealers in the specific bank have knowledge of each trade. Trading with customers entirely lacks transparency; i.e. the rest of the market does not know the customer trading of a bank. This may be of significance since the low transparency of trade enables a dealer to utilize the private information over a long time span, and also makes other dealers take the possible existence of private information into account when trading. Customer trades provide the dealers with a signal of whether the market will be buyer or seller dominated within a certain time horizon. It may also provide signals on market sentiment or beliefs about future return.

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

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

Table 4.1: The Norwegian currency market

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

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

The interbank market is a decentralized multiple dealer market. The trading options available to dealers in the interbank market can be illustrated in a 2×2 matrix as in figure 4.1. Direct trading is usually done through the Reuters D2000-1, a system for bilateral communication over a computer-network. In direct trading, Market Makers are expected to give quotes on request in the same way as a NYSE specialist. Direct trading is the preferred channel when the volume traded is either of an unusual size (like 525,000) or very large. Since orders on the D2000-1 system are often large (often executed shortly after the receipt of a customer order), and because the identity of the initiator of the trade is revealed to the Market Maker, direct trading is regarded as the most informative trading channel. The data of Evans and Lyons are from the direct trading system D2000-1, the importance of which has decreased somewhat since 1996.

Figure 4.1: Interbank trading options

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

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

Indirect trading takes place through a broker, either a traditional voice-broker or an electronic broker system.[9] A Market Maker may give quotes to brokers. The dealer decides whether to

[9]During the 1970s and most of the 1980s, traditional voice brokers were the dominant tool for trading. Voice brokers have lost much of their market share to electronic broker systems, because these offer tighter spreads and faster execution of trades. Since voice-brokers have no access to electronic brokers, there is also the problem of knowing

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

The foreign exchange market is usually said to have low transparency. In foreign exchange, all customer trades and all direct trades are kept secret from everyone except the two parties. As for indirect trade, a small subset of the trades is communicated to the market, thereby giving the dealers a proxy of overall market activity.[10] Many stock exchanges, on the other hand, provide information on all trades, sometimes with a small time lag. Low transparency indicates that it may take longer before private information is reflected in prices.

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

The importance of transparency may also be related to the motives for trading. There may be other reasons for trading in the major currencies than in the smaller currencies. Major currencies function as “vehicle” currencies (used as an intermediate in an exchange of two smaller currencies), and are also traded due to the fact that the most important commodities in the world are priced in these currencies. The smaller currencies, on the other hand, are typically more “regional”

what prices to compete against. Furthermore, their information advantage from seeing much flow has also decreased, thus making it even harder to give competitive quotes. In 1998, their market share of spot transactions in New York was only 24% compared to 47% in 1995. In the same period, electronic brokers have become very popular, with a market share of 31% in 1998 up from 10% in 1995 (FED NY, 1998). In London, electronic brokers are used in 25% of all spot transactions.

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

or country-specific. The NOK for example is supposedly very dependent on oil prices, giving the NOK a reputation as a "Petro-currency", which is public information. However, the results in this paper indicate that the NOK is not a "Petro-currency." Whether the trade in NOK-exchanges is more or less transparent than that in USD-exchanges is difficult to say.

4.3 Model

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

Consider an exchange economy with two assets, one risk free and one risky asset, represented by a currency.[11] There are N dealers, and a public sector (customers) that is distributed in the continuous interval $[0,1]$; this captures the fact that customers are more numerous than dealers and hence have a greater capacity for bearing risk. The horizon is infinite and timing within a period of the model is shown in figure 4.2. The information of each group will be clear from the below description of the timing. Dealers decide on prices in each round, $\{P_{i1,t}, P_{i2,t}, P_{i3,t}\}$, and the interdealer trade that takes place in round two, $T_{i2,t}$, while the public decide their demand in round three, $c_{3,t}$. Round 1, public trade, is stochastic (see below).

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

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

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

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

Rule P1 ensures that prices cannot be conditioned on other dealers' prices, and that dealers cannot choose not to give quotes. Simultaneous quoting is consistent with the functioning of the interbank market: When trades are initiated electronically in a multiple dealer market, this can potentially lead to simultaneous quotes, trades and both. Quoting and trading in the foreign exchange market is also extremely fast. Finally, not quoting would be a breach of the implicit contract of being a Market Maker, and could be punished later by other dealers.[12] Examples of

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

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

punishment might be not receiving trades from other dealers, and only obtaining wide spreads. Rule P2 states that there is costless search for quotes, which is true in the interbank market for normal trade sizes traded through the electronic broker systems. The foreign exchange market is extremely liquid with quotes and spread constant up to 10 mill USD, making rule P3 less restrictive than what might first be considered to be the case.

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

T1. Trading is simultaneous and independent

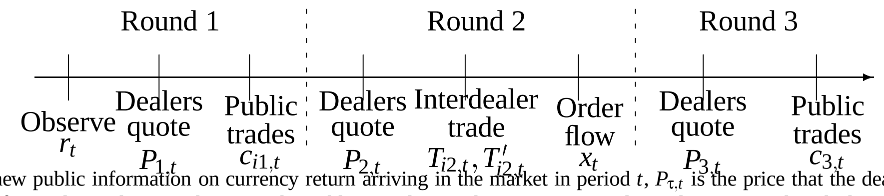
T2. Trading with multiple partners is feasible

T3. Trades are divided equally among dealers with the same quote, if this is a quote at which a transaction is desired.[13]

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

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

Figure 4.2: Period t timing



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

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

$$c_{i1,t} = r_{t+1} + \eta_{it}, \tag{4.1}$$

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

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

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

$$T_{i2,t} = c_{i1,t} + D_{i2,t} + E\left[T'_{i2,t}|\Omega^D_{i2,t}\right], \tag{4.2}$$

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

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

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

$$U\left(W_{i3}\right) = -\exp\left(-\theta W_{i3,t}\right), \tag{4.3}$$

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

4.3.1 Equilibrium

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

$$P_{1,t} = P_{2,t} = P_{3,t-1} + r_t - \pi x_{t-1}, \tag{4.4}$$

$$P_{3,t} = P_{2,t} + \lambda x_t,\ \lambda > 0, \tag{4.5}$$

where x_t is aggregate order flow[14] in the inter dealer trading in round 2, and λ a parameter that will be determined below. In round 1, all information is public when prices are set; hence all dealers set the same prices only adding the increment to currency value that was not included in the price already, here represented by $r_t - \pi x_{t-1}$. Equilibrium (no-arbitrage), and full transparency of prices, ensure that all dealers also set the same price in round 2. If the prices in round 2 are to be equal, these can only be conditioned on public information, and therefore the round 2 price must equal the round 1 price. Setting a price different from the others would reveal information and attract all supply/demand. Instead, dealers utilize their private information in forming their speculative demand in round 2. Interdealer trade is only observed by the parts participating in the transaction.

Equilibrium trade by dealer i is given by

$$T_{i2,t} = c_{i1,t} + D_{i2,t}\left(c_{i1,t}\right) = \alpha c_{i1,t}, \alpha > 1, \tag{4.6}$$

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

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

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

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

$$P_{3,t} = E\left[P_{3,t+1} | \Omega_{3,t}^P\right] + \rho x_t,\ \rho = 1/\left(\alpha\gamma\right) > 0. \tag{4.7}$$

In addition to their expectations, the public must be compensated for bearing the additional risk, so the risk premium is given by ρx_t. This risk premium coefficient is a constant, but increases with uncertainty about future prices, and with risk aversion (see appendix).

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

Inserting for the expectation in (4.7), we get

$$P_{3,t} = P_{2t} + \pi x_t + \rho x_t = P_{2t} + \lambda x_t \tag{4.8}$$

$$P_{3,t} = \sum_{\tau=1}^{t} (r_\tau + \rho x_\tau) + \pi x_t \tag{4.9}$$

where $\pi = \phi/\alpha$ and ϕ is the parameter on new information in the public's conditional expectation ($\phi \in (0,1)$). The price in round 3 equals the expected fundamental value for the next period ($F_t + \pi x_t$) plus the accumulated risk premium related to the accumulated risk the public have absorbed ($\sum_\tau^t \rho x_\tau$). From (4.4) and (4.8), the change in price equals the adjusted increment, an element for the expected return in the next period, and the additional compensation for taking additional risk:

$$\Delta P_{3,t} = r_t - \pi x_{t-1} + \pi x_t + \rho x_t \tag{4.10}$$

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

$$\Delta P_{3,t} = r_t + \rho x_t. \tag{4.11}$$

This is the equation tested by Evans and Lyons. By rewriting (4.10), it can empirically coincide with the above equation. After observing r_t, the aggregate noise from the flow in the previous period can be aggregated,

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

where I use (4.1) to insert for $c_{i1,t-1}$. Inserting this in equation (4.10) gives

$$\Delta P_{3,t} = (1 - N\phi)\, r_t + \lambda x_t + \tilde{\eta}_t, \tag{4.12}$$

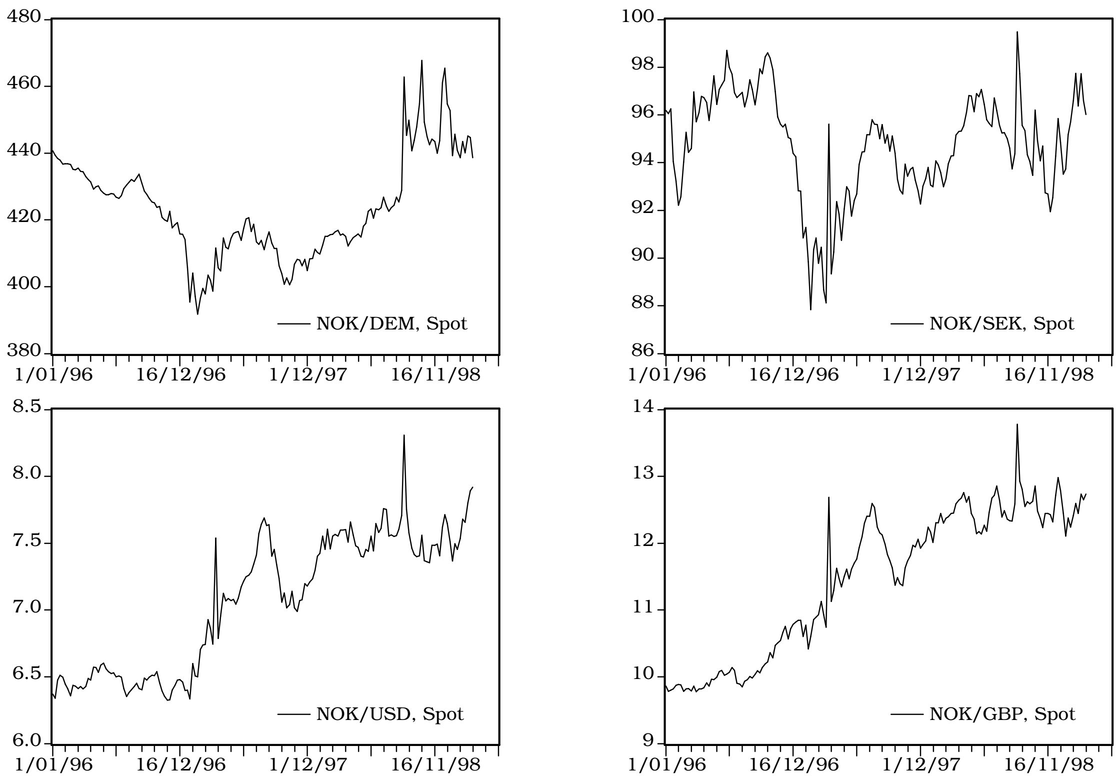
where $\tilde{\eta}_t = \sum_i \phi \eta_{it-1}$. This term is uncorrelated with r_t by definition and with x_t, since $x_t = \alpha \sum_i c_{i1,t}$ which are all *IID*, i.e. r_t and x_t are weakly exogenous with respect to $(1 - N\phi)$ and λ. The term $\tilde{\eta}_t$ is unobservable for the econometrician,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

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

4.4 Data

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

Figure 4.3: Spot Exchange Rates



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

Figure 4.3 plots the four exchange rates, which are quoted at the end of the week. Since

Table 4.2: Summary statistics for exchange rates

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

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

December 1992, Norway has followed a floating exchange rate regime, but the Central Bank has been instructed to aim at keeping the exchange rate stable against the ECU/EURO. Table 4.2 summarizes the descriptive statistics for the four exchange rates from the beginning of 1996 until May 1999.

As shown in table 4.3, the exchange of these four foreign currencies into NOK represents the major part of NOK trading in Norway. Although the trade in DEM/USD is also substantial (as in the rest of the world), trading in NOK-crosses are the most important crosses in Norway. Besides, the trading volume in the major exchange rates, e.g. DEM/USD, in Norway is probably too small to influence DEM/USD rates and is most likely related to the use of the cross as a vehicle for trading in other currencies.[15] Trading in NOK/SEK is only reported for 1992, when the total daily volume was 42 million USD. Judging from the GBP trading in 1995 and 1998, probably all of the 21 million in the "Other"-column in 1992 are exchanges into NOK. This might indicate that the NOK/SEK currency cross is more traded in Norway than the NOK/GBP, which has been confirmed by dealers. This is as expected, bearing in mind the importance of trade between Sweden and Norway and the otherwise close relations between the two countries.

The table reports total trading, including spot, outright forward and swaps.[16] The reason for NOK/USD trading being so much larger than NOK/DEM is the dominant role of USD as part of swaps. In spot trading, NOK/DEM is the most traded exchange rate.

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

4.4.1 Currency flows

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

[15] Currencies that are primarily traded against USD.

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

Table 4.3: Main currency pairs traded in Norway

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

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

According to Norges Bank, the reports cover at least 90% of the Norwegian market. Although NOK-exchanges are certainly made outside of Norway, the series included most likely cover a majority of NOK-exchanges, given the regional nature of the NOK. The series are divided into the main counterparties of the Norwegian banks, namely (A) the Central bank, (B) foreigners, and (C) Norwegian non-bank customers. The numbers are not directly comparable to those in table 4.1. Table 4.4 shows the flow variables reported together with their average, their standard deviation and the average of absolute values.

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

Figure 4.4 plot the cumulative order flow and the per period order flow. From the graphs of per period trading it may seem that the activity in the market increased somewhat after the beginning of 1997. The jump in CB spot trading in early 1997 is related to the appreciation pressure on NOK in this period. The central bank had to buy currency from the Norwegian banks. In the cumulative graphs I have set the initial point to zero since I have no observations on initial positions.

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

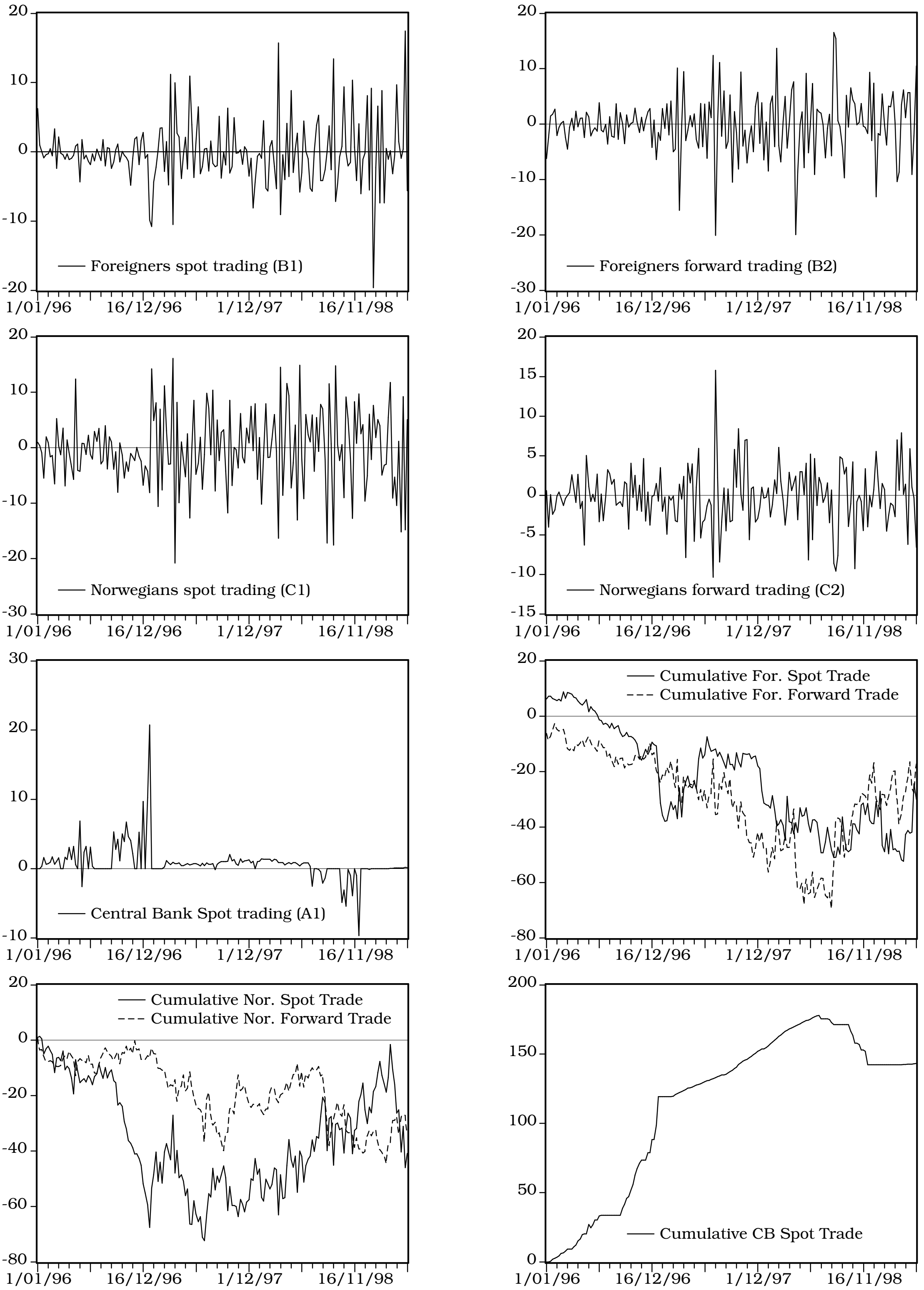
In the relationship between banks and customers, banks provide the service of access to the interbank market. Hence, trading between banks and customers only occurs when customers

Table 4.4: Currency flows in the Norwegian foreign exchange market

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

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

Figure 4.4: Weekly trading flows



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

demand these services, and therefore takes the initiative to the trade. According to table 4.1, most of these customer trades are with Norwegian customers.[17]

The low share of foreigner customer trading reported in table 4.1 indicates that the major part of the foreigners' group (group B) above is interbank trading. Since a majority of trading in Norway is with NOK on one side, with a Norwegian bank as one of the parties, it may suggest that Norwegian banks have an information advantage in NOK-trading. Hence, foreign banks are most likely not interested in trading when Norwegian banks take the initiative, and will give a wide spread to protect themselves against private information. Therefore, most interbank trading with foreign banks is most likely initiated by foreigners. The data from Bjønnes and Rime (2000b) support this. According to these data, all of the NOK/USD trades and 63–65% of the NOK/DEM trades are initiated outside the bank. In value terms, 70% of all NOK/DEM trades are not initiated by the bank.

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

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

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

In the empirical implementation, I will use the spot trading of all three groups, Central Banks, foreigners and Norwegian non-bank customers, as a measure of currency flow. In addition, I also use the forward trading of foreigners and Norwegian non-bank customers.[18] I choose these variables because they are the result of actual trading. Furthermore, it creates a flow that better matches the complete market.The other currency variables are not directly related to trading. Some

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

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

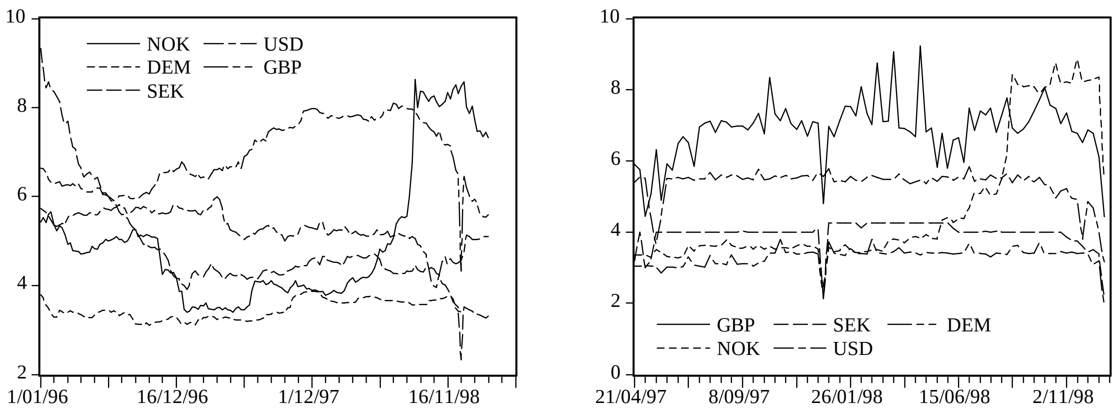
of those other variables also contain an element of exchange rate variation, and are therefore endogenous variables. The correlations between the different flow variables, and the variables that contain an element of exchange rate variation (D2 in particular) are reported in table 4.5. Note that the correlations between spot trading of foreigners and Norwegians on the one hand and the endogenous variables D1, D2 and D3 on the other are small. In the case of foreigners' forward trading, the correlations are higher. The possibility of the flow variables being endogenous is further addressed below.

It is important to note that only *unexpected* order flows should influence the price, as the expected order flow should already be captured in the price. In the model, all order flow is unexpected, but this will not be the case in reality. As a proxy for unexpected order flow, I use the one-week change of order flow. Estimating the expected flow as the forecast from some regression equation has also been tried. In general, the effects from the flow are the same, but the fit of the equation is lower.

4.4.2 Public information

As public information, I use the overnight interest rates $(i_{On,t})$ and the 3-month interest $(i_{3,t})$. The overnight rate is only available from week 17 of 1997 until the end of 1998, while the 3-month rate is available for the whole sample.[19] Figure 4.5 plots the interest rates.

Figure 4.5: Overnight and 3-month interest rates



a) 3 month interest rates   b) Overnight interest rates

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

I also include information on the oil sector, due to Norway's dependence on oil revenues. First, the USD denominated spot price of Brent Crude oil from the North Sea is included, and available for the whole period. Second, the companies operating on the Norwegian shelf of the North Sea have to pay several kinds of transfers to the Norwegian Government on specific dates, and information on these dates is included. These predetermined dates may involve much currency

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

Table 4.5: Correlation matrix of the flow variables

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

trading, since the revenue of the oil companies comes in USD while the transfers are to be made in Norwegian krone (NOK). There is one dummy variable for each of the four kinds of transfers:

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

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

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

4. $d_{\text{SDØE}}$: The Norwegian government has direct ownership of parts of the fields operated,[20] called SDØE, and the return on the SDØE is transferred every month on the 20th. Since August 1998, these dates are confidential, and the transfers are no longer in NOK but in the currency generating the revenue.

The theoretical model puts few restrictions on how public information variables enter the public information component r_t. Evans and Lyons (1999) chooses the *change* in the interest differential. This is a fairly natural implementation, since r_t is the increment in return in each period. I follow Evans and Lyons and use change in the interest differential, $\Delta\left(i_{\ell,t} - i^*_{\ell,t}\right)$ ($\ell =$On,3m) with an * indicating the foreign interest rate.[21] In addition, the change in the spot price of Crude oil from the North Sea, $\Delta P_{\text{Oil},t}$, will be used as public information in all formulations. In an alternative formulation, I also include dummies for transfers from the oil industry to the Norwegian government.

The correlation matrix of dependent and independent variables is given in table 4.6. Noteworthy is the correlation between the change in interest differentials and the change in logs of exchange rates and flow variables. Correlations with the dependent variables are rather high, while the correlations with the flow variables are rather low.

4.5 Results

Evans and Lyons formulated the model for the daily frequency, which can also be argued to be applicable at the weekly frequency. In the third round of trading, dealers trade with the public to share their risk with them. However, within a week, it is also likely that dealers share the risk by trading with each other in different time zones, since the foreign exchange market is a 24-hour open market. When the Europe market is closing, dealers trade with US dealers to get rid of the inventory risk. Trading with the public to share risk may be a more important alternative at the end of week, since most regional markets are less active during weekends. Another feature that makes the weekly frequency applicable on the Norwegian market is that NOK-dealers do not necessarily "square" their positions in e.g. NOK/DEM at the end of each day within the week, compared

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

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

Table 4.6: Correlation matrix of regression variables

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

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

to what is normal for DEM/USD-dealers, due to the fact the NOK-market more or less closes when Norwegian banks end the day. Over the weekend, however, there is sufficient uncertainty to "square" the position. Furthermore, if one believes that the periods in the model should be strictly interpreted as days, I can still test the model with weekly data on order flow. My approach would be equivalent to taking the 7th-difference in price as the dependent variable instead of the first difference, using the 7 day cumulative sum of order flow as a regressor, and testing the equation by only choosing end of week observations.

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

$$\begin{aligned}\Delta P_t = \alpha + \beta_1 \Delta\left(i_{\ell,t} - i^*_{\ell,t}\right) + \beta_2 \Delta P_{\text{Oil},t} + \beta_3 \Delta\text{ForSpot}_t + \beta_4 \Delta\text{NorSpot}_t \\ + \beta_5 \Delta\text{CBSpot}_t + \beta_6 \Delta\text{ForForward}_t + \beta_7 \Delta\text{NorForward}_t + u_t \qquad (4.13)\end{aligned}$$

and

$$\begin{aligned}\Delta P_t = \alpha + \beta_1 \Delta\left(i_{\ell,t} - i^*_{\ell,t}\right) + \beta_2 \Delta P_{\text{Oil},t} + \delta_1 d_{\text{Tax},t} + \delta_2 d_{\text{Area},t} + \delta_3 d_{\text{Prod},t} + \delta_4 d_{\text{SDØE},t} \\ + \beta_3 \Delta\text{ForSpot}_t + \beta_4 \Delta\text{NorSpot}_t + \beta_5 \Delta\text{CBSpot}_t \\ + \beta_6 \Delta\text{ForForward}_t + \beta_7 \Delta\text{NorForward}_t + u_t. \qquad (4.14)\end{aligned}$$

These two models are closest in spirit to equations (4.11) and (4.12). As a third model, labeled "Model III" in the tables, I include a version that strictly tests equation (4.10), where both the difference and the level of the order flow enter:

$$\begin{aligned}\Delta P_t = \alpha + \beta_1 \Delta\left(i_{\ell,t} - i^*_{\ell,t}\right) + \beta_2 \Delta P_{\text{Oil},t} + \beta_3 \Delta\text{ForSpot}_t + \beta_4 \Delta\text{NorSpot}_t + \beta_5 \Delta\text{CBSpot}_t \\ + \beta_6 \Delta\text{ForForward}_t + \beta_7 \Delta\text{NorForward}_t + \beta_8 \text{ForSpot}_t + \beta_9 \text{NorSpot}_t \\ + \beta_{10} \text{CBSpot}_t + \beta_{11} \text{ForForward}_t + \beta_{12} \text{NorForward}_t + u_t \qquad (4.15)\end{aligned}$$

In this equation, the change in flow variables is supposed to capture the updating information element, while the level of the flow variables captures the risk premium. The problem with this last specification is the high correlation between the difference and the level of the flow variables, as is evident from table 4.13 in the appendix. Furthermore, the lagged flow in the theoretical model enters as a correction to public information. At the weekly horizon, this correction seems less plausible, and I therefore focus on Models I and II. This comes at a cost, since I cannot disentangle the updating information part of order flow from the risk premium part. Both are, however, initially related to private information.

All regressions use the change in the log of nominal exchange rates for NOK/USD, NOK/DEM, NOK/SEK and NOK/GBP as a dependent variable. Using the change in levels as in the theoretical model instead of change in logs does not affect the results. Results using overnight rates are shown in table 4.7 and 4.9, respectively. Results using 3-month rates are shown in table 4.8 and 4.10. Model III is reported in 4.11.

The fit of the regressions, as measured by adjusted R^2, is unusually high for this frequency, with numbers as high as 33% for NOK/DEM. That the best fit is observed for NOK/DEM is natural since NOK/DEM is the most heavily traded spot exchange rate in the Norwegian market, meaning that the aggregate flow variables contain considerable NOK/DEM trading. The NOK/USD and NOK/GBP exchange rates are more volatile than the NOK/DEM and NOK/SEK, as shown in table 4.2, which also explains the some what weaker fit for the NOK/USD and NOK/GBP. The lower volatility of NOK/DEM (and NOK/SEK) is due the fact that the Norwegian Central Bank stabilizes the NOK against the ECU/EURO which, in practice, means stabilizing against the DEM.

In all regressions, one or more of the flow variables enter with a coefficient significantly different from zero at the 5%-level, and several of the flow variables are significant at the 10% level. The strongest effect is on NOK/DEM, which is, once more, as expected. The effect from flow variables is more or less equal for NOK/SEK, NOK/USD and NOK/GBP. Furthermore, if one accepts the presumption that a majority of these trades are initiated outside of Norwegian banks, all flow variables enter correctly signed. When there is buying pressure on currency in the overall market, this conveys information that pushes up prices, i.e. a depreciation of the NOK. The flow variable that is most often significant is the spot trading with Norwegian customers. This may be the flow most accurately capturing the portfolio shift, the information and the sentiment of the public in the theoretical model. This result may also indicate that even if high concentration may reduce the amount of private information, its utility may be large due to access to a larger share of customer trading. The size of the foreigners' and customers' flow coefficients is generally less than 0.1%, meaning that an unexpected increase in e.g. foreigners' spot buying of 1 billion depreciates the NOK with less than 0.1%. From table 4.4, the average absolute size of the customers' and foreigners' spot trading is 5.22 and 3.2, respectively.

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

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

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

If there is negative news about the NOK, this leads to a flow out of NOK, and NOK will depreciate both towards SEK and DEM. The flow variables may then contain a great deal of buying of SEK and DEM from the banks.

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

Table 4.7: Model I: Regressing weekly change in log exchange rates on overnight interest rates and flow variables. (1997:18 to 1998:52)

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

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

There are signs of ARCH-effects in the equations using 3-month rates. In table 4.14 and 4.15 in the appendix, I report the result of a GARCH-estimation for model I and III, which confirms the overall picture. One may argue that even if the forward flow is a trading flow, it is the only spot trading that should be included, since I use the spot exchange rate as the dependent variable. The spot and forward rates are, however, linked by covered interest rate parity. In table 4.16 of the appendix, I make an ARCH-estimation with only the spot trading of foreigners and Norwegians, and find the same pattern as earlier.

The effects of oil prices are insignificant. This may indicate that the oil price is not that important for NOK exchange rates as is commonly perceived. It might be that the effect from oil

Table 4.8: Model I: Regressing weekly change in log exchange rates on 3-month interest rates and flow variables. (1996:3 to 1999:10)

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

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

prices is non-linear, as in Akram (1999).

The effect of including the transfer dummies is shown in tables 4.9 and 4.10. These dummies identify weeks with a great deal of publicly know currency trading. Only the production tax dummy is significant, when using 3-month rates. These taxes are paid every month. It is only for NOK/SEK that this dummy is significant and, in that case, with a positive coefficient. One first thought might be that since these tax transfers would mean a demand for NOK, these date-dummies should lead to an appreciation (a negative coefficient) instead. However, since the dates are known in advance, this is already compounded into the prices. A significant coefficient can only be regarded as a sign of an important transfer. For flow variables and interest rates, the results are as above. Inclusion of the publicly known trading periods does not alter the effect of the flow variables, thereby strengthening the model.

The results above indicate that private information may be important in the Norwegian currency market. In table 4.12, I present evidence of whether private information is more or less important than public information. Each cell reports how large a share the two information sources explain, based on partR^2 from stepwise regression for each variable in the regression with overnight rates.

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

Table 4.9: Model II: Regressing weekly change in exchange rates on overnight interest rates, transfer dummies and flow variables. (1997:18 to 1998:52)

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

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

Table 4.10: Model II: Regressing weekly change in exchange rates on 3-month interest rates, transfer dummies and flow variables. (1996:3 to 1999:10)

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

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

Table 4.11: Model III: Regressing weekly change in log exchange rates on 3-month interest rates and flow variables. (1996:3 to 1999:10)

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

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

Table 4.12: PartR^2 for public and private information

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

4.5.1 Discussion

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

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

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

Finally, the effect from order flow on price is more than merely "supply and demand," or quantity adjustment. Information on volume of trade only would not give much structural information about the supply and demand of currency. It is not clear what is supply and what is demand, however. The key to say anything structural about the relationship between trading and price is the signing of the trades. Since all dealers both play the role as suppliers and demanders, and it is possible to determine which role the dealer has in a transaction, we can sign the trades. This makes it sensible to talk about "buyer"-pressure or "seller"-pressure in equilibrium, despite the necessary equality between selling and buying. Only unexpected flow, however, will influence prices. Expected transfers will already be discounted in the price, and hence have no effect. If the flow is unexpected, it will carry more informational content. So while order flow in the foreign exchange market serves the role of influencing prices to balance supply and demand, as in other markets, it also influences prices through changing beliefs. The results of Model III in tables 4.11 and 4.15 give some evidence of this being the most important effect of the two. However, as noted above, one should be careful in drawing conclusions from these regressions, due to high correlations between regressors.

The interpretation of order flow as an indication of private information can be tested. If the lagged flow variables are also significant, or make the contemporaneous flow variables insignificant, we should doubt the private information interpretation. This is reported in table 4.17 of the appendix. The contemporaneous flow variables remain significant, while all lagged flow variables are insignificant except for the foreigner's spot trading in the NOK/SEK equation. In this equation, the contemporaneous effect is still significant, however. Furthermore, the effect from order flow is permanent, as would be the case if contributing new information.

On the exogeneity issue, in all standard models of market microstructure order flow cause price changes. Even when order flow and price changes are simultaneous, causality goes from order flow to price changes. However, this need not be the case in reality. The kind of behavior necessary to create causation the other way, namely some mechanical trading rule, seems less likely on a weekly horizon than in intra day trading. Furthermore, for there to be a positive effect from order flow on exchange rates due to feedback trading, positive autocorrelation in exchange rates is required for this to be optimal. This positive autocorrelation is not present in the data, nor in exchange rates in general (Goodhart, Ito, and Payne, 1996). I address the issue of feedback trading by lagging the exchange rate. If order flow were driven by exchange rates, as in feedback trading, this would make the flow variables insignificant while the lagged exchange rate would be significant. As table 4.18 reports, this is not the case. In the NOK/DEM equation, the lagged rate is insignificant. In the other equations, the lagged rate is significant, but does not alter the significance of the flow variables for NOK/SEK and NOK/GBP. In these cases, the lagged rate simply picks up the autocorrelation estimated earlier on. The choice of end-of-week exchange rates is also made to partly circumvent such a problem.

To finish the issue of exogeneity of flow variables, I also estimate a system approach. I use a two-stage procedure where, in the first step, I form instruments for the flow variables by regressing these on lagged values of the flow variables and an ARMA error term.[22] Then, I use these instruments in an ARCH-estimation, reported in table 4.20. The method is not efficient, but gives consistent estimates and should be sufficient to document that the coefficients on the flow variables are not biased. Notice that the size of the coefficients is not affected.

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

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

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

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

$$\lambda = \pi + \rho_1 Var\left[P_{3,t+1}|\Omega^P_{3,t}\right]. \tag{4.16}$$

Since change in log exchange rate is the dependent variable, I cannot use the residual as a proxy for the variance. Instead, I use the squared of the level forecast from the equation minus the realized exchange rate, $\left(\widehat{\text{NOKDEM}} - \text{NOKDEM}\right)^2_{t+1}$. I then iterate over a two-step procedure where the first step is to obtain the forecast, and the second step includes the suggested variance proxy, conditioned on all information up to period t. The results reported in table 4.21 in the

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

appendix show that the fixed component of the flow coefficient is significant, correctly signed and of the same magnitude as earlier. The variable component is much smaller, not correctly signed, and not significant.

4.6 Conclusion

Since the float of the major currencies in the 1970s, there have been enormous amounts of empirical research on exchange rates. However, our knowledge of the functioning of the market is still limited. Most research has been within the asset approach to foreign exchange. It has proved difficult to explain several of the puzzles of the foreign exchange market, e.g. the volume of trading and the large swings in exchange rates. In fact, there is little evidence that macroeconomic variables have consistent strong effects on floating exchange rates, except in extraordinary circumstances, such as hyperinflation. In a classic study, Meese and Rogoff (1983a) find that three structural macroeconomic models do not perform better than a random walk model, even when uncertainty about future values of the explanatory variables is removed.

Recently, the approach of market microstructure theory has made some progress in explaining the short-term aspects of the foreign exchange market. The microstructure approach seeks to relax the most constraining assumptions of the macroeconomic approach, namely that (i) agents are identical, (ii) information is perfect, and (iii) that the trading mechanism is inconsequential (Lyons, 2001; Frankel, Galli, and Giovannini, 1996). So far, the microstructure approach has been concerned with intraday and daily analysis. In that respect, the microstructure approach can be viewed as a complementary approach to macroeconomic models.

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

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

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

That the order flow have effect even on the weekly horizon may be surprising, and indicate that microstructural effects are to be considered also on longer horizons than intraday. This may have implications for monetary policy actions in the foreign exchange market. Central Bank spot trading of currency leads to a depreciation of NOK. Thus, the regressions also indicate that Central Bank interventions work to stabilize the exchange rate.

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

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

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

4.A Tables

Table 4.13: Correlation matrix for change and level of flow variables

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

Table 4.14: Model I: ARCH estimation of weekly change in log exchange rates on 3-month interest rates and flow variables. (1996:3 to 1999:10)

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

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

Table 4.15: Model III: ARCH estimation of weekly change in log exchange rates on 3-month interest rates and flow variables. (1996:3 to 1999:10)

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

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

Table 4.16: ARCH estimation of weekly change in log exchange rates on 3-month interest rates and spot flow variables. (1996:3 to 1999:10)

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

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

Table 4.17: ARCH estimation of weekly change in log exchange rates on 3-month interest rates, spot flow and lagged spot flow. (1996:3 to 1999:10)

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

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

Table 4.18: ARCH estimation of weekly change in log exchange rates on 3-month interest rates, spot flow variables and lagged dependent variables. (1996:3 to 1999:10)

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

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

Table 4.19: ARCH estimation of weekly change in log exchange rates on 3-month interest rates, spot flow variables, lagged flow and lagged dependent (1996:3 to 1999:10)

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

Table 4.20: Model I: Two stage system ARCH estimation of weekly change in log exchange rates on 3-month interest rates and flow variables. (1996:3 to 1999:10)

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

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

Table 4.21: Model I: Two-step ARCH estimation of weekly change in log exchange rates on 3-month interest rates, flow variables and variance of future price. (1996:3 to 1999:10)

	NOK/DEM
Constant	-0.000549
	(-1.65)
$\Delta(i_t - i_t^*)$	0.021924
	***(3.46)
ΔOil Spot	-0.000337
	(-0.56)
ΔFor. Spot	0.000339
	***(3.16)
ΔNor. Spot	0.000215
	***(3.38)
$\left(\widehat{\text{NOKDEM}} - \text{NOKDEM}\right)^2_{t+1} \Delta\text{For. Spot}$	-0.000002
	(-1.28)
$\left(\widehat{\text{NOKDEM}} - \text{NOKDEM}\right)^2_{t+1} \Delta\text{Nor. Spot}$	-0.000001
	(-1.07)
Adjusted R^2	0.27
Durbin-Watson stat	2.34

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

4.B Model solution

Each dealer chooses quotes and trading strategy by maximizing a negative exponential utility function defined over expected nominal terminal wealth.[23] The public decide on their round 3 demand by maximizing an identical utility function. The horizon is infinite. However, because returns are independent across periods, with an unchanging stochastic structure, the problem collapses into a series of independent trading problems, one for each period. Since all shocks are normally distributed, the conditional variances in each period do not depend on the realization of the shock and is constant across periods.

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

The problem solved by the dealers is the following:

$$\max_{\{P_{i1,t}, P_{i2,t}, P_{i3,t}, T_{i2,t}\}} E\left[-\exp\left(-\theta W_{i3,t}\right)|\Omega^D_{i\tau,t}\right] \tag{4.B.1}$$

subject to

$$\begin{aligned} W_{i3,t} &= W_{i0,t} + c_{i1t}P_{i1t} + T'_{i2,t}P_{i2} + I_{i2t}P_{i3} - T_{i2t}P'_{i2t} \\ &= W_{i0,t} + c_{i1t}\left(P_{i1t} - P'_{i2t}\right) + \left(D_{i2,t} + E\left[T'_{i2,t}|\Omega^D_{i2,t}\right]\right)\left(P_{i3t} - P_{i2t}\right) \\ &+ T'_{i2t}\left(P_{i3t} - P_{i2t}\right). \end{aligned} \tag{4.B.2}$$

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

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

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

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

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

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

respectively:

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

4.B.1 Equilibrium prices

Equilibrium prices are given by

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

$$P_{i3t} = P_{2t} + \lambda x_t. \tag{4.B.5}$$

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

$$E\left[c_{i1,t} + D_{i2,t}\left(P_{1,t}\right)|\Omega_{1,t}\right] = 0 \tag{4.B.6}$$

$$E\left[\sum_{i=1}^{N}\left[c_{i1,t} + D_{i2,t}\left(P_{2,t}\right)\right]|\Omega_{1,t}\right] = 0 \tag{4.B.7}$$

$$E\left[\sum_{i=1}^{N} c_{i1,t} + c_{3,t}\left(P_{3,t}\right)|\Omega^P_{3,t}\right] = 0. \tag{4.B.8}$$

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

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

$$c_{3t}\left(P_{3,t}\right) = -\sum_{i=1}^{N} c_{i1t}. \tag{4.B.9}$$

The conjectured trading strategy of dealers equal

$$T_{i2,t} = \alpha c_{i1,t}. \tag{4.B.10}$$

We can now write the sum on the right-hand-side of (4.B.9) in terms of observed interbank order flow:

$$\begin{aligned}x_t &= \sum_{i}^{N} T_{i2,t} = \alpha \sum_{i}^{N} c_{i1,t}\\ \sum_{i}^{N} c_{i1,t} &= \frac{1}{\alpha} x_t.\end{aligned} \tag{4.B.11}$$

Customers' optimal demand follows

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

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

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

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

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

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

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

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

The testable equation is

$$\Delta P_{3,t} = r_t + \pi x_{t-1} + \pi x_t + \rho x_t,\ \rho = 1/\gamma\alpha,\ \pi = \phi/\alpha. \tag{4.B.12}$$

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

4.B.2 Trading strategy

The trading strategy is given by

$$T_{i2,t} = \alpha c_{i1t}. \tag{4.B.13}$$

The problem the dealers must solve is the following:

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

subject to

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

This utility function has the convenient property of maximizing its expectation, when variables are normally distributed, i.e. that $W \sim N\left(\mu, \sigma^2\right)$, is equivalent to maximizing[24]

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

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

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

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

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

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

Hence, I can write the problem as

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

The first-order condition is

$$2\lambda D_{i2t} + c_{i1t} - \theta\sigma^2 D_{i2t} = 0, \tag{4.B.14}$$

which implies a speculative demand of

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

Trading then becomes

$$T_{i2} = D_{i2t} + c_{i1t} = \left(\frac{1}{\theta\sigma^2 - 2\lambda} + 1\right)c_{i1t} = \alpha c_{i1t}. \tag{4.B.15}$$

The second-order condition,

$$2\lambda - \theta\sigma^2 < 0 \Rightarrow \theta\sigma^2 - 2\lambda > 0, \tag{4.B.16}$$

ensures that $\alpha > 1$.

4.C Time-varying risk premium parameter

The parameter I estimate on the flow variables equals

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

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

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

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

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

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

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

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

$$\frac{d\lambda}{d\sigma_P^2}\left[\frac{\alpha^2\left(\theta\sigma^2-2\lambda\right)^2+2\left(\phi+1/\gamma\right)}{\alpha^2\left(\theta\sigma^2-2\lambda\right)^2}\right]=\frac{\theta}{\alpha}$$
$$\frac{d\lambda}{d\sigma_P^2}=\frac{\alpha\theta\left(\theta\sigma^2-2\lambda\right)^2}{\alpha^2\left(\theta\sigma^2-2\lambda\right)^2+2\left(\phi+1/\gamma\right)}>0 \tag{4.C.1}$$

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

$$\frac{d\lambda}{d\theta}=-\frac{1}{\alpha^2}\left(\frac{-\left(\sigma^2-2d\lambda/d\theta\right)}{\left(\theta\sigma^2-2\lambda\right)^2}\right)\left(\phi+\frac{1}{\gamma}\right)+\frac{\sigma_P^2}{\alpha}$$
$$\frac{d\lambda}{d\theta}\left[1+\frac{2\left(\phi+1/\gamma\right)}{\alpha^2\left(\theta\sigma^2-2\lambda\right)^2}\right]=\frac{1}{\alpha^2}\left(\frac{\sigma^2}{\left(\theta\sigma^2-2\lambda\right)^2}\right)\left(\phi+\frac{1}{\gamma}\right)+\frac{\sigma_P^2}{\alpha}$$
$$\Rightarrow\frac{d\lambda}{d\theta}>0. \tag{4.C.2}$$

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CHAPTER 5

U.S. Exchange Rates and Currency Flows[1]

5.1 Introduction

In the last couple of years several papers have found that order flow is an important determinant of exchange rates. Lyons (1995), Yao (1998) and Bjønnes and Rime (2000b) have studied dealer response to order flow intra day, Evans (1998) and Payne (1999) have studied the importance of intra day order flow on the whole market, while Evans and Lyons (1999) have studied the impact of daily order flow and Rime (2000) for weekly order flow. Drawing on the theory of financial markets' microstructure, the authors have concluded that there exist private information in the foreign exchange market, and that order flow aggregates this information into prices.

The significance of these results becomes apparent when contrasted to the kind of result that we have been used to in exchange rate economics (e.g. Meese and Rogoff, 1983a,b). Typically, the traditional macroeconomic models receive low support at the biannual frequency, and almost no support at the monthly frequency.

There may be several reasons for the lack of empirical support for the macroeconomic models. A questionnaire study of London-based foreign exchange analysts by Allen and Taylor (1989) showed considerable heterogeneity of expectations. Several recent survey studies confirm the view of agent heterogeneity.[2] The data in Bjønnes and Rime (2000a) reveal that dealers expect other dealers to have different information than themselves.

Furthermore, in the traditional macroeconomic models exchange rates are determined by public macroeconomic information, while trading activities are completely irrelevant. As an example,

[1] I would like to thank Steinar Holden for valuable comments.

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

consider the effect of trading in the traditional flexible price monetary model, one of the traditional models. In this model, the exchange rate is determined by public information about the relative size of monetary aggregates and of the aggregate economics. Thus, trading as such has no effect on prices, since all available information will be aggregated into prices prior to trading. Trading will only occur to the extent that dealers require exchange for known reasons, e.g. trade in goods or liquidity needs. This kind of trade will have no effect on exchange rates, since the trading does not reveal any new information by assumption.

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

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

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

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

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

This study utilizes a recent data set on currency trading by the "major players" in the U.S. currency market, collected by the U.S. Treasury. I have weekly observations from July of 1995 until September of 1999 on the volume of purchases and sales of spot transactions and changes in options positions. As far as I know there are only three similar studies on foreign exchange markets. Wei and Kim (1997) were the first to use the present data set. Their approach was very different from the present, and they found no evidence that trading was informative about exchange rate changes. This paper is very close in spirit to Evans and Lyons (1999) and Rime (2000). Evans and Lyons (1999) develop a version of the model used in this paper and test it on daily data created from the real-time trading observations of Evans (1998). They find that order flow is more significant than the change in interest differentials.

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

The results in the present study are consistent with the results of Evans and Lyons. For DEM/USD, GBP/USD and CHF/USD order flow has a strong effect on price changes. A sale of foreign currency by U.S banks lead to a appreciation of the USD. This is consistent with an interpretation that U.S banks act as aggressors (take initiative to trade) when they have good information, which is possible because U.S banks do most of their trading while the European market is active. What might be most surprising is the fact that order flow has an effect over a week, implying that order flow analysis is useful also for longer horizons than the usual intra day and daily horizon that is most often considered. The results are however in accordance with the results of Evans (1999) and Rime (2000).

The remainder of the paper is organized as follows: The model is presented in section 5.2. Section 5.3 presents the data. Results are presented and discussed in section 5.4, while section 5.5 concludes.

5.2 Model

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

Consider an exchange economy with two assets, one risk free and one risky asset represented by a currency.[3] There are N dealers, and a public sector (customers) that is distributed in the continuous interval $[0,1]$, so customers are more numerous than dealers and hence have a greater capacity for bearing risk (as a group). The horizon is infinite and timing within a period of the model is shown in figure 5.1. The information of each group will be clear from the below description of the timing. Dealers decide on prices in each round, $P_{i1,t}, P_{i2,t}$ and $P_{i3,t}$, and the interdealer trade that takes place in round two, $T_{i2,t}$, while the public decide their demand in round three, $c_{3,t}$. The public trade in round 1 is stochastic (see below).

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

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

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

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

Rule P1 ensures that prices cannot be conditioned on other dealers' prices, and that dealers cannot choose not to give quotes. When trades are initiated electronically in a multiple dealer market, this can potentially lead to simultaneous quotes and trades. Quoting and trading in the foreign exchange market is also extremely fast. Finally, not quoting would be a breach of the social norms for a Market Maker, and could be punished by other dealers.[4] Rule P2 states that there is costless search for quotes, which is true in the interbank market for normal trade sizes traded through the electronic broker systems. Through the different trading systems dealers can observe several quotes, making transparency of price very high. The foreign exchange market is extremely liquid with quotes and spread constant up to 10 mill USD, making rule P3 less restrictive than what might first be considered the case.

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

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

[4] The survey by Cheung and Chinn (1999b) shows that the "norms" of the market are considered important. Examples of punishment might be not receiving trades from other dealers, and only obtaining wide spreads.

T1. Trading is simultaneous and independent

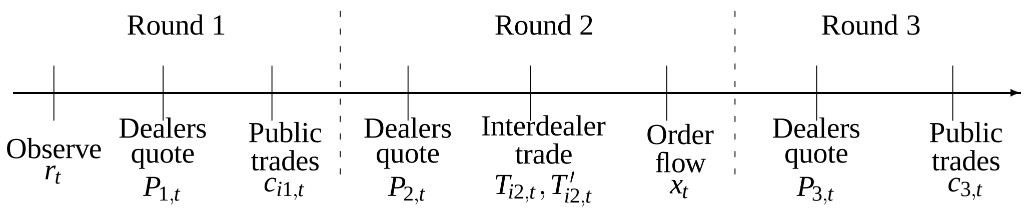
T2. Trading with multiple partners is feasible

T3. Trades are divided equally among dealers with the same quote, if someone wants to trade at the quote.[5]

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

Rule T1, that trading is simultaneous and independent, implies that trades received from other dealers, T'_{it}, is an unavoidable disturbance to dealer i's inventory. This is in line with the fact that Market Makers in foreign exchange cannot perfectly control their inventory. It is also consistent with the low transparency of trade in the interbank market, where dealers only observe their own trades and a subset of trades through brokers. Rules T2 and T3 are more technical, and rule T3 can be relaxed. T4 captures that dealers have limits on their overnight positions.[6]

Figure 5.1: Period t timing



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

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

$$c_{i1,t} = r_{t+1} + \eta_{it}, \tag{5.1}$$

where $\eta_{it} \sim IID\left(0, \sigma_c^2\right)$. The trading with customers in round 1 is only observable to the dealers involved in the trade, so that customer trades are private information to the dealers involved. Since trading in round 1 is stochastic, the public should be considered as divided into two groups, with one group trading in round 1 and the other in round 3. Each customer in round 1 is small, and does

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

[6] This assumption seems to be too strong given the data set, and I will return to this in section 5.4.

not regard his own trading in round 1 as informative about overall trading in round 3. The public will not speculate in round 3 prices based on their own round 1 trading.

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

$$T_{i2,t} = c_{i1,t} + D_{i2,t} + E\left[T'_{i2,t}|\Omega^{D}_{i2,t}\right], \tag{5.2}$$

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

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

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

$$U(W_{i3}) = -\exp(-\theta W_{i3,t}), \tag{5.3}$$

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

5.2.1 Equilibrium

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

$$P_{1,t} = P_{2,t} = P_{3,t-1} + r_t - \pi x_{t-1}, \tag{5.4}$$

$$P_{3,t} = P_{2,t} + \lambda x_t,\ \lambda > 0, \tag{5.5}$$

where x_t is aggregate order flow[7] in the inter dealer trading in round 2, and λ a parameter that will be determined below. In round 1, all information is public when prices are set; hence all dealers set the same prices only adding the increment to currency value that was not included in the price already, represented by $r_t - \pi x_{t-1}$. Equilibrium (no-arbitrage), and full transparency of prices, ensures that all dealers also set the same price in round 2. If the prices in round 2 are to be equal, these can only be conditioned on public information, and therefore the round 2 price must equal the round 1 price. Setting a price different from the others would reveal information and attract all supply/demand. Instead, dealers utilize their private information in forming their speculative demand in round 2.[8] Interdealer trade is only observed by the parts participating in the transaction.

Equilibrium trade by dealer i is given by

$$T_{i2,t} = c_{i1,t} + D_{i2,t}\left(c_{i1,t}\right) = \alpha c_{i1,t}, \alpha > 1, \tag{5.6}$$

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

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

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

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

$$P_{3,t} = E\left[P_{3,t+1}|\Omega_{3,t}^P\right] + \rho x_t,\ \rho = 1/\left(\alpha\gamma\right) > 0. \tag{5.7}$$

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

Inserting for the expectation in (5.7), we get

$$P_{3,t} = P_{2t} + \pi x_t + \rho x_t = P_{2t} + \lambda x_t \tag{5.8}$$

$$P_{3,t} = \sum_{\tau=1}^{t}\left(r_\tau + \rho x_\tau\right) + \pi x_t \tag{5.9}$$

where $\pi = \phi/\alpha$ and ϕ is the parameter on new information in the public's conditional expectation

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

[8] Bjønnes and Rime (2000a) show empirically that dealers utilize their private information from customer trades in their trading strategy and not in their pricing strategy.

($\phi \in (0,1)$). The price in round 3 equals the expected fundamental value for the next period ($F_t + \pi x_t$) plus the accumulated risk premium related to the accumulated risk the public have absorbed ($\sum_\tau^t \rho x_\tau$). From (5.4) and (5.8), the change in price equals the adjusted increment, an element for the expected return in the next period, and the additional compensation for taking additional risk:

$$\Delta P_{3,t} = r_t - \pi x_{t-1} + \pi x_t + \rho x_t \tag{5.10}$$

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

$$\Delta P_{3,t} = r_t + \rho x_t. \tag{5.11}$$

This is the equation tested by Evans and Lyons. By rewriting (5.10), it can empirically coincide with the above equation. To see this, insert for x_{t-1}. After observing r_t, the noise from the flow in the previous period can be aggregated,

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

where I use (5.1) to insert for $c_{i1,t-1}$. Inserting this in equation (5.10) gives

$$\Delta P_{3,t} = (1 - N\phi)\, r_t + \lambda x_t + \tilde{\eta}_t, \tag{5.12}$$

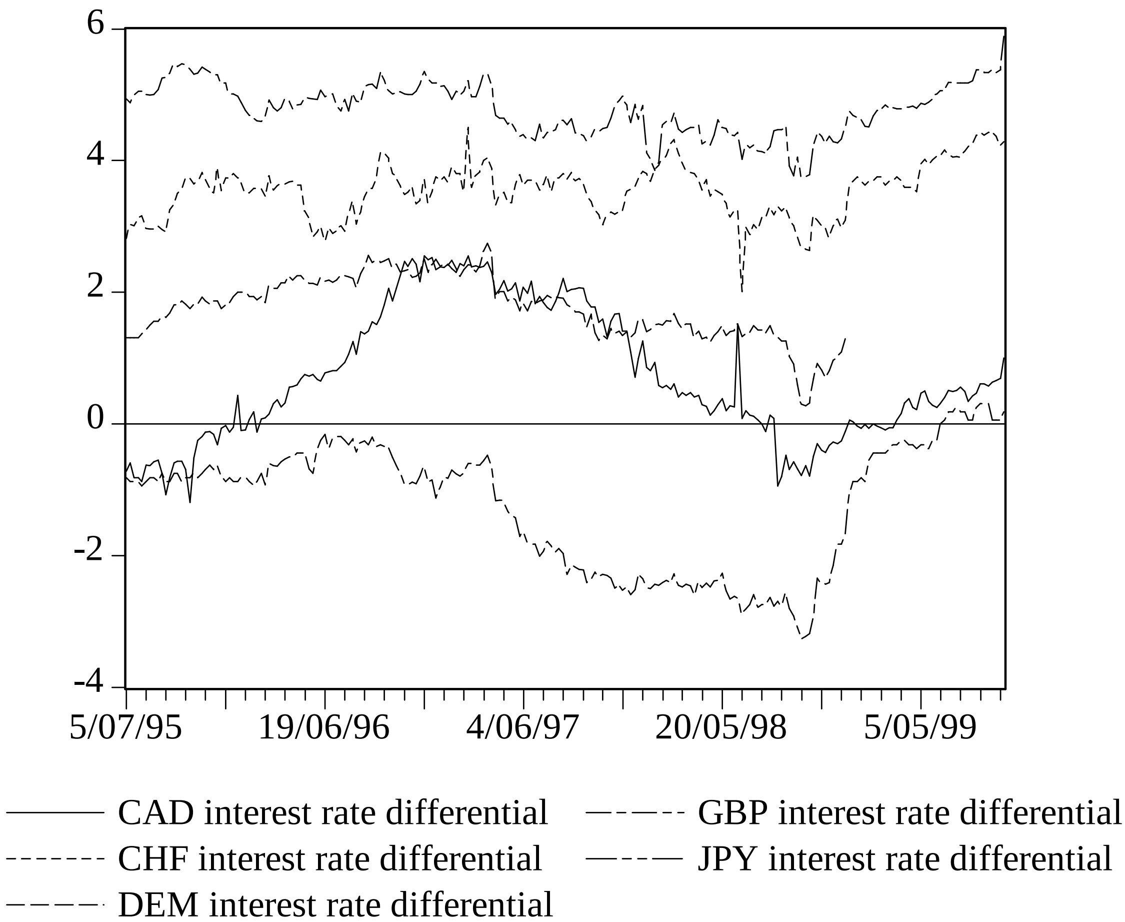
where $\tilde{\eta}_t = \sum_i \phi \eta_{it-1}$. This term is uncorrelated with r_t by definition. It is uncorrelatd with x_t since $x_t = \alpha \sum_i c_{i1,t}$, which are all *IID*. Therefore, r_t and x_t are weakly exogenous with respect to $(1 - N\phi)$ and λ. The term $\tilde{\eta}_t$ is unobservable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

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

5.3 Data

The public information set consists of weekly observations on the interest rates for the six countries USA, Germany, Japan, Great Britain, Canada and Switzerland. In some regressions I will also use stock market indexes from the five countries. Figure 5.2 plots the interest rate differential between the U.S interest rate and the JPY, CHF, DEM, CAD and GBP interest rates, in that sequence from above.

Figure 5.2: 3-month interest rate differential

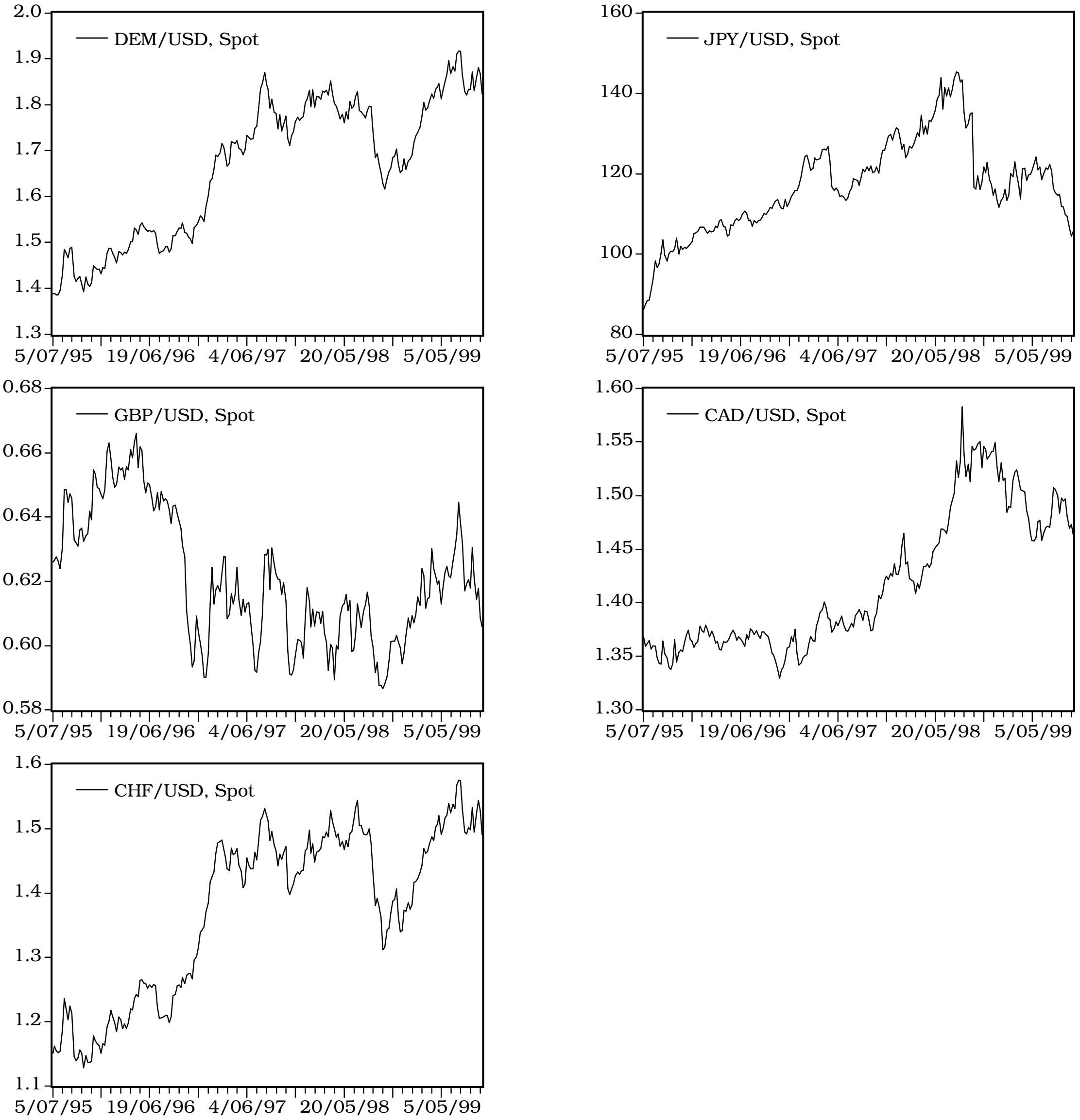


The graphs are $\left(i_t^{USD} - i_t^*\right)$, where $*$ indicate the foreign interest rate. The 3-month interest rates are interest rates from the so-called "EuroDollar" market, and are provided by Norges Bank. The DEM interest rate ends in 1998 due to the introduction of Euro in 1999.

The exchange rates are quoted at the end of the week. If there is no observation available at the Friday, I use the observations from the following Monday. Exchange rates are the USD against the DEM, the JPY, the GBP, the CAD and the CHF. These six currencies are among the seven most traded currencies globally (the French franc is no. 6, before the CAD). Similarly, the five exchange rates are among the six most traded exchange rates (BIS, 1998).

Figure 5.3 plots the five exchange rates. We see that the USD depreciated against the DEM, JPY, GBP and CHF in the fall of 1998, during the Asian crises. Also, notice that the DEM and the

Figure 5.3: Spot Exchange Rates



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

CHF are highly correlated.

Table 5.1 summarizes the descriptive statistics for the four exchange rates from the beginning of July 1995 until September 1999. The GBP/USD and the CAD/USD are the two most stable exchange rates, with standard deviation being 3% and 5% of the mean, respectively. Standard deviation as percentage of mean is ca. 9 – 10% for the others.

Table 5.1: Summary statistics for exchange rates

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

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

5.3.1 Currency flows

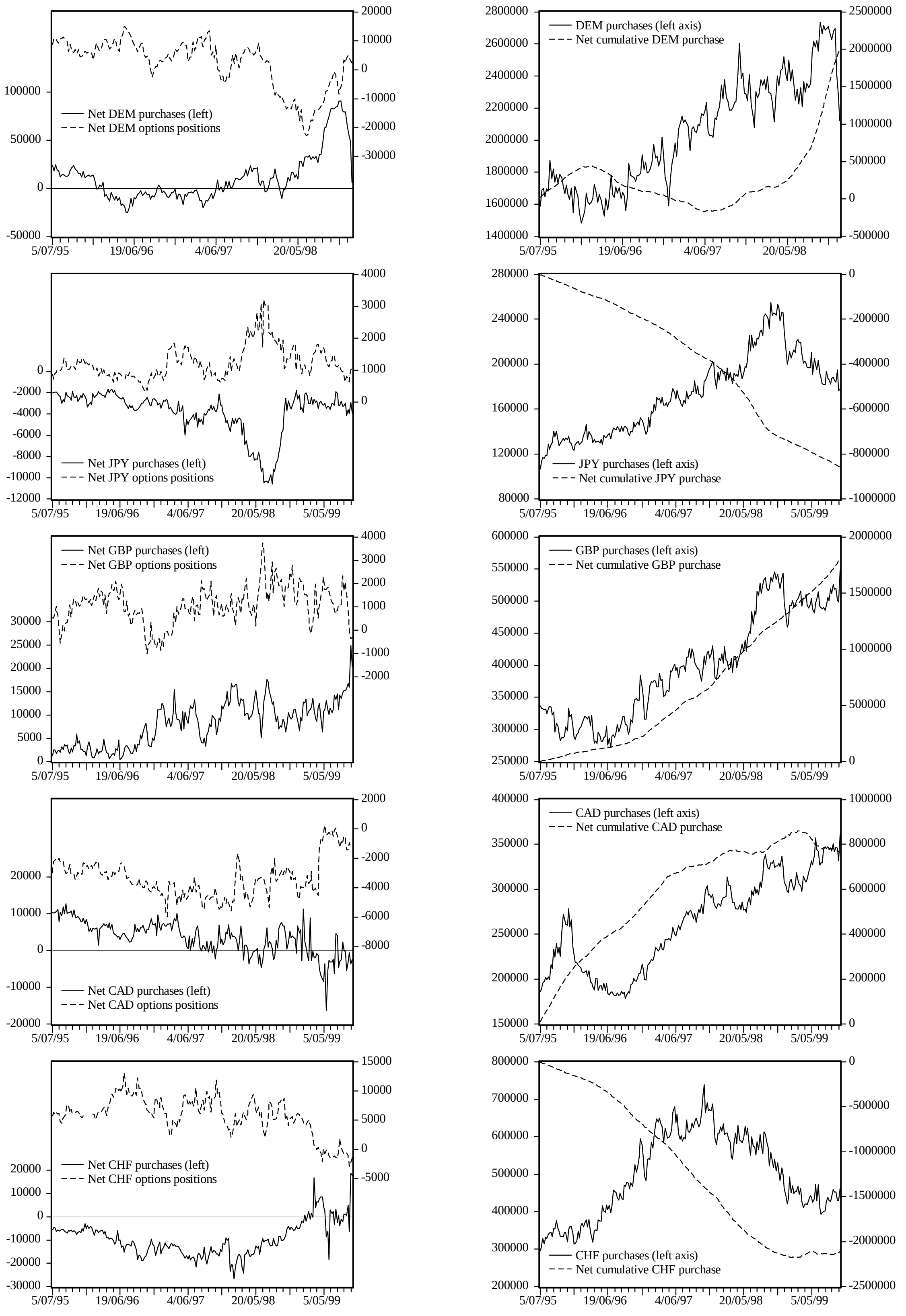
The order flow in the theoretical model is represented by weekly observations on currency trading in Deutsche mark (DEM), Japanese yen (JPY), British pound sterling (GBP), Canadian dollar (CAD) and Swiss franc (CHF) by large market participants in the U.S.

The observations on currency trading are collected by the U.S. Treasury. The Treasury began publishing these weekly time series in the quarterly Treasury Bulletin in September 1994, with observations beginning in January 1994. In this study, I use observations from the beginning of July 1995 until the end of September 1999, which makes a total of 222 weeks.[9] The series include the weekly net positions of currency options, and the weekly sale and purchase of spot, forwards and futures together, by the major foreign exchange market participants in the U.S. All series are measured in the foreign currency, so DEM purchases are purchases of DEM by the major U.S. participants. The net option positions are measured as delta equivalent values. The delta equivalent equals the product of the first derivative of the option value with respect to the exchange rate, and the notional principal of the contract. The value of a call option (right to buy currency) is increasing in the price of the underlying currency. Hence, if a bank is long in call-options, they will have a positive net option position. If a bank is equally long in similar put and call options, the net position will be zero.

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

[9] Observations from January 1994 until July 1995 are only available in paper copies, which the author has not yet obtained.

Figure 5.4: Weekly order flows



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

Figure 5.4 plot the weekly trading activity, with one row for each currency. In the left column, there are net purchases of currency, while the right column shows currency purchases on the left axis, and net cumulative purchases at the right axis. All flow variables are measured in millions of the foreign currency, except JPY flows which are measured in billions JPY. In the cumulative graphs, I have set the initial point to zero since I have no observations on initial positions. The Purchase and Net Purchase series includes spot, forwards and futures. These series contain trading with all counterparties, meaning it is not only interbank trading. The banks will report both the sales to customers and the subsequent interbank trading to cover the customer transaction. From the graphs, it is clear that the net position taking of the banks in each week is very small. However, the cumulative grahs show that the position taking over time may be substantial. This problem is addressed in section 5.4. Augmented Dickey-Fuller tests show that all of the flow variables have unit roots, except the Net Options Position of CAD and CHF.

Table 5.2: Summary statistics for currency flows

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

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

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

In the data set in this study there is no information about the sign, and in the regressions I will include the observations as they are. The following conditional prediction can be made: *If* the U.S. banks are the main market makers in these currencies, then a net (unexpected) sale of the foreign currency should lead to an appreciation of the exchange rate, i.e. increase the value of the currency. In the data, a net sale by the U.S. banks would in this case mean that most of the initiators bought currency. The reason might be that the initiators believed the currency to be undervalued, or that they needed currency and US banks charged a compensation for the risk they took when they provided the currency demanded. *If*, on the other hand, the U.S banks do not engage very much in market making, then it would mean that they are the ones that take initiative to trades. Then a net sale of foreign currency should lead a depreciation of the currency.

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

5.4 Results

The model is tested on the weekly frequency. While initial work by Evans and Lyons (1999) were on daily frequency, the testable implications is equally applicable at the weekly frequency as the daily. In the third round of the model, the dealers trade with the public to share risk. Within a week, it is likely that dealers share the risk by trading with each other in different time zones, since the foreign exchange market is a 24-hour open market. When the Europe market is closing, European dealers trade with US dealers to get rid of the inventory risk. Trading with the public to share risk may be a more important alternative at the end of week, since most regional markets are less active during weekends. Finally, if the effect from order flow is permanent it should matter at the weekly horizon as well.

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

The theoretical model puts few restrictions on which public information variables to include in r_t, and in which form. I follow Evans and Lyons and use change in the interest differential, $\Delta\left(i_t^{\text{USD}} - i_t^*\right)$ with an * indicating the foreign interest rate. This is line with e.g. the monetary approach.

It is important to note that only *unexpected* order flows should influence the price, as the expected order flow should already be captured in the price. In the model, all order flow is unexpected, but this will not be the case in reality. I will test two versions of the theoretical model. In the first, I estimate the expected flow with an ARIMAX-model,[10] while in the second I use the

[10] In the ARIMAX formulation I use lagged flow variables as exogenous variables, e.g. lagged spot purchase in the equation for spot sales.

flow from the previous week as a proxy for the expected flow. The two formulations are,

$$\Delta P_t = \alpha + \beta_1 \Delta\left(i_t^{\text{USD}} - i_t^*\right) + \beta_2[\text{SpotPurchase}_t - \widehat{\text{SpotPurchase}}_t] + \beta_3[\text{SpotSale}_t - \widehat{\text{SpotSale}}_t] + \beta_4[\text{OptionsPos}_t - \widehat{\text{OptionsPos}}_t] + u_t \quad (5.13)$$

and

$$\Delta P_t = \alpha + \beta_1 \Delta\left(i_t^{\text{USD}} - i_t^*\right) + \beta_2 \Delta\text{SpotPurchase}_t + \beta_3 \Delta\text{SpotSale}_t + \beta_4 \Delta\text{OptionsPosition}_t + u_t \quad (5.14)$$

All regressions use the change in the log of nominal exchange rates for DEM/USD, JPY/USD, GBP/USD, CAD/USD and CHF/USD as dependent variable. Using the change in levels, as in the theoretical model, instead of change in logs does not affect the results. Results are shown in table 5.3 to 5.7.

Table 5.3: Change in log exchange rates regressed on interest rates, net unexpected flow, and unexpected options position

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

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

From table 5.3 we get the general picture from all the regressions. Net unexpected spot sale of foreign currency is significant and positive for DEM/USD, GBP/USD and CHF/USD, while Unexpected Options positions is significant for JPY/USD as well as for the exchange rates already mentioned. The coefficients on both flow variables are measured as the effect of a 1 billion flow. The coefficients on Net Unexpected Spot sale are positive. Since the flow variables are measured in the foreign currency, this means that an unexpected net sale of DEM, CHF or GBP by the major U.S. banks (i.e. an unexpected purchase of USD) appreciates the USD against the currency in question. The model would predict that the foreign currency should depreciate when the U.S. banks take the initiative to trade and sell currency. In this perspective, the U.S. banks rather trade at other banks quotes than to act as market makers. This can only be part of an equilibrium if somebody else is being market makers. If the U.S. banks do most of their trading while the European market is active, this might very well be the case.

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

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

In table 5.9 and 5.10 in the appendix we run the regression without the option variables. The unexpected spot flow remains significant, and the coefficients are only slightly less in value.

Table 5.4: Change in log exchange rates regressed on interest rates, net unexpected flow, and stock exchange indexes

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

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

In table 5.4 I also include two stock indexes in each regression as well. The Standard & Poor 500 is included in all regressions, while the other indexes; the Frankfurt-index (Commerzbank) from Germany; the Nikkei 225 index from Tokyo, Japan; the FT-SE 100 from London, UK; the Toronto TSE-300 from Canada; and the SPI General Index from Zurich, Switzerland, are only included in their respective regressions. The stock indexes are included to see if the flow variables remain significant even when more public information that may be related to exchange rate return are included in the regressions. The table shows that the flow still is significant, although only at the 10% level for the DEM/USD. From the table we see that it is primarily the foreign stock index return that have explanatory power for the exchange rates, and that the coefficients have different signs. The effect is positive for the DEM/USD, GBP/USD and the CHF/USD, while it is negative for CAD/USD. One can also notice that the coefficient on the flow decrease somewhat compared to the previous table. This, together with the positive coefficient on the foreign stock exchange, suggest the following explanation. When the foreign stock exchange increases US investors rebalance their portfoilio and sell some foreign currency, making the foreign currency less worth and picking up some of the effect from the flow.

Changes in interest differentials have negative and significant coefficients for CAD/USD and CHF/USD, and positive for GBP/USD. The negative coefficients are a bit counter-intuitive. When the US interest rate increase relative to the foreign interest rate, the USD depreciates (the exchange rate decreases, so the foreign currency appreciates). From figure 5.2 and 5.3 we see that the USD has appreciated against the CHF and CAD over the sample, and at the same time the interest differential has remained stable (CHF) or fallen (CAD). Hence, it may be that the negative coefficient is due to long term trends not captured here. The lack of significance for the two other exchange rates may be due to that interest differentials are not very good indicators of new information since many interest changes are anticipated by the market.

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

Table 5.5: Change in log exchange rates regressed on interest rates, net unexpected flow, and unexpected flow lagged

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

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

In the regressions in table 5.3 and 5.4 the flow variables have a permanent effect on exchange rates, in line with the presumption that they aggregate new information. This can however be tested, which is done in table 5.5. If the flow variables do not provide new information, the effect should not be permanent. The effect could then either be countered or disappear when lagged flows are included in the regressions. For the DEM/USD, GBP/USD and CHF/USD, the exchange rates with significant coefficients on the flow variables above, the lagged flow is insignificant while the current flows remain significant and with the same value on the coefficients. In case of JPY/USD, the current flow is insignificant, as before, but the lagged flow is significant.

Table 5.6: Change in log exchange rates regressed on interest rates, and change in flow variables

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

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

Table 5.7: Change in log exchange rates regressed on interest rates, change in flow variables, and stock exchange indexes

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

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

In table 5.6 and 5.7, I test the model with unexpected flow proxied by the change in the flow variables. I also include the sale of currency and purchase of currency as separate variables, instead of the net of the two, to see if they have different coefficients. This is also done in table 5.10 to 5.13 in the appendix, there with estimated expected flow as previous. First we see that the flow variables enter significantly for the same exchange rate as above, and with similar absolute values on the coefficients as before. The coefficients on sale and purchase are also of opposite sign, as expected. Therefore, the results do not seem to be very sensitive to the formulation of the unexpected flow. Second, there seems to be no asymmetric response to the flow. The coefficients on the sale and purchase look very similar, which they also are in case of DEM/USD. For GBP/USD and CHF/USD however, it depends on which regression we use to test the coefficients. In the regression in table 5.6, the coefficients for CHF/USD are insignificantly different, while they are significantly different at the 10% level in case of GBP/USD using a Wald test.

The flow variables in the data set contains all the trading of the banks, while the order flow in the model only comes from interbank trading. This creates a problem. In the model, dealer i close his position at the end of the period so his total trading sum to zero. In the data, an unexpected net purchase flow of currency means that the U.S. banks are unexpectedly taking positions (building inventory). Although position taking may be reasonable if the banks receive private fundamental information, building position taking into the model is very difficult The problem is that the dealer then needs to take account of his inventory when entering a period. This can result in very complicated trading strategies. Trading strategies as simple functions of customer trades, as in the model, can be obtained by assuming that all customer trades are of fixed absolute size. However, this makes the parameter in the trading strategy time-dependent because it will depend on the inventory, and hence not very useful for empirical analysis.

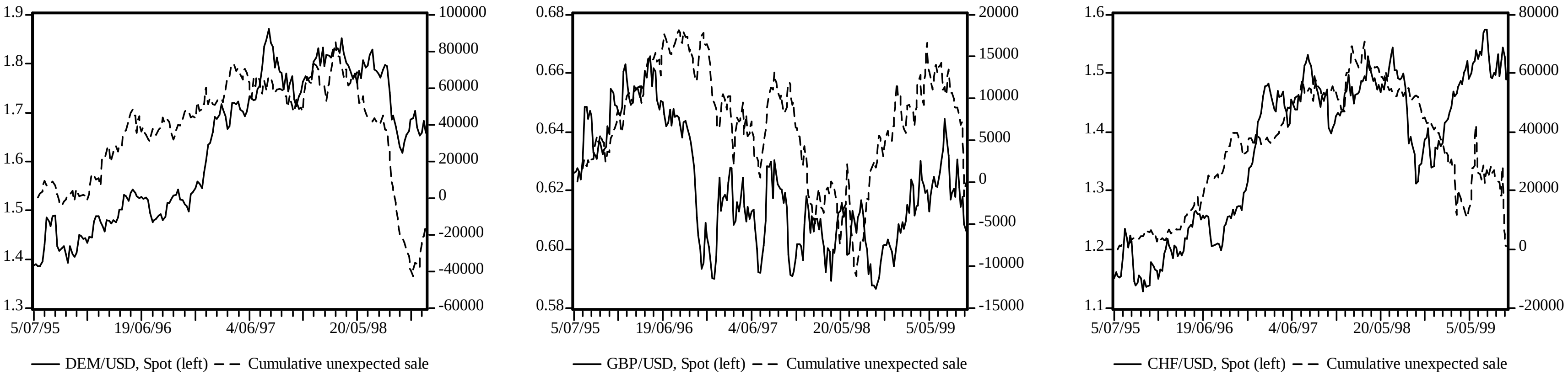
A possible interpretation of the results, in the spirit of the model, is the following: When customers buy currency it provides a signal to the bank that the exchange rate will appreciate due to fundamental reasons. The bank take the same position as the customers, and are willing to hold this position because it is based on fundamental information. If the bank only speculated on the risk premium however, they should not, at least in a finite horizon framework, take a position because they know that in the end it is the fundamentals that determine the exchange rates.

It is important for the interpretation of order flow as valuable information that the effect from unexpected flow is permanent. In that case we also have a relationship between the level of the exchange rate and the cumulative unexpected flow, i.e. the exchange rate and the cumulative flow cointegrate. This is evident in the theoretical model from equation (5.9). In figure 5.5 the level of the exchange rates is plotted on the left axes, while cumulative unexpected sales of foreign currency is plotted on the right axes. The figure shows the three exchange rates where I find significant relationship between the change in the exchange rate and the flow of unexpected sales. The cumulative unexpected sale is calculated as the cumulative sum of the net unexpected sale from table 5.3.

From the figure it seems that the series cointegrate, and the cointegrating relationsships are shown in table 5.8 together with unit root test statistics.

The coefficients are multiplied with 10^3, so they measures the effect of the cumulative sum of unexpected sales of 1 billion foreign currency. The coefficients are reported with t-values in parenthesis. Since the variables have unit roots we do not report significance levels. The trend is included to capture latent variables (Engle and Yoo, 1991). The cointegration result confirm the results from above. The cumulative sum of unexpected net sales of currency goes together with a weaker exchange rates.

Figure 5.5: Exchange rates and cumulative unexpected sale of foreign currency



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

Table 5.8: Tests of cointegration between price and cumulative order flow

	DEM/USD	GBP/USD	CHF/USD
Constant	1.36308	0.63218	1.14972
	(173.58)	(246.38)	(142.02)
Cumulative spot flow	0.0022	0.0010	0.0056
	(17.56)	(6.06)	(13.37)
Trend	0.00209	-0.00016	-0.00002
	(30.92)	(-9.96)	(-0.15)
ADF-test	**3.12	**3.43	**3.42
PP-test	**3.12	**3.25	**3.18

The parameters are estimated using ordinary least square. t-values are reported in parenthesis. Since the variables have one unit root, we do not report significance levels. The dependent variable is price. Cumulative flow is created from the cumulative flow of net unexpected spot sales. ADF-test is a standard augmented Dickey-Fuller test on the regression residual. PP-test is a Phillips-Perron test (Perron, 1988) on the regression residual. The Phillips-Perron test incorporates the Newey and West (1987) modification procedure. The number of lags included is calculated from the sample size (Newey-West automatic truncation lag selection). The tests do not include a trend since a trend is included in the original regression equation. "***", "**" and "*" indicate significance at the 1%, 5% and 10% level respectively. All flow coefficients multiplied by 10^3. This means that the coefficients measure the effect of a 1 billion flow.

5.5 Conclusion

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

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

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

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

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

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

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

5.A Tables

Table 5.9: Change in log exchange rates regressed on interest rates and unexpected spot sale

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

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

Table 5.10: Change in log exchange rates regressed on interest rates, unexpected sale, purchase and options positions

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

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

Table 5.11: Change in log exchange rates regressed on interest rates lagged, unexpected sale and purchase

	DEM/USD	JPY/USD	GBP/USD	CAD/USD	CHF/USD
Constant	0.000906	0.000861	0.000194	0.000297	0.001083
	(1.00)	(0.64)	(0.29)	(0.61)	(1.08)
$\Delta\left(i_t^{\text{USD}} - i_t^*\right)$, lagged	0.009631	-0.002424	-0.010143	0.006109	0.007512
	(1.24)	(-0.25)	**(-2.01)	***(2.67)	*(1.85)
Unexp. Spot sale	0.000415	-0.000634	-0.000777	-0.000057	0.000301
	**(2.35)	(-0.26)	**(-2.09)	(-0.31)	**(2.18)
Unexp. Spot purchase	-0.000403	0.000021	0.000691	0.000065	-0.000358
	**(-2.31)	(0.01)	*(1.86)	(0.35)	**(-2.53)
Adjusted R^2	0.03	0.02	0.03	0.02	0.02
Durbin-Watson stat	2.01	2.07	1.97	2.12	1.84

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

Table 5.12: Change in log exchange rates regressed on interest rates, unexpected flow variables, and stock exchange indexes

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

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

Table 5.13: Change in log exchange rates regressed on interest rates, unexpected flow variables, and flow variables lagged

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

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

5.B Model solution

Each dealer chooses quotes and trading strategy by maximizing a negative exponential utility function defined over expected nominal terminal wealth.[11] The public decide on their round 3 demand by maximizing an identical utility function. The horizon is infinite. However, because returns are independent across periods, with an unchanging stochastic structure, the problem collapses into a series of independent trading problems, one for each period. Since all shocks are normally distributed, the conditional variances in each period do not depend on the realization of the shock and is constant across periods.

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

The problem solved by the dealers is the following:

$$\max_{\{P_{i1,t},P_{i2,t},P_{i3,t},T_{i2,t}\}} E\left[-\exp\left(-\theta W_{i3,t}\right)|\Omega^D_{i\tau,t}\right] \tag{5.B.1}$$

subject to

$$\begin{aligned} W_{i3,t} &= W_{i0,t} + c_{i1t}P_{i1t} + T'_{i2,t}P_{i2} + I_{i2t}P_{i3} - T_{i2t}P'_{i2t} \\ &= W_{i0,t} + c_{i1t}\left(P_{i1t} - P'_{i2t}\right) + \left(D_{i2,t} + E\left[T'_{i2,t}|\Omega^D_{i2,t}\right]\right)\left(P_{i3t} - P_{i2t}\right) \\ &\quad + T'_{i2t}\left(P_{i3t} - P_{i2t}\right). \end{aligned} \tag{5.B.2}$$

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

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

$$\begin{aligned} T_{i2t} &= D_{i2t} - I_{i1t} + E\left[T'_{i2t}|\Omega^D_{i2t}\right] \\ &= D_{i2t} + c_{i1t} + E\left[T'_{i2t}|\Omega^D_{i2t}\right], \end{aligned} \tag{5.B.3}$$

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

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

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

respectively:

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

5.B.1 Equilibrium prices

Equilibrium prices are given by

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

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

$$E\left[c_{i1,t} + D_{i2,t}\left(P_{1,t}\right)|\Omega_{1,t}\right] = 0 \tag{5.B.6}$$
$$E\left[\sum_{i=1}^{N}\left[c_{i1,t} + D_{i2,t}\left(P_{2,t}\right)\right]|\Omega_{1,t}\right] = 0 \tag{5.B.7}$$
$$E\left[\sum_{i=1}^{N} c_{i1,t} + c_{3,t}\left(P_{3,t}\right)|\Omega^P_{3,t}\right] = 0. \tag{5.B.8}$$

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

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

$$c_{3t}\left(P_{3,t}\right) = -\sum_{i=1}^{N} c_{i1t}. \tag{5.B.9}$$

The conjectured trading strategy of dealers equal

$$T_{i2,t} = \alpha c_{i1,t}. \tag{5.B.10}$$

We can now write the sum on the right-hand-side of (5.B.9) in terms of observed interbank order flow:

$$x_t = \sum_{i}^{N} T_{i2,t} = \alpha \sum_{i}^{N} c_{i1,t}$$
$$\sum_{i}^{N} c_{i1,t} = \frac{1}{\alpha} x_t. \tag{5.B.11}$$

Customers' optimal demand follows

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

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

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

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

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

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

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

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

The testable equation is

$$\Delta P_{3,t} = r_t + \pi x_{t-1} + \pi x_t + \rho x_t,\ \rho = 1/\gamma\alpha,\ \pi = \phi/\alpha. \tag{5.B.12}$$

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

5.B.2 Trading strategy

The trading strategy is given by

$$T_{i2,t} = \alpha c_{i1t}. \tag{5.B.13}$$

The problem the dealers must solve is the following:

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

subject to

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

This utility function has the convenient property of maximizing its expectation, when variables are normally distributed, i.e. that $W \sim N\left(\mu, \sigma^2\right)$, is equivalent to maximizing[12]

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

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

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

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

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

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

Hence, I can write the problem as

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

The first-order condition is

$$2\lambda D_{i2t} + c_{i1t} - \theta\sigma^2 D_{i2t} = 0, \tag{5.B.14}$$

which implies a speculative demand of

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

Trading then becomes

$$T_{i2} = D_{i2t} + c_{i1t} = \left(\frac{1}{\theta\sigma^2 - 2\lambda} + 1\right)c_{i1t} = \alpha c_{i1t}. \tag{5.B.15}$$

The second-order condition,

$$2\lambda - \theta\sigma^2 < 0 \Rightarrow \theta\sigma^2 - 2\lambda > 0, \tag{5.B.16}$$

ensures that $\alpha > 1$.

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