A Market Microstructure Analysis of FX Intervention in Canada

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Abstract

Central banks have used foreign exchange intervention to influence both the level and volatility of nominal exchange rates, but evidence suggests that these policies do not usually have their desired impact. The effectiveness of intervention policies depends largely on the ability of the monetary authority to predict the market's reaction to different intervention schemes. Market microstructure models may provide us with a deeper understanding of why intervention policies have not worked. This paper investigates the relationship between the behaviour of traders and the effectiveness of foreign exchange intervention using a unique dataset collected by the Bank of Canada that dissaggregates trades by dealer and by type of trade. The results in this paper suggest that the impact of central bank intervention is partially determined by market-wide order flows generated subsequent to intervention operations. These flows are caused by dealers who find that central bank intervention operations, much like other customer orders, are informative from an information standpoint.

***Keywords**:* Central bank intervention, Market microstructure, Nominal exchange rates

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1. Introduction

While most studies[2] suggest that central bank intervention operations can influence both the level and the variance of the nominal exchange rate, empirical evidence[3] indicates that these policies do not usually have their desired impact. In general, the effectiveness of intervention policies depends largely on the ability of the monetary authority to predict the market's reaction.

A natural starting point in any study of the effectiveness of intervention operations is the formulation of a model of the exchange rate that correctly predicts or explains dynamics in the foreign exchange (FX) market. In fundamental models of exchange rate, macroeconomic variables such as interest rates, money supplies, gross domestic products, trade account balances, and commodity prices have long been perceived as the determinants of the equilibrium exchange rate. The foreign exchange market in fundamental models of the exchange rate is classified as a highly liquid market where all information is public, and traders in the market share the same expectations with no informational advantage over each other. However, research on exchange rate movements has generated results contradicting these models. Empirical studies (Meese and Rogoff, 1983) show that macroeconomic variables perform poorly in explaining short-run exchange rate movements.

Market microstructure models, applied widely across equity and fixed income markets,[4] may provide us with a better understanding of exchange rate dynamics and why intervention policies have not worked. However, market microstructure models have been slow to develop in the area of foreign exchange intervention.[5] This is surprising since many of the arguments for intervention are firmly grounded in market microstructure theory. Microstructure models make explicit that the behaviour of dealers and other market participants, impacts on the effectiveness of intervention operations conducted by central banks. Information dissemination and inventory adjustment are two examples in which dealer behaviour affects price determination in the foreign exchange market. This paper investigates the relationship between the behaviour of traders and foreign exchange intervention flows between the a central bank and FX dealers using a unique dataset collected by the Bank of Canada that dissaggregates trades by dealer and by type of trade. The dataset provides an additional dimension of interest in that it covers two sample periods in which the Bank engaged in very different foreign exchange operations. In the first period, the Bank of

2. See Shwartz (2000) for a recent review of the literature and a record of past intervention episodes.
3. In Canada, Beattie and Fillion (1999) and Murray et al. (1997) test the effectiveness of foreign exchange intervention.
4. See O'Hara (1995) and Madhavan (2000).
5. Recent papers include Dominguez (1999) and Evans and Lyons (2000).

Canada intervened in the foreign exchange market in an attempt to influence the volatility of the exchange rate. In the second sample, we consider its most recent operations, the replenishment of foreign exchange reserves. In this latter period, the Bank's objective was to replenish with little or no impact on the Canadian-US nominal exchange rate.

The results in this paper confirm the finding that central bank intervention has a significant impact on the level of the exchange rate, but not necessarily the volatility of the exchange rate. More importantly, the impact on exchange rates is partially determined by market-wide order flows generated subsequent to central bank operations. These market-wide order flows are a key feature of market microstructure models. Furthermore, trade flows and exchange rate dynamics generated subsequent to central bank trades in the two sample periods are significantly different from each other, lending support to the signalling-type hypotheses of foreign exchange intervention. Finally, central bank trade flows are not dissimilar from other customer flows in terms of their impact on dealer behaviour.

2. Microstructure Models

The failure of the traditional models in explaining exchange rate movements, and more specifically, the role that information plays in determining these movements suggests that a new approach is required. A new direction of research is proposed in Lyons (1997). He argues that exchange rate models should focus on information and institutions, where information incorporates both public and private information, and institutions refers to how the market is organized and how market participants learn and aggregate non-public information. Unlike fundamental FX models, the microstructure approach addresses the existence of private information and focuses on how this information is mapped into expectations of exchange rate movements.

Two examples of private information in the foreign exchange market are order flow information and private information about central bank intervention. Order flow information arises when dealers execute customers' orders and these orders provide information that is not available to other dealers. In microstructure models, order flow is almost always an integral part of determining price. Private information of central bank intervention is relevant to dealers because a dealer who receives a central bank's order has also received a private signal from the central bank concerning future monetary and intervention policies. Microstructure analysis postulates that credible signals from the central bank may influence market participants' expectations and may possibly explain short-term exchange rate movements.

One difficulty with macroeconomic models is the assumption made in these models that prices are set by the hypothetical Walrasian auctioneer. Specifically, fundamentally relevant information in news announcements is embedded into prices instantaneously. In actual markets, traders recognize that prices may also be related to more transitory liquidity effects, and in particular, the market clearing mechanism will have important effects on the behaviour of prices and trades, a complication virtually ignored in the macroeconomic literature. The trading mechanism does matter because it determines how trades affect prices, which, in turn, affects trading strategies. The order flow view of price determination predicts a continuous price path as the market gradually learns about changes in the overall market view from order flow. This aggregation of market views is in sharp contrast to the traditional view that dealers can simply infer changes in market expectations from the macro announcement itself. For example, market expectations of future macro variables are difficult to measure empirically. Given how important these expectations are for exchange rate determination it is perhaps not surprising that macro empirical models do so poorly. Microstructure variables, in particular order flow, may provide a much more accurate measure of variation in market expectations.

3. Foreign Exchange Intervention in Canada

In Canada, recent intervention policy has sought to reduce the short-term volatility of the Canadian dollar-US dollar exchange rate. Uncertainty among market participants about the future stance of monetary policy and extrapolative expectations of chartists are two possible causes of excessive volatility. Inadequate market liquidity is another explanation, though this is less of an issue today as the Canadian dollar is actively traded on a global basis.

There are a number of mechanisms through which intervention by the Bank of Canada[6] might affect the exchange rate. First, a change in the composition of the outstanding stock of domestic and foreign assets may induce investors to adjust their portfolios. This rebalancing of portfolios will affect the demand for foreign and domestic currencies and require an adjustment in the exchange rate. Second, providing additional liquidity to the market when trading activity is thin, usually during periods of market uncertainty, could ensure that the FX market is operating efficiently and prevent large swings in the exchange rate. Third, by altering the technical outlook for the currency, the Bank of Canada can avoid the emergence of extrapolative expectations amongst chartists that can generate rapid movements in the exchange rate. Lastly, intervention activities can also convey information about the current or future course

6. Intervention is usually sterilized, having no effect on the monetary base, only a change in the relative composition of Government of Canada domestic and foreign assets.

of domestic monetary policy. This signal, if credible, may reduce market uncertainty and excessive exchange rate volatility.

On April 12, 1995, the Bank of Canada adjusted its intervention program guidelines. Dollar sums used for intervention were raised, non-intervention exchange rate bands were widened, and non-intervention bands were rebased automatically at the end of each business day. The purpose of these new guidelines was to make intervention more effective at reducing exchange rate volatility and more consistent with maintaining orderly markets.

In a regression model, Murray, Zelmer and McManus (1996) test whether Canadian FX intervention lessened volatility[7] of the Canadian dollar-U.S. dollar exchange rate over the period January 2, 1992 to June 30, 1996. This period overlaps both old and new intervention programs. The authors use daily data on intervention levels and exchange rate volatilities in their analysis. A number of macroeconomic and financial time series variables are also included in the analysis to control for the effects of macroeconomic announcements and changing economic conditions on exchange rate volatility. The intervention data is divided into three sub-categories: expected intervention, unexpected light intervention and unexpected heavy intervention. Unexpected, or discretionary intervention, occurs when the Bank of Canada rebases its non-intervention bands to make intervention more likely in one direction. Although not officially revealed, details of the new and old intervention programs are assumed to be known to market participants. Under the old program guidelines, none of the intervention variables were found to be significant. After the new intervention guidelines were introduced, unexpected heavy intervention was slightly effective at stabilizing the exchange rate. The authors also find that intervention that was anticipated by the market failed to reduce the volatility of the Canadian dollar-US dollar exchange rate under both old and new programs.

Beattie and Fillion (1999) also test the effectiveness of Canada's FX intervention program but make one major change in methodology: the authors investigate whether high frequency data is better able to capture the effect of intervention on volatility. A two-and-a-half year sample of ten minute data is accumulated from April 12, 1995 to January 30, 1998. The time span of the data falls exclusively on the period after the new intervention guidelines were introduced.

The estimated equations in the model explain volatility[8] in terms of four factors: intraday seasonal patterns, daily volatility persistence, macroeconomic news announcements, and the impact of intervention.

7. Implied volatility, calculated from options market data, is employed as a measure of expected volatility.
8. Volatility in Beattie and Fillion (1999) is estimated using a GARCH (generalized autoregressive conditional heteroskedasticity) methodology.

Controlling for the systematic everyday patterns in the nominal exchange rate is extremely important if valid inferences are to be made about the effectiveness of intervention. In general, macroeconomic news announcements are included in the analysis because they are capable of generating large surprises in the market.

As in the previous study, Beattie and Fillion find that expected intervention had no direct impact on volatility while discretionary unexpected intervention did reduce exchange rate volatility. Furthermore, over a short period of time, repeated unexpected intervention in the market was effective.

In theory, non-intervention bands should have a stabilizing effect on the exchange rate if the bands are credible and defendable. Consider the special case of a fixed exchange rate: a non-intervention band with equal upper and lower bounds. If the fixed exchange rate is credible and defended by the monetary authority, there will be no variability in the exchange rate. The regression analysis of Beattie and Fillion does indicates that intervention bands were only marginally stabilizing.

In general both papers reach the same conclusion: non-discretionary intervention has no effect on volatility, while discretionary intervention can have a small influence. If intervention is consistent with the underlying fundamentals of the economy, volatility of the exchange rate may be reduced if any uncertainty is resolved. On the other hand, if intervention is not credible or has multiple objectives it only creates confusion in the market.

4. Institutional Considerations

The foreign exchange (FX) market refers to the market where buyers and sellers trade different kinds of foreign currencies. In Canada, the foreign exchange market is composed of spot, forward, futures, options and swap transactions. The main element of the FX market is the spot market. This market is described as a decentralized multiple dealership market since it does not have a physical location where the dealers meet, but instead it is a network of financial institutions or investors linked together by high speed communication devices such as telecommunication system and computer.

Two important characteristics that distinguish FX trading from trading in other markets are that trades between dealers account for most of the trading volume in FX markets, and secondly, trade transparency is low. Order flow in the FX market is not transparent, as there are no disclosure requirements. Consequently trades in this market are not generally observable, so that the trading process is less informative and the information reflected in prices is reduced. Therefore private payoff information can be exploited for a longer amount of time.

The players in the FX market include dealers, customers and brokers. Dealers provide two-way prices to both customers and other dealers. In Canada, the top eight banks handle nearly all order flow (87%) in the spot market. Dealers receive private information through their customer's orders. Each dealer will know their own customer orders through the course of the day, and will try to deduce the positions of other dealers in the market. The customers are those financial and non-financial corporations who are the end-users of foreign currencies for settling imports or exports, investing overseas, hedging business transactions or speculating. Brokers are the intermediaries who gather buy and sell information and try to match the best orders among dealers. Brokers in the FX market are involved only in interdealer transactions, where they communicate dealer prices to other dealers without revealing the dealers' identities, as would be necessary in an interdealer trade. Brokers are pure matchmakers, they do not take positions on their own.

In addition to their own customers, dealers also learn about order flow from brokered interdealer trades. When a transaction exhausts the quantity available at the advertised bid/ask, the broker announces this fact. This indicates that a transaction was initiated. Though the exact size is not known, dealers have a sense of the typical size. Most importantly, this is the only public signal of market order flow in the FX market.

Intervention can be narrowly defined as any official central bank sale or purchase of foreign assets against domestic assets in the foreign exchange market. Between January 1992 and April 1995, the Bank of Canadian was a regular intervener in the foreign exchange market. The intervention practices were designed to provide resistance to all exchange rate movements that lay outside a relatively narrow non-intervention band. The guidelines that became effective April 1995 adopted a widened non-intervention band and a rebase of the band based on closing rate on each day, which contributed to less frequent intervention. According to the April 1995 guidelines, Canadian authorities also decomposed the intervention program into two components, one mechanical and the other discretionary. The aim of this hybrid program was to promote an orderly market by leaning against the prevailing exchange rate trend while at the same time providing greater flexibility for authorities to intervene. By late 1998, authorities had dropped mechanical intervention leaving only discretionary intervention. With the exception of a coordinated effort by the Bank of Japan, U.S. FED, the Bank of England, the ECB and the Bank of Canada to defend the euro in September 2000, the Bank of Canada has not intervened since 1998 and all recent purchases of foreign currencies are only replenishments of foreign currency reserve.

5. Data

The primary source of data employed in this paper is the Bank of Canada's Daily Foreign Exchange Volume Report. The report is co-ordinated by the Bank of Canada, and organised through the Canadian Foreign Exchange Committee (CFEC). It provide details about daily foreign exchange trading volumes by dealer in Canada.

The dataset covers nearly four years of daily data (January 1996 through September 1999) or 941 observations for the eight largest Canadian foreign exchange market participants. Trading flows (in Canadian dollars) are categorized by the institution type of each dealer's trading partners. Business transactions for Canadian FX dealers are broken down as follows: Commercial client business (CC) includes all transactions with resident and non-resident non-financial customers; Canadian-domiciled investment flow business (CD) are transactions with non-dealer financial institutions located in Canada, regardless of whether or not the institution is Canadian-owned; foreign-domiciled investment business (FD) includes all transactions with financial institutions, including FX dealers, located outside Canada; and lastly, interbank (IB) business includes transactions with the domestic offices of other Canadian chartered banks, plus transactions with other financial institutions, such as credit unions, investment dealers, and trust companies, that are dealt with on a reciprocal basis in the interbank market.

Trade flows, or more specifically, net purchases of outright spot trades, are defined in this manner in an attempt to distinguish between trade-related and capital-related flows. The "type" of institution is used as a proxy for the type of transaction. In particular, commercial client business is defined so that there is particular emphasis on FX transactions related to commercial, or trade-related, activity. On the other hand, Canadian-domiciled investment flow business and foreign-domiciled investment business emphasize the investment, or capital, flow nature of these transactions.

Foreign exchange rate returns for the Canadian/US exchange rate are continuously compounded returns, defined as the log difference of the exchange rate determined at close of each business day. The measure of exchange rate volatility used in this paper is the implied volatility contained in foreign exchange options prices. This measure is a proxy for the expected volatility of the Canadian/U.S. exchange rate. Murray et al. (1997) state that "the advantage of this option-based approach over GARCH models is that it uses current market-determined prices that reflect the market's true volatility forecast, rather than a time-series model that is based on an assumed relationship between future volatility and past exchange rate movements."

6. Stylized Facts

Tables 1 through 7 present various descriptive statistics for the Can$/US$ exchange rate and each order flow in the Canadian foreign exchange market. The data is split in to three samples. The subsample used in the empirical tests throughout the paper were chosen on the basis of pre-announced intervention regime changes and data availability. The first sample includes the period January 2, 1996 to September 30, 1998. During this period, the Bank of Canada had laid out intervention objectives and procedures that, although not publicly announced, were well known by the market. The subsequent period, starting October 1, 1998 to September 30, 1999, was a period in which the Bank of Canada did not intervene in the foreign exchange market in order to have an impact on exchange rates, but rather a period in which the Bank of Canada was involved in numerous transactions in the foreign exchange market in an attempt to replenish its foreign exchange reserves. The last sample covers the whole period January 2, 1996 to September 30, 1999---a total of 942 observations.

During the first sample, the Bank of Canada intervened 80 days out of the 692 total days (12 percent of all business day)s. This compares with the second sample in which the Bank replenished reserves 79 days out of a possible 250 days (32 percent of all business days). In the earlier sample, 30 of the 80 days were occasions where the Bank used discretionary intervention. The Bank of Canada sold U.S dollars on 69 days and bought Canadian dollars on 11 days.

Tables 1 reports descriptive data about the aggregate foreign exchange market and the eight dealers studied. The dealers are ranked from 1 to 8 by average total daily trading volumes (purchases+sales) in the spot market over the 942 daily observations, with dealer 1 being the most active and dealer 8 the least active in the Canadian foreign exchange market. The mean, standard deviation, and median, from the frequency distribution of a particular descriptive statistic are each listed. Medians are listed in addition to means and standard deviations because they are informative in skewed distributions.

Trading volumes, trading imbalances are presented in each table, which is then further broken down by type of business transaction (all types, CB, CC,CD, FD, IB). Correlations between key variables, over each period are presented in Tables 2-4.

The statistics in Tables 5-7 indicate that skewness and kurtosis are generally significant over all variables. Percentage change in the exchange rate data consistently exhibits a high degree of kurtosis over all subsamples. The Box-Pierce Q-statistic tests for high-order serial correlation generally indicate that both the change and squared percentage changes in the exchange rate series exhibit significant autocorrelation.

The latter is indicitive of strong conditional heteroscedasticity. The first four sample autocorrelation and partial autocorrelation coefficients for the exchange rate series indicate homogenous nonstationarity. The first lag of the sample partial autocorrelation is approximately one, and subsequent lags are close to zero. The statistics confirm that daily exchange rates are strongly heteroskedastic martingale processes. These findings are consistent with the previous literature. Standard Dickey-Fuller unit roots tests are performed on all variables (Tables 8 and 10). Prices and the implied volatility variable were found to be non-stationary. In contrast, the hypothesis of a unit root in daily order flows is rejected in both periods.

7. Econometric Analysis

7.1 Is Order Flow Important?

Why should order or trade flows matter when determining or predicting movements in the exchange rate? In Section 7.2, a market microstructure model is presented to demonstrate how order flow and exchange rates can be determined jointly in equilibrium. In this section, we draw only on the casual link from order flow to exchange rates.

The idea that order flow matters is inspired by some striking empirical results provided by Lyons (1999). He finds that market wide order flow in the spot FX market (DM/$ and Yen/$), when cumulated over time, exhibited large and persistent departures from zero, and that order flow covaries positively with the exchange rate over horizons of days and weeks. Recall, that macro fundamental models provide no role for trading, since marcoeconomic information is publicly available and can therefore be impounded in exchange rates without trading. Lyons provides further statistical evidence in the spirit of traditional tests of structural models of exchange rate. A similar exercise is performed in this paper. In a regression equation, order flow (x_t) is included as a regressor, in addition to traditional variables employed by the Bank of Canada, such as the overnight interest rate differential, oil prices, natural gas prices, and non-energy commodity prices. All variables except interest rates and order flows are in log-levels:

$$\Delta \log e_t = a_0 + a_1(i_t' - i_t) + a_2\Delta oil_t + a_3\Delta gas_t + a_4\Delta non\text{-}eneregy_t + a_5 x_t + u_t . \qquad \text{(EQ 1)}$$

Regressions of this sort have long been the subject of study in the macro exchange rate literature (see Frankel and Rose (1995)). If the macro approach is correct, estimates of a_5 should be insignificant. Lyons (1999) finds that they are in fact quite significant, suggesting that there is something to the microstructure approach to exchange rates. Here trade flows related to total net trade, interdealer net trade, and various customer dealer net trade flows are found to be highly significant in explaining movements in exchange rates.

Fitting a model, in-sample, is one thing. Forecasting out-of-sample is quite another, as many researchers have found. The evaluation criterion used in this paper was also used by Meese and Rogoff (1983) to evaluate a model's forecasting performance. The root-mean squared forecast error (RMSE) of a model is

$$\left[\frac{1}{T}\sum_{t=k+1}^{T}(\Delta\hat{\log}e_t - \Delta\log e_t)^2\right]^{\frac{1}{2}}. \qquad \text{(EQ 2)}$$

The out-of-sample forecasts generated by the model are later compared to that of a random walk. The model is initially estimated over part of the sample (the first k periods). Forecasts are then generated over the different time horizons of interest. After, a new observation is added to the sample (period $k+1$), the model is re-estimated, and again forecasts are generated. The process continues until the point in the sample in which it becomes impossible to forecast over all time horizons considered. A useful summary measure of the forecast performance of the model in the context of the RMSE is the Theil-U statistic which is just the ratio of the model's RMSE to the random walk's RMSE. A value less than one implies that the model performs better than a random walk, whereas a value greater than one implies the reverse. It should be noted that the forecasts are conditional on ex-post information on future fundamentals and order flows.

7.2 Simultaneous Interdealer Trading Model

The following model is based on Lyons' (1997) simultaneous trade model of the foreign exchange "hot potato." Although, customer trades drive interdealer trading, it is the subsequent multiple periods of interdealer trading that provide real insight into the dynamics of the foreign exchange market. The model includes n dealers who behave strategically and a large number of competitive customers who are assigned to these dealers. All dealers have identical negative exponential utility defined over terminal wealth. After an initial round of customer-dealer trades, there are two rounds of interdealer trading. The interdealer trading rounds correspond to the two periods of the models. A key feature of the models is that trading within a period occurs simultaneously. Simultaneous trading has the effect of constraining dealers' conditioning information: within any period dealers cannot condition on that period's realization of others' trades. Constraining conditioning information in this way allows dealers to trade on information before it is reflected in price.

There are two assets, one riskless and one risky. The payoff on the risky asset is realized after the second round of interdealer trading, with the gross return on the riskless asset normalized to one. The risky asset is initially in zero supply and has a payoff of F, where $F \sim N(\bar{F}, \sigma_F^2)$.

The seven events of the model occur in the following sequence (See Figure 1):

Period One:

1. Dealers quote
2. Customers trade with dealers
3. Dealers trade with dealers
4. Interdealer order flow is observed

Period Two:

5. Dealers quote
6. Dealers trade with dealers
7. Payoff F realized

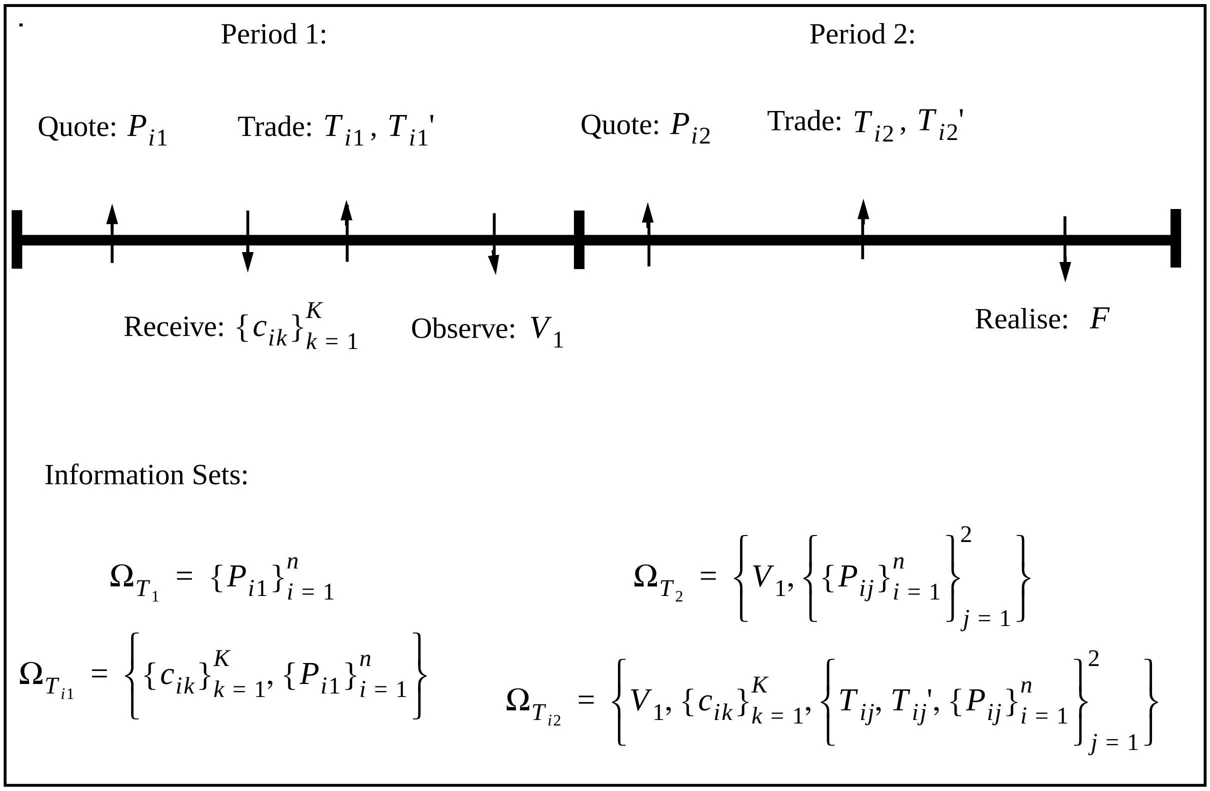
7.2.1 Customer Trades

Customer market orders are not independent of the payoff to the risky asset F. They occur in period-one only, and are cleared at the receiving dealer's period-one quote P_{it}. As opposed to the Lyons (1999) model, there are a number of customer "types." For example, commercial clients, non-dealer financial institutions and central banks are all customers of dealers in the FX market. Each customer trade is assigned to a single dealer, resulting from a bilateral customer relationship. The net type-*k* customer order received by a dealer-*i* is

$$c_{ik} = F + \varepsilon_{ik} \qquad \varepsilon_{ik} \sim N(0, \sigma_{ik}) \qquad \forall k = 1 \ldots K. \qquad \text{(EQ 3)}$$

c_{ik} is positive for net customer sales and negative for net purchases. Customer trades provide a noisy signal about the unobserved payoff to the risky asset. Customer trades, c_{ik}, are not observed by other dealers. They are private information in the model. In the foreign exchange market, dealers have no direct information about other banks' customer trades.

FIGURE 1. Timing of Simultaneous Trade Model



7.2.2 Quoting Rules

In both periods, the first event is dealer quoting. Let P_{it} denote the quote of dealer i in period t. The rules governing dealer quotes are:

1. Quoting is simultaneous, independent, and required
2. Quotes are observable and available to all participants
3. Each quote is a single price at which the dealer agrees to buy and sell any amount

Simultaneous moves in the foreign exchange market, for example, occur through electronic dealing products that allow simultaneous quotes and simultaneous trades. The key implication of Rule 1 is that P_{it} cannot be conditioned on P_{jt}. The rule that specifies that quotes are required is consistent with the fact that in actual multiple dealer markets, refusing to quote violates an implicit contract of reciprocal immediacy and can be punished by reciprocating with refusals in the future. Rule 2 implies that there is costless search to find the best quote, while the last rule prevents a dealer from exiting the game at times of informational disadvantage.

7.2.3 Interdealer Trading Rules

The model's two-period structure is designed around the interdealer trading that occurs in each period. Let T_{it} denote the net outgoing interdealer order placed by dealer i in period t and let T_{it}' denote the net incoming interdealer order received by dealer i in period t, placed by other dealers. T_{it}' is positive for purchases by other dealers from dealer i. The rules governing interdealer trading are as follows:

4. Trading is simultaneous and independent and independent
5. Trading with multiple partners is feasible
6. Trades are directed to the dealer on the left if there are common quotes at which a transaction is desired (dealers are arranged in a circle)

Rule 4 generates an role for T_{it}' in the model because interdealer trading is simultaneous and independent: T_{it} is not conditioned on T_{it}'. This means that T_{it}' is an unavoidable disturbance to dealer i's position in period t that must be carried into the following period.

Consider now the determination of dealer i's outgoing interdealer orders in each period. Letting D_{it} denote dealer *i*'s speculative demand we have

$$T_{i1} = D_{i1} - \sum_k c_{ik} + E_{i1}T_{i1}' \quad \text{(EQ 4)}$$

$$T_{i2} = D_{i2} - D_{i1} + T_{i1}' - E_{i1}T_{i1}' + E_{i2}T_{i2}' \quad \text{(EQ 5)}$$

where $E_{i1}T_{i1}' = E[T_{i1}'|\Omega_{T_{i1}}]$, $\Omega_{T_{i1}}$ denotes dealer *i*'s information set in period *1*, and T_{it}' denotes the net incoming interdealer order received by dealer *i* in period *t*. Public and private information sets are defined in Figure 1. The top two sets include publicly available information at the time of interdealer trading in each period. The second two information sets include public and private information available to each dealer-*i* just before interdealer trading in that period.

Notice in (EQ 4) that when dealers are determining their out-going trade, they must consider both their desired amount, D_{it}, determined by private information, but also incoming c_{ik}'s and $E_{i1}T_{i1}'$. Trades with customers must be offset in interdealer trading to establish a desired position D_{it}. Dealers also do their best to offset the incoming dealer order T_{i1}' (which they cannot know ex-ante due to simultaneous trading). In period-two, inventory control has four components, three from the realized period-one position and one from the offset of the incoming T_{i2}'.

7.2.4 The Last Period-One Event: Interdealer Order Flow Observed

An additional element of transparency in the model is provided at the close of period-one to all dealers. Period-one interdealer order flow, V_1, is observed

$$V_1 = \sum_{i=1}^{n} T_{i1} \qquad \text{(EQ 6)}$$

The sum over all interdealer trades, T_{i1}, is net interdealer demand -- the difference in buy and sell orders. In foreign exchange markets, V_1 is the information on interdealer order-flow provided by interdealer brokers.

7.2.5 Dealer Objectives and Information Sets

Each dealer determines quotes and speculative demand by maximizing a negative exponential utility function defined over terminal wealth. Letting W_{it} denote the end-of-period t wealth of dealer i, we have

$$\underset{\{P_{ij}, T_{ij}\}_{j=1}^{2}}{Max} E_i[-\exp(-\theta W_{iFinal})] \qquad \text{(EQ 7)}$$

subject to

$$\begin{aligned} W_{i1} &= W_{i0} + P_{i1}\left[-\sum_k c_{ik} + T_{i1}'\right] - P_{i1}'T_{i1} \\ W_{i2} &= W_{i1} + P_{i2}T_{i2}' - P_{i2}'T_{i2} \\ W_{iFinal} &= W_{i2} + F\left[(T_{i1} - T_{i1}') + (T_{i2} - T_{i2}') + \sum_k c_{ik}\right] \end{aligned} \qquad \text{(EQ 8)}$$

or

$$W_{iFinal} = W_{i0} - (P_{i1} - F)\sum_k c_{ik} + \sum_j^2 (P_{ij} - F)T_{ij}' - \sum_j^2 (P_{i1}' - F)T_{i1} . \qquad \text{(EQ 9)}$$

Equivalently, by substituting (EQ 4) and (EQ 5) into (EQ 9), we can define the problem in terms of desired positions instead of out-going trades:

$$\underset{\{P_{ij}, D_{ij}\}_{j=1}^{2}}{Max} \; E_i[-\exp(-\theta W_{iFinal})] \qquad \text{(EQ 10)}$$

$$W_{iFinal} = W_{i0} - (P_{i1} - P_{i1}')\sum_k c_{ik} + (D_{i1} + E_{i1}T_{i1}')(P_{i2}' - P_{i2}) \qquad \text{(EQ 11)}$$
$$+ (D_{i2} + E_{i2}T_{i1}')(F - P_{i2}') + T_{i1}'(P_{i2}' - P_{i1}) - T_{i2}'(F - P_{i2})$$

7.2.6 Equilibrium Quoting Strategies

The equilibrium concept used in this paper is that of a Perfect Bayesian Equilibrium, or PBE. Under PBE, Bayes rule is used to update beliefs, while strategies are sequentially rational given those beliefs. Quotes must be common to avoid arbitrage under risk aversion and in light of the quoting rules and trading rules discussed above. The actual derivation of the PBE is provided in Lyons (1997). Below, equilibrium quotes and trades are specified, but only intuition is supplied.

$$P_1 = \bar{F} \qquad \text{(EQ 12)}$$

$$P_2 = \bar{F} + \lambda V_1 \qquad \lambda > 0 \qquad \text{(EQ 13)}$$

Since prices in both periods are common across dealers and conditioned only on public information, the only variable in Ω_{T_2} relevant for determining period-two's price is V_1, interdealer order flow from period-one. With common prices, the dealer trading rules in each period (equations (EQ 4) and (EQ 5)) pin down the equilibrium price in each period once conditioned on public information.

Consider the following intuition for why $\lambda > 0$. Each agent knows one component of V_1, specifically their own outgoing trade, which is a function of period-1 customer orders. A negative observed V_1 means that, on average, T_{j1} is negative -- dealers are selling in interdealer trading. This implies that, prior to interdealer trading, customers sold on average. Dealers are long on average in period-2. To clear the market, the expected return on holding foreign exchange must be positive to induce dealers to hold this long position $P_2 < \bar{F}$. The end result is that the negative V_1 drives a reduction in price.

7.2.7 Equilibrium trading strategies

The derivation of trading strategies is tedious and the reader should refer to Lyons (1997) for additional information. In summary, the dealer's problem must be framed as a maximization over realizations of the order flow V_1. Next, because each must dealer needs to account for his own impact on V_1, the problem is redefined again, now over a random variable that is independent of a dealer's own actions. In equilibrium

$$T_{i1} = \sum_k \beta_{1k} c_{ik} \qquad \beta_{1k} < -1 \qquad \forall k. \tag{EQ 14}$$

$$T_{i2} = \sum_k \beta_{2k} c_{ik} + \beta_3 T_{i1}' + \beta_4 (P_2 - \bar{F}) + \beta_5 V_1 \tag{EQ 15}$$

Consider the case that a trader receives a customer order, c_{ik}. If the trader only sought to hedge his risk, he would cover his position $T_{i1} = -c_{ik}$. But suppose that $V_1 = \sum_i T_{i1} < 0$. In this case, on average all traders want to sell. To compensate for additional risk of holding on to the asset, prices must fall $P_2 < \bar{F} = P_1$. Knowing this, the agent strategically alters his out-going order to capitalize on the higher return by choosing $T_{i1} > -c_{ik}$.

7.3 VAR Analysis

Modelling all features of the foreign exchange market jointly is impractical. This section strives to determine the impact of trades on exchange rates and volatility in a framework that is robust to deviations from the assumptions of a formal model like the simultaneous trade model laid out above. In the process, the framework establishes a rich characterisation of the dynamics by which trades and prices interact.

The framework of vector autoregressions (VARs) is employed in this section to address both the source of exchange rate variations, and whether these variations are permanent or transitory. From an economic perspective, market prices can be interpreted as a informationally efficient prices corrupted by perturbations attributable to the frictions of the trading process. New fundamental information imparts a permanent revision to the expectation of the exchange rate, while microstructure effects are short-lived and transient. The response of exchange rates to a buy order will depend on the chances that the trade was initiated by positive information known by the buyer, but unknown to the public. The proportion of the permanent price movement that can be attributed to trades is therefore related to the degree of information asymmetry in the market. From a statistical viewpoint, it is measured by the explanatory power of trade related variables in accounting for exchange rate variations. The transitory effects of a trade are perturbations induced by the trade that drive the current rate away from the corresponding informationally accurate permanent component price. Inventory control considerations induce transitory effects, as does order fragmentations or even private information about a dealer’s inventory (D’Souza (2000b)).

The VAR methodology also allows a proper examination of the relationship between trade flows. Of particular interest are the flows generated among dealers (both domestic and foreign) subsequent to customer trades. If tests indicate that interdealer flows are a necessary requirement to make the VAR complete, or that these flows are not exogenous, then this is evidence of the of the microstructure view.

Numerous studies have already examined the dynamics of trades and stock prices (see Hasbrouck (1988, 1991, 1993), Glosten and Harris (1988), Hasbrouck and Sofianos (1993), and Madhaven and Smidt (1991, 1993)). A common approach of these studies is to assess the impact of trades on stock price, where any persistent impact presumably stems from the asymmetric fundamental information signalled by trades. By examining trade flows in the Canadian foreign exchange market, this paper extends these studies in the direction of assessing the information content of the underlying determinants of trades.

The impact of the various trade flows on exchange rate returns cannot be judged from a linear regression of returns on current and lagged flows because flows and returns are endogenous. For example, while an unexpected purchase of foreign exchange by a customer can lead to trade flows and exchange rate changes, the causality can also work in the other direction: an unexpected increase in the exchange rate can influence customer purchases. Thus, while a linear regression might give some insight into the expected return conditional on a given pattern in trade flows, it will not support inference about the implied effect of a particular trade. In the present application, this limitation would preclude identification of the exchange rate effects attributable to the customer order.

This section describes a vector autoregression (VAR) that captures the dynamic relations among the variables and allows for lagged endogenous effects. The most useful statistics from this approach are 1) impulse response functions, which are used to access the price impact of various trade flow types, and 2) variance decompositions, which measure the relative importance of the variables in driving exchange rate returns. Here we can judge the impact of different customer flows and the subsequent interdealer flows, on exchange rate returns and volatility.

A VAR is a linear specification in which each variable in the model is regressed against lags of all variables. Letting z_t denote the column vector of model variables,

$$z_t = [c_t, FD_t, IB_t, \sqrt{trad}, returns_t], \qquad \text{(EQ 16)}$$

the VAR specification may be written:

$$z_t = A_1 z_{t-1} + A_2 z_{t-2} + \ldots + A_K z_{t-K} + \nu_t \qquad \text{(EQ 17)}$$

where the A_i's are coefficient matrices, K is the maximum lag length, and ν_t is a column vector of serially uncorrelated disturbances (the VAR innovations) with variance-covariance matrix Ω. c_t is either commercial client trade flow (CC), Canadian domiciled trade flow (CD), or central bank trade (CB), while returns are either exchange rate returns or percent changes in implied volatility. Foreign domiciled trade flows (FD) are entered separately in the VAR. These flows include trade with foreign FX dealers, who receive their own customer orders for Canadian dollars. Estimates of VAR coefficients and associated variance-covariance matrices may be obtained from least-squares. Textbook discussions of vector autoregressions and related time-series techniques used in this paper are given in Judge et al. (1988) and Hamilton (1994).

In summarizing the behaviour of the model, impulse response functions are often more useful than the VAR coefficients. The impulse response functions represent the expected future values of the system conditional on an initial VAR disturbance ν_t and may be computed recursively from equation (EQ 17) as

$$\begin{aligned} E[z_t|\nu_t] &= \nu_t \\ E[z_{t+1}|\nu_t] &= A_1\nu_t = \Phi_1\nu_t \\ E[z_{t+2}|\nu_t] &= (A_1^2 + A_2)\nu_t = \Phi_2\nu_t \\ &\text{etc.} \end{aligned} \quad \text{(EQ 18)}$$

where the Φ_i are the impulse coefficient matrices (Hamilton, pp. 318-324). Since most of the variables in the present model are either flows or changes, it is also useful to consider cumulative quantities. The accumulated response function coefficients are the Ψ_i implicitly given by

$$\begin{aligned} E[z_t|\nu_t] &= \nu_t \\ E[z_t + z_{t+1}|\nu_t] &= (1 + \Phi_1)\nu_t = \Psi_1\nu_t \\ E[z_t + z_{t+1} + z_{t+2}|\nu_t] &= (1 + \Phi_1 + \Phi_2)\nu_t = \Psi_2\nu_t \\ &\text{etc.} \end{aligned} \quad \text{(EQ 19)}$$

The accumulated response coefficients are continuous functions of the VAR coefficients: $\Psi_i = \Psi_i(A_1, A_2, \ldots)$.

A particularly important component of the accumulated response function is the long-run impact of an innovation on the cumulative (log exchange rate) return. This quantity measures the payoff-relevant information content of the innovation. While numerous microstructure effects may lead to transient effects on the cumulative return, any persistent impact must reflect new payoff information. In terms of the accumulated response coefficient, the cumulative return implied by a particular disturbance may be written:

$$E[r_t + r_{t+1} + \ldots | \nu_t] = \Psi_{\infty, r} \nu_t, \tag{EQ 20}$$

where $\Psi_{\infty, r}$ is the row of the Ψ_∞ matrix that corresponds to the log exchange rate return (the last row as z_t is defined above). If the VAR representation is invertible (a condition that holds for the present estimations), this may be estimated by $\Psi_{\infty, r}$ where n is large enough to approximate convergence.

In the present study, hypothetical initial disturbances will be used to study the impact of particular market events. For example, the arrival of a customer trade to sell 1 million Canadian dollars at time t might be represented by letting $v_t = [1, 0, 0, 0, 0]'$. Setting the remaining components to zero would imply that the order has no contemporaneous impact on trades and returns. While this possibility exists, it is more likely that the order will engender a contemporaneous trade and a price revision. Ignoring the contemporaneous effect will lead to understatement of the implied trade order impact.

The innovation associated with the arrival of a purchase order is considered to be structural in the sense that it refers to the economic structure of the model (rather than its statistical representation). The VAR disturbance, ν_t, implied by a structural innovation is not identified because the VAR does not identify causal links among the contemporaneous structural innovations. Identification requires some assumptions about which variables are allowed to contemporaneously affect others, such as the imposition of a particular contemporaneous recursive structure.

The present analysis assumes that central bank trade disturbances, commercial client trade flows and Canadian domiciled investment flows are each determined before foreign domiciled investment flows, market-wide trade flows, and return disturbances. Assigning primacy to central bank trade, commercial client trade and Canadian domiciled investment disturbances means that the effects of the other disturbances can be considered incrementally, in accordance with the paper's goal of analysing the incremental informational content of trade flows. Subsequent to these flows, foreign domiciled investment flow and domestic interbank innovations are determined. Innovations in net purchases of Canadian dollars in the foreign exchange market, a measure of order-flow, over the day are not permitted to affect the individual trade flows within the day, though they may affect exchange rate returns over the day. Lastly, any unexpected changes in the exchange rate over the day are not permitted to affect any of the other variables over the course of the day. This assumed ordering of the innovations is identical to the ordering in the z_t vector described above.

A variable representing a signal of market order flow is added to the VAR to reflect the information communicated to dealers through brokers (voice-based or electronic brokers). The square-root form ($\sqrt{trad}$) is employed in view of evidence that the price-trade relation is concave in financial markets (Hasbrouck (1991)).

The VAR disturbance may be written as $v_t = Bu_t$, where u_t is a (5×1) column vector of mutually uncorrelated structural disturbances with the property that $\mathrm{Var}(u_{i,t}) = \mathrm{Var}(u_{j,t})$ and B is a lower-triangular matrix with ones on the diagonal computed by factoring the VAR disturbance covariance matrix Ω, subject to the desired ordering of the variables. This is equivalent to modifying equation (EQ 17) to include a contemporaneous term

$$z_t = A_0 z_t + A_1 z_{t-1} + A_2 z_{t-2} + \ldots + A_K z_{t-K} + \nu_t \qquad \text{(EQ 21)}$$

where the A_0 coefficient is lower triangular.

One hypothesis tested in this paper is whether the various trade flows have similar impacts on exchange rate returns. The hypothesis is tested by comparing the average price impact implied by the impulse response functions corresponding to different trade flow innovations. For ease of interpretation, the total size of each innovation is $C 1 million.

In addition to assessing the effect of particular innovations, it is also of interest to consider broader summary measures of the information contained in these trade flows. Intuitively, the left-hand side of (EQ 20) represents the impact of the innovation on the exchange rate net of any transient microstructure effects. The variance of this term is approximately equal to the return variance per unit time, with the return computed over an interval long enough that transient effects can be neglected. Alternatively, the variance term is the variance of the random walk component implicit in the exchange rate. This connection is developed more formally in Hasbrouck (1991b). Denoting this random walk component as w_t, its variance can be computed from (EQ 20) as

$$\sigma_w^2 = var(E[r_t + r_{t+1} + \ldots | \nu_t]) = \Psi_{\infty,r} \Omega \Psi_{\infty,r}'. \qquad \text{(EQ 22)}$$

Since the disturbance covariance matrix will not generally be diagonal, the right-hand side of (EQ 22) will typically involve terms reflecting the contemporaneous interaction of the disturbances. Thus, it is not generally possible to identify a component of σ_w^2 that measure the contribution of each type of innovation.

In standard regression analysis, however, the incremental explanatory power of model variables may be measured by adding these variables sequentially to the specification. The incremental explanatory power of a variable derives from its residual (after linearly projecting it on the variables that preceded it in the specification). This assumption of a particular ordering for the addition of model variables in the general regression case is formally equivalent to the assumption of a particular ordering of contemporaneous effects in the present model.

In the discussion of structural innovations, the assumption was that central bank trade innovations (CB), commercial client trade flow innovations (CC), and Canadian domiciled investment flow (CD) are determined first, followed by foreign domiciled investment flow (FD), market-wide trade ($\sqrt{trad}$), and return disturbances. This effectively diagonalizes Ω in (EQ 22), and the variance of the random walk component of the exchange rate can be written:

$$\sigma_w^2 = \sigma_{w,c}^2 + \sigma_{w,FD}^2 + \sigma_{w,IB}^2 + \sigma_{w,\sqrt{trad}}^2 + \sigma_{w,returns}^2. \qquad \text{(EQ 23)}$$

Each variance on the right-hand side reflects an incremental contribution relative to the variables that precede it in the ordering. That is $\sigma_{w,c}^2$ is the component of the variance explained by central bank trade flows (CB), commercial client trade flows (CC), or Canadian domiciled investment flows (CD), $\sigma_{w,FD}^2$ is the incremental contribution to foreign domiciled trade flows, etc. To highlight the relative contributions, these values will be reported in proportional form, normalized by σ_w^2,

$$1 = R_{w,c}^2 + R_{w,FD}^2 + R_{w,IB}^2 + R_{w,\sqrt{trad}}^2 + R_{w,returns}^2. \qquad \text{(EQ 24)}$$

where $R_{w,c}^2 = \sigma_{w,c}^2 / \sigma_w^2$, etc.

Although VARs are commonly used to characterise dynamic models, this approach also has limitations stemming from the time aggregation, which leads to co-determined model disturbances and the consequent necessity of identification restrictions. The underlying economic model is based in continuous time. Although trades are discrete events, they can occur at any time. In principle, it would be necessary to specify a sampling interval fine enough to virtually preclude simultaneous occurrence of events, and so minimize the problems of contemporaneous endogeneity. In practice, however, the time grid is dictated by the data availability.

To summarize, the VAR provides a tractable and comprehensive specification that is capable of capturing the dynamic relations among trade flows and exchange rate returns. Impulse response analysis is one useful way of characterizing a VAR in the present analysis by constructing the implied price changes associated with the various types of trade flows. A second characterization of the exchange rate return specification in the VAR involves decomposing the sources of (long-run) return variation among the variables. Since returns are ultimately driven by changes in information, these analyses are useful in attributing information effects and the channels through which they operate.

8. Results

The stationarity of each variable is examined using an Augmented Dickey-Fuller (ADF) test. A regression of the following form is estimated:

$$\Delta y_t = a_0 + a_1 y_t + \sum_{l=1}^{f} b_t \Delta y_{t-l} + \nu_t \qquad \text{(EQ 25)}$$

where ν_t is assumed to be Gaussian white noise, and f is the number of lagged terms included in the regression is chosen to ensure that the errors are not serially correlated. If $a_1 = 0$, prices are non-stationary and have a unit-root. Results are presented in Table 8 and 10. In nearly all cases, the null hypothesis of a unit root is rejected at the 1% significance level.

Tables 9 and 11 presents our estimates of (EQ 1) over the two sample periods. The first regression in each table includes only traditional macroeconomic variables that are available at a daily frequency: interest rate differentials, crude oil prices, natural gas prices, and non-energy commodity prices. Judging by the model's explanatory power, the model is clearly inferior to that of a model which includes individual trade flows. More interesting is the predictive power of the regression model that includes order flows. Over all forecast horizons, and across both sample periods, the order flow regression not only beats the fundamental model. but is far superior to the random walk model.

8.1 Inventory-Information Model

The following equation would make it possible to test jointly the effects of contemporaneous and lagged customers orders, lagged incoming trade orders, and market-wide order flow on outgoing trade flows:

$$T_{it} = \alpha_1 c_{it} + \alpha_{21} c_{it-1} \ldots + \alpha_{2j} c_{it-j} + \alpha_{31} T_{it-1}' \ldots + \alpha_{3k} T_{it-k}' + \alpha_{41} V_{t-1} \ldots + \alpha_{4l} V_{t-l} \qquad \text{(EQ 26)}$$

The representation extends the model laid out in Section 7.2 naturally to include multi-period customer orders, and trade-flows that extend beyond two periods. Although individual dealer data dissaggregated incoming and outgoing interdealer trades $\{T_{it}, T_{it}'\}$ is not available (see Section 6.0), It is still possible to test the model with the net trade flows (T_{it}''), defined here as trade between each dealers and all other dealers $T_{it}'' \equiv T_{it} - T_{it}'$. If over the course of the day, dealers trade frequently the only position a dealer will be left holding at the end of the day is the speculative one. Specifically, traders will pass on to other dealers any undesired position. Consider the adjusted equation to (EQ 26):

$$T_{it}'' = \gamma_1 c_{it} + \gamma_{21} c_{it-1} \dots + \gamma_{2j} c_{it-j} + \gamma_4 V_t + \gamma_{41} V_{t-1} \dots + \gamma_{4l} V_{t-l} \qquad \text{(EQ 27)}$$

The model predicts that $0 > \gamma_1 > -1$. OLS estimates of (EQ 27) for each of the 8 dealers in the sample in the spot FX markets are presented in Table 12 and 14. On the whole, results in the spot market support dealer speculation based on private information. Most of the coefficients are of the correct sign. Lagged customer orders (CB. CC, CD, FD) and lagged net trade flows are not usually significant. Overall, the results confirm the hypothesis of dealer speculation. While there is evidence that this type of speculation does exist, it is short lived (lasting no more that one day). In Tables 13 and 15, F-statistics are constructed to test if the coefficients on contemporaneous central bank trade flows are equal to the coefficients on commercial client trade flows and Canadian domiciled financial institution trade flows. Across dealers and in both samples, in virtually all cases the null hypothesis that the coefficients were equal could not be rejected at the 95% significance level.

8.2 VAR Estimation

When we want to take into account all possible relations between variables, it seems sensible to construct a model for a vector of time series. In case we also do not know a priori which variable is affecting which, or when it is uncertain which variables are exogenous and which are endogenous, it seems useful to start with the construction of a general time series model for a vector time series.

VARs may also be sensitive to lag length, or K in equation (EQ 17). AIC criterion, defined as

$$AIC(K) = \ln(det\hat{\Omega}) + \frac{2n^2K}{T} \qquad \text{(EQ 28)}$$

where n is the number of variables in the system, T is the sample size, and $\hat{\Omega}$ is an estimate of the residual covariance matrix, is employed to determine the lag length of the VAR. The order is chosen in order to minimize the criterion. Usually one lag (and sometimes two lags) minimized the AIC criterion in each VARs estimated.

One of the key questions that can be addressed with VARs is how useful some variables are for forecasting others. A variable, x, is said to Granger-cause another variable, y, if the information in past and present x helps to improve the forecasts of the y variable. A block exogeneity test has as its null hypothesis that the lags on one set of variables do not enter the equations for the remaining variables. This is the multivariate generalization of Granger-Sims causality tests. The testing procedure used is the Likelihood Ratio test

$$(T-c)(\log(|\Sigma_r|)-\log(|\Sigma_u|)) \quad \text{(EQ 29)}$$

where $|\Sigma_r|$ and $|\Sigma_u|$ are the restricted and unrestricted covariance matrices and T is the number of observations. This is asymptotically distributed as an χ^2 distribution with degrees of freedom equal to the number of restrictions. c is a correction to improve small sample properties. Sims (1980) suggests using a correction equal to the number of variables in each unrestricted equation in the system.

Block exogeneity tests are conducted on aggregate and dealer data, over both samples, using VARs that include central bank trade, foreign domiciled trade, interbank trade, market wide trade, and finally either exchange rate returns or implied volatility returns. Three null hypotheses are tested: 1) dealer i interdealer trade flows are block exogenous; and 2) dealer i foreign domiciled trade are block exogenous; and 3) market-wide trade flows ($\sqrt{trad}$) are block exogenous. Results are presented in Table 16. In nearly all cases, the null hypotheses are rejected. Therefore all VARs performed will include each of these variables. This result suggests that interdealer trade (domestic and foreign) is a necessary requirement in the price discovery process.

The VAR specification described in the previous section (and slight variations in the specification) are estimated for all dealers in the sample. The coefficients estimates of the VAR are not reported since there is little information to be gained from these estimates. Any one variable in the VAR can affect any other variable in the system both directly, or indirectly through another equation. We instead focus on the impulse response functions and the variance decompositions.

Impulse response functions are computed in each sample subsequent to six different initial shocks. These shocks correspond to C$1 million hypothetical spot market sell orders by the central bank, a commercial client, a Canadian domiciled (non-dealer) financial institution, a foreign domiciled financial institution, and a Canadian dealer. The accumulated responses over 20 days are presented in Figures 3 and 4. As noted above, the long-term cumulative exchange rate returns subsequent to a trade flow shock may be interpreted as the information content of the order. There is a clear change in the impact of central bank flows on exchange rate returns from one sample to the next. In the intervention period, central bank trade with dealers (dealers purchasing Canadian dollars and the central bank selling Canadian dollars) resulted in a nearly permanent depreciation of the Canadian dollar. This is not true in the replenishment period.

Section 7.3 describes a method for decomposing the long-run exchange rate return variance implied by the model into components attributable to the different model variables. These calculations are contingent on the identification restrictions governing the contemporaneous influences among the structural innovations. The first decomposition uses the same identification as the impulse response calculations. For each dealer in the sample, a relative variance decomposition corresponding to (EQ 24) is computed. The relative variance components, the R^2s in (EQ 24) are reported in Tables 17-28. Only central bank trade flows, commercial client trade flows, and foreign domiciled trade flows could explained a significant proportion of the relative variance in exchange rate returns. If exchange rate returns are replaced with percentages change in implied volatility the results are at best poor. In particular, central bank operations were not found to be influential, in either period, in explaining the relative variance in volatility.

9. Conclusion

The results in this papers suggest that central bank trade flows have not been treated very differently from other customer orders by dealers in the FX market. In particular, dealers may speculate with the information implicit in trades directly or indirectly with the central bank, and that this behavour may impact on the effectiveness of intervention. The paper also illustrates that the impact of central bank intervention or replenishment operations is partially determined by market-wide order flows generated subsequent to intervention operations. For further research, our results (particularly the variance decompositions) also point to the impact of foreign domiciled financial trade flows on prices in the Canadian FX market. The impulse response functions indicate that these flows have become more important recently.

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A.1 Tables and Figures

Table 1: Descriptive Statistics ($C millions)

REGIME:	INTERVENTION PERIOD: Jan/95-Sep/98			REPLENISHMENT PERIOD:Oct/98-Sep/99		
Variables	**Mean**	**Median**	**Std. Dev.**	**Mean**	**Median**	**Std. Dev.**
Aggregate Trading Volumes						
Cen. Bank1	27.00	0.00	107.85	0.00	0.00	0.00
Cen. Bank2	0.00	0.00	0.00	18.94	0.00	37.98
Total	7722.51	7203.50	3173.54	7778.08	7327.00	2398.22
Interbank	2434.16	2251.30	1232.73	2018.98	1811.95	938.83
Foreign	3385.70	3179.60	1566.97	3719.79	3561.85	1296.52
Com. Client	1537.04	1462.40	524.66	1639.18	1533.50	635.27
Can. Dom	338.61	296.00	190.45	381.19	346.40	169.34
Aggregate Net Trade						
Cen. Bank1	-16.18	0.00	110.00	0.00	0.00	0.00
Cen. Bank2	0.00	0.00	0.00	18.94	0.00	37.98
Total	130.09	79.20	429.92	37.41	13.40	569.43
Interbank	15.38	16.40	193.09	-1.99	-6.60	140.30
Foreign	122.66	100.90	471.79	49.87	30.40	419.69
Com. Client	-16.36	-23.20	232.68	-44.95	-86.45	495.76
Can. Dom	24.58	14.70	113.60	15.54	9.05	119.69
Trading Volume, Central Bank Intervention						
Dealer 1	8.64	0.00	40.86	0.00	0.00	0.00
Dealer 2	3.97	0.00	20.92	0.00	0.00	0.00
Dealer 3	6.29	0.00	28.81	0.00	0.00	0.00
Dealer 4	4.41	0.00	19.37	0.00	0.00	0.00
Dealer 5	2.44	0.00	12.57	0.00	0.00	0.00
Dealer 6	0.41	0.00	3.07	0.00	0.00	0.00
Dealer 7	0.27	0.00	2.47	0.00	0.00	0.00
Dealer 8	0.56	0.00	6.36	0.00	0.00	0.00
Trading Volume, Central Bank Replenishment						
Dealer 1	0.00	0.00	0.00	3.39	0.00	11.45

Table 1: Descriptive Statistics ($C millions)

REGIME:	**INTERVENTION PERIOD: Jan/95-Sep/98**			**REPLENISHMENT PERIOD:Oct/98-Sep/99**		
Variables	**Mean**	**Median**	**Std. Dev.**	**Mean**	**Median**	**Std. Dev.**
Dealer 2	0.00	0.00	0.00	2.82	0.00	9.47
Dealer 3	0.00	0.00	0.00	2.38	0.00	8.94
Dealer 4	0.00	0.00	0.00	3.47	0.00	12.12
Dealer 5	0.00	0.00	0.00	2.88	0.00	9.54
Dealer 6	0.00	0.00	0.00	1.13	0.00	4.75
Dealer 7	0.00	0.00	0.00	1.42	0.00	5.62
Dealer 8	0.00	0.00	0.00	1.45	0.00	5.50
Trading Volumes, Total						
Dealer 1	1648.24	1508.20	793.34	1979.22	1846.60	716.64
Dealer 2	1672.14	1547.00	841.79	1113.39	1010.50	609.70
Dealer 3	1312.88	1175.00	668.85	1720.17	1686.50	640.73
Dealer 4	1160.66	1086.00	622.49	1200.00	1132.85	518.55
Dealer 5	979.87	938.00	650.51	892.66	910.00	536.35
Dealer 6	393.64	343.40	244.64	492.36	475.80	240.31
Dealer 7	300.67	274.50	152.49	330.49	302.50	148.30
Dealer 8	254.42	80.00	375.25	49.79	17.50	86.26
Trading Volumes, Interbank						
Dealer 1	507.09	458.07	287.45	478.50	422.86	250.92
Dealer 2	522.55	469.00	295.59	289.44	248.56	172.58
Dealer 3	337.89	292.00	215.36	401.10	379.50	192.62
Dealer 4	421.22	376.90	264.44	358.81	334.60	200.53
Dealer 5	342.83	318.00	279.42	272.60	249.00	235.80
Dealer 6	87.67	75.10	61.81	102.31	90.45	62.01
Dealer 7	112.36	96.70	73.89	116.14	100.80	74.10
Dealer 8	102.55	0.00	199.65	0.08	0.00	13.12
Trading Volumes, Foreign Domiciled						
Dealer 1	665.49	569.10	397.81	910.07	852.80	401.77
Dealer 2	869.53	774.00	504.29	525.82	494.00	251.18

Table 1: Descriptive Statistics ($C millions)

REGIME:	INTERVENTION PERIOD: Jan/95-Sep/98			REPLENISHMENT PERIOD:Oct/98-Sep/99		
Variables	**Mean**	**Median**	**Std. Dev.**	**Mean**	**Median**	**Std. Dev.**
Dealer 3	578.03	497.00	386.96	929.23	862.50	453.29
Dealer 4	467.10	408.50	310.98	586.80	561.95	300.76
Dealer 5	331.51	308.00	270.60	274.58	263.50	208.94
Dealer 6	230.54	197.60	153.36	318.78	302.75	165.91
Dealer 7	118.54	102.30	77.98	146.13	132.85	77.46
Dealer 8	124.96	48.00	179.57	28.37	3.00	72.73
Trading Volume, Commercial Clients						
Dealer 1	375.01	336.10	180.54	472.32	387.30	299.35
Dealer 2	221.85	196.00	127.40	240.11	194.50	448.10
Dealer 3	331.37	297.00	166.63	311.24	295.50	119.50
Dealer 4	223.90	197.30	112.03	185.99	172.60	71.62
Dealer 5	244.84	212.00	134.87	286.21	264.50	143.76
Dealer 6	61.69	44.00	60.59	62.80	52.80	46.26
Dealer 7	63.18	51.30	44.26	64.70	57.05	34.96
Dealer 8	15.18	7.00	25.15	15.81	6.00	29.81
Trading Volume, Canadian Domiciled						
Dealer 1	92.00	74.00	71.33	114.94	98.45	68.14
Dealer 2	54.25	36.00	65.92	55.20	46.00	36.74
Dealer 3	59.30	41.00	59.37	76.22	53.50	79.00
Dealer 4	44.03	25.00	61.09	64.92	39.00	76.97
Dealer 5	58.24	43.00	69.26	56.40	46.50	55.93
Dealer 6	13.33	10.00	21.17	7.34	4.15	11.10
Dealer 7	6.31	2.70	12.17	2.10	0.00	4.22
Dealer 8	11.17	3.00	23.91	4.08	0.00	25.35
Net Trade, Central Bank Intervention						
Dealer 1	-6.49	0.00	41.26	0.00	0.00	0.00
Dealer 2	-2.06	0.00	21.20	0.00	0.00	0.00
Dealer 3	-3.78	0.00	29.25	0.00	0.00	0.00

Table 1: Descriptive Statistics ($C millions)

REGIME:	INTERVENTION PERIOD: Jan/95-Sep/98			REPLENISHMENT PERIOD:Oct/98-Sep/99		
Variables	**Mean**	**Median**	**Std. Dev.**	**Mean**	**Median**	**Std. Dev.**
Dealer 4	-1.72	0.00	19.79	0.00	0.00	0.00
Dealer 5	-1.47	0.00	12.72	0.00	0.00	0.00
Dealer 6	-0.25	0.00	3.08	0.00	0.00	0.00
Dealer 7	-0.13	0.00	2.48	0.00	0.00	0.00
Dealer 8	-0.29	0.00	6.38	0.00	0.00	0.00
Net Trade, Central Bank Replenishment						
Dealer 1	0.00	0.00	0.00	3.39	0.00	11.45
Dealer 2	0.00	0.00	0.00	2.82	0.00	9.47
Dealer 3	0.00	0.00	0.00	2.38	0.00	8.94
Dealer 4	0.00	0.00	0.00	3.47	0.00	12.12
Dealer 5	0.00	0.00	0.00	2.88	0.00	9.54
Dealer 6	0.00	0.00	0.00	1.13	0.00	4.75
Dealer 7	0.00	0.00	0.00	1.42	0.00	5.62
Dealer 8	0.00	0.00	0.00	1.45	0.00	5.50
Net Trade, Total						
Dealer 1	19.58	21.10	170.67	-9.17	-0.75	188.14
Dealer 2	14.27	5.00	172.49	26.19	1.00	453.43
Dealer 3	35.49	22.00	204.41	-3.94	-4.00	154.76
Dealer 4	21.05	12.70	143.57	8.08	12.50	136.15
Dealer 5	14.58	8.00	142.32	-2.14	-3.00	147.37
Dealer 6	9.44	3.70	56.66	10.59	3.60	58.16
Dealer 7	14.39	8.10	62.95	23.37	15.20	61.80
Dealer 8	1.30	0.00	75.30	-15.57	0.00	75.50
Net Trade, Interbank						
Dealer 1	-9.29	-8.10	144.04	-11.89	-11.85	138.79
Dealer 2	-8.48	-8.00	134.46	-0.32	5.00	84.56
Dealer 3	15.10	10.00	117.75	12.99	3.19	114.69
Dealer 4	1.46	1.70	115.76	-3.04	-0.05	122.88

Table 1: Descriptive Statistics ($C millions)

REGIME:	INTERVENTION PERIOD: Jan/95-Sep/98			REPLENISHMENT PERIOD:Oct/98-Sep/99		
Variables	Mean	Median	Std. Dev.	Mean	Median	Std. Dev.
Dealer 5	12.40	0.00	102.75	-4.85	-1.00	86.73
Dealer 6	4.30	4.50	40.22	5.99	3.80	41.60
Dealer 7	-2.49	-3.00	44.39	0.57	-2.95	50.68
Dealer 8	2.38	0.00	61.67	-1.42	0.00	6.41
Net Trade, Foreign Domiciled						
Dealer 1	23.99	23.40	148.91	12.56	12.55	160.04
Dealer 2	33.32	25.00	179.18	0.97	8.00	114.92
Dealer 3	31.78	20.00	203.45	7.44	8.50	129.23
Dealer 4	15.58	7.50	118.80	24.85	20.65	106.50
Dealer 5	10.89	2.00	104.13	6.34	0.00	84.28
Dealer 6	8.65	4.90	50.95	5.81	0.05	54.34
Dealer 7	0.62	0.40	45.14	9.79	2.05	43.84
Dealer 8	-2.17	0.00	80.45	-17.88	0.00	71.94
Net Trade, Commercial Clients						
Dealer 1	0.40	-7.10	95.63	-19.49	-18.55	94.25
Dealer 2	-12.67	-14.00	87.70	18.76	-16.00	443.48
Dealer 3	-14.01	-13.00	116.01	-36.74	-39.00	95.09
Dealer 4	0.78	-1.30	68.33	-8.39	-3.60	49.44
Dealer 5	-5.99	-4.00	83.29	-7.49	-13.50	105.48
Dealer 6	-4.12	-3.90	31.30	-3.53	-5.20	26.13
Dealer 7	18.04	11.10	41.88	11.22	6.80	32.25
Dealer 8	1.21	0.00	23.45	0.70	0.00	20.07
Net Trade, Canadian Domiciled						
Dealer 1	10.98	5.40	56.22	6.27	2.55	53.66
Dealer 2	4.16	2.00	52.86	3.96	5.50	37.51
Dealer 3	6.40	2.00	47.68	10.00	2.00	57.21
Dealer 4	4.95	0.10	44.25	-8.81	-0.15	64.52
Dealer 5	-1.26	0.00	53.06	0.98	0.00	34.84

Table 1: Descriptive Statistics ($C millions)

REGIME:	**INTERVENTION PERIOD: Jan/95-Sep/98**			**REPLENISHMENT PERIOD:Oct/98-Sep/99**		
Variables	**Mean**	**Median**	**Std. Dev.**	**Mean**	**Median**	**Std. Dev.**
Dealer 6	0.85	0.00	20.19	1.20	0.30	10.52
Dealer 7	-1.66	0.00	12.08	0.37	0.00	4.08
Dealer 8	0.16	0.00	18.17	1.57	0.00	18.74

Table 2: Correlations

Sample period: January 2, 1996 - September 30, 1998								
Exchange Rate	1.00							
Exchange Rate Returns	-0.03	1.00						
Central Bank Net Trade	-0.34	-0.04	1.00					
Total Net Trade	0.04	0.01	-0.15	1.00				
Interbank Net Trade	0.02	0.01	-0.05	0.19	1.00			
Foreign Domiciled Net Trade	0.06	-0.01	-0.39	0.75	-0.11	1.00		
Commercial Client Net Trade	0.01	0.05	0.10	0.16	-0.14	-0.34	1.00	
Canadian Domicile Net Trade	0.16	0.02	-0.00	0.16	0.02	-0.13	0.05	1.00

Table 3: Correlations

Sample period: October 1, 1998 - September 30, 1999								
Exchange Rate	1.00							
Exchange Rate Returns	0.11	1.00						
Central Bank Net Trade	-0.33	-0.01	1.00					
Total Net Trade	0.16	-0.08	-0.14	1.00				
Interbank Net Trade	0.00	0.01	-0.02	0.18	1.00			
Foreign Domiciled Net Trade	0.15	-0.02	-0.36	0.46	-0.11	1.00		
Commercial Client Net Trade	0.08	-0.05	0.06	0.73	0.04	-0.19	1.00	
Canadian Domicile Net Trade	0.01	-0.10	0.01	-0.07	-0.09	-0.27	-0.06	1.00

Table 4: Correlations

Sample period: January 2, 1996 - September 30, 1999								
Exchange Rate	1.00							
Exchange Rate Returns	0.04	1.00						
Central Bank Net Trade	-0.10	-0.02	1.00					
Total Net Trade	-0.03	-0.03	-0.15	1.00				
Interbank Net Trade	0.00	0.01	-0.05	0.19	1.00			
Foreign Domiciled Net Trade	-0.00	-0.02	-0.38	0.66	-0.11	1.00		
Commercial Client Net Trade	-0.02	-0.00	0.06	0.43	-0.06	-0.25	1.00	
Canadian Domicile Net Trade	0.06	-0.02	-0.02	0.09	-0.00	-0.16	0.01	1.00

Table 5: Sample period: January 2, 1996 - September 30, 1998

z	S_t	$\Delta \ln S_t$	**CB Net Trade**	**TradNet Trade**	**IB Net Trade**	**FD Net Trade**	**CC Net Trade**	**CD Net Trade**
Skewness	**1.33	0.08	**-4.08	**1.96	**0.46	**1.22	**-0.42	0.07
Kurtosis	**1.30	**3.51	**50.3	**16.9	**3.70	**8.61	**3.67	**8.87
$Q_{\Delta z}(15)$	**9191	**34	**247	**52.8	16.74	**48.3	21.84	**32.5
$Q_{(\Delta \ln z)^2}(15)$	**9167	**243	**169	3.46	20.98	2.42	**25.1	5.80
Auto-correlations	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	0.99	0.05	0.26	0.08	0.01	0.16	0.10	-0.01
	0.98	0.03	0.14	0.11	0.06	0.07	0.03	0.05
	0.97	0.04	0.26	0.03	0.01	0.07	0.04	-0.03
	0.96	-0.07	0.09	0.01	0.03	0.00	0.05	0.01
Partial auto-correlations	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	0.99	0.05	0.26	0.08	0.01	0.16	0.10	-0.01
	0.07	0.03	0.07	0.10	0.06	0.05	0.02	0.05
	-0.01	0.04	0.22	0.02	0.01	0.06	0.04	-0.03
	-0.03	-0.08	-0.03	0.00	0.03	-0.02	0.04	0.00
ADF statistic	1.28	**-744	**-57.8	**-72.3	**-153	**-190	**-832	**-47.5

The skewness and kurtosis statistic are normalized so that a value of 0 corresponds to the normal distribution. $Q_{\Delta z}(15)$ pertains to the Box-Pierce Q-statistic test for high-order serial correlation in Δz ; * denotes significance at the 95% level; ** denotes significance at the 99% level.

Table 6: Sample period: October 1, 1998 - September 30, 1999

z	S_t	$\Delta \ln S_t$	**CB Net Trade**	**TradNet Trade**	**IB Net Trade**	**FD Net Trade**	**CC Net Trade**	**CD Net Trade**
Skewness	0.12	*0.38	**2.28	**7.59	**-1.63	-0.03	**11.1	-0.18
Kurtosis	**-1.18	**1.43	**4.60	**94.2	**11.5	**2.72	**155	**3.84
$Q_{\Delta z}(10)$	**1918	12.03	**43.1	8.23	1.82	**70.1	5.27	5.84
$Q_{(\Delta \ln z)^2}(10)$	**1917	14.41	**24.4	0.13	3.52	14.8	0.07	14.91
Auto-correlations	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	0.97	-0.05	0.28	0.07	0.00	0.37	-0.07	0.00
	0.94	-0.04	0.09	0.06	0.03	0.24	0.03	-0.07
	0.91	0.03	0.00	0.12	-0.05	0.19	0.04	0.03
	0.89	0.20	0.09	0.01	-0.00	0.12	0.07	-0.01
Partial auto-correlations	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	0.97	-0.05	0.28	0.07	0.00	0.37	-0.07	0.00
	0.02	-0.04	0.01	0.05	0.03	0.11	0.02	-0.07
	-0.01	0.02	-0.03	0.11	-0.05	0.08	0.04	0.03
	0.00	0.00	0.22	-0.00	-0.00	0.01	0.07	-0.01
ADF statistic	**-5.13	**-331	**-82.4	**-90.1	**-563	**-67.8	**-454	**-235

The skewness and kurtosis statistic are normalized so that a value of 0 corresponds to the normal distribution. $Q_{\Delta z}(15)$ pertains to the Box-Pierce Q-statistic test for high-order serial correlation in Δz ; * denotes significance at the 95% level; ** denotes significance at the 99% level.

Table 7: Sample period: January 2, 1996 - September 30, 1999

z	S_t	$\Delta \ln S_t$	**CB Net Trade**	**TradNet Trade**	**IB Net Trade**	**FD Net Trade**	**CC Net Trade**	**CD Net Trade**
Skewness	**0.47	**0.30	**-4.50	**4.33	*0.17	**1.02	**9.72	0.00
Kurtosis	**-1.12	**2.96	**61.8	**54.7	**4.94	**7.93	**205	**7.50
$Q_{\Delta z}(20)$	**11781	**40.7	**442	**67.2	21.16	**101	18.73	*28.3
$Q_{(\Delta \ln z)^2}(20)$	**11779	**373	**238	0.51	20.34	8.19	0.18	9.03
Auto-correlations	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	0.99	0.00	0.28	0.09	0.01	0.21	0.00	-0.00
	0.99	0.01	0.16	0.10	0.06	0.11	0.03	0.02
	0.98	0.04	0.27	0.08	-0.00	0.10	0.04	-0.01
	0.98	-0.06	0.12	0.02	0.03	0.03	0.06	0.00
Partial auto-correlations	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	0.99	0.00	0.28	0.09	0.01	0.21	0.00	-0.00
	-0.00	0.01	0.08	0.09	0.06	0.07	0.03	0.02
	-0.01	0.04	0.22	0.06	-0.01	0.07	0.04	-0.01
	-0.03	-0.06	-0.01	0.02	0.02	-0.01	0.06	0.00
ADF statistic	-1.90	**-590	**-100	**-108	**-254	**-370	**-436	**-132

The skewness and kurtosis statistic are normalized so that a value of 0 corresponds to the normal distribution. $Q_{\Delta z}(15)$ pertains to the Box-Pierce Q-statistic test for high-order serial correlation in Δz; * denotes significance at the 95% level; ** denotes significance at the 99% level.

Table 8: ADF Unit Root t-tests, Intervention Period

Variable	t-test	Lags(f)	Variable	t-test	Lags(f)
Exchange Rate Level	0.55	0	Exchange Rate Returns	-25.17	0
Implied Volatility	-0.19	2	Implied Volatility (%change)	-29.95	0
Interest Rate Differential	-1.20	6	Change in Interest Rate Differential	-16.52	5
Oil Price	-1.74	0	Oil Price Returns	-20.82	1
Natural Gas Prices	-1.67	0	Natural Gas Price Returns	-25.23	0
Non-Energy Commodity Prices	0.01	0	Non-Energy Commodity Price Returns	-20.56	1
CB	-10.22	2	FD	-22.26	0
CC	-23.50	0	IB	-25.61	0
CD	-26.34	0	TRAD	-15.93	0
Critical values are from Hamilton (1994): -3.43 (1%), -2.86 (5%), -2.57 (10%)					

Table 9: In-Sample Fit & Out-of-Sample Forecasting Performance, Intervention Period

Variable	No Trade Flows	Including Trade Flow Variables
Constant ($a_0 \times 10^{-4}$)	1.61 (0.12)	-2.04 (0.02)
Interest Rate Changes ($a_1 \times 10^{-1}$)	-0.41 (0.37)	-0.69 (0.06)
Oil Price Returns ($a_2 \times 10^{-2}$)	-0.48 (0.18)	-0.04 (0.89)
Standard errors are corrected for heteroskedasticity. p-values are listed in parentheses below estimated coefficients. Theil-U statistic is the ratio of the model's RMSE relative to the RMSE of a random walk.		

Table 9: In-Sample Fit & Out-of-Sample Forecasting Performance, Intervention Period

Variable	No Trade Flows	Including Trade Flow Variables
Natural Gas Returns ($a_3 \times 10^{-2}$)	-0.45 (0.08)	-0.43 (0.04)
Non-Energy Returns ($a_4 \times 10^{-2}$)	-0.58 (0.54)	-0.69 (0.40)
Central Bank Trade ($a_5 \times 10^{-6}$)		-6.46 (0.00)
Commercial Client Trade ($a_6 \times 10^{-6}$)		-2.02 (0.00)
Canadian Domiciled Trade ($a_7 \times 10^{-6}$)		-0.84 (0.29)
Foreign Domiciled Trade ($a_8 \times 10^{-6}$)		1.89 (0.00)
Interbank Trade ($a_9 \times 10^{-6}$)		-0.78 (0.34)
$\bar{R}^2$	0.004	0.352
Theil-U: 1-period ahead forecast	1.0007	0.6707
Theil-U: 2-period ahead forecast	0.9995	0.6694
Theil-U: 4-period ahead forecast	1.0024	0.6734
Theil-U: 5-period ahead forecast	1.0028	0.6745
Theil-U: 10-period ahead forecast	0.9999	0.6654
Theil-U: 20-period ahead forecast	1.0003	0.6761
Theil-U: 40-period ahead forecast	0.9906	0.7534
Theil-U: 60-period ahead forecast	0.9968	0.7413

Standard errors are corrected for heteroskedasticity. p-values are listed in parentheses below estimated coefficients. Theil-U statistic is the ratio of the model's RMSE relative to the RMSE of a random walk.

Table 10: ADF Unit Root t-tests, Replenishment Period

Variable	t-test	Lags(f)	Variable	t-test	Lags(f)
Exchange Rate Level	-1.54	0	Exchange Rate Returns	-16.42	0
Implied Volatility	-2.30	0	Implied Volatility (%change)	-17.50	0
Interest Rate Differential	-2.86	1	Change in Interest Rate Differential	-11.34	5
Oil Price	-0.82	0	Oil Price Returns	-15.69	0
Natural Gas Prices	-1.28	0	Natural Gas Price Returns	-15.61	0
Non-Energy Commodity Prices	-0.80	1	Non-Energy Commodity Price Returns	-13.16	0
CB	-10.22	0	FD	-10.58	0
CC	-16.94	0	IB	-16.09	0
CD	-15.98	0	TRAD	-15.93	0

Critical values are from Hamilton (1994): -3.43 (1%), -2.86 (5%), -2.57 (10%)

Table 11: In-Sample Fit & Out-of-Sample Forecasting Performance, Replenishment Period

Variable	No Trade Flows	Including Trade Flow Variables
Constant ($a_0 \times 10^{-4}$)	-0.82 (0.74)	4.27 (0.07)
Interest Rate Changes ($a_1 \times 10^{-1}$)	-0.02 (0.29)	-1.22 (0.31)
Oil Price Returns ($a_2 \times 10^{-2}$)	-2.00 (0.08)	-0.84 (0.34)

Standard errors are corrected for heteroskedasticity. p-values are listed in parentheses below estimated coefficients. Theil-U statistic is the ratio of the model’s RMSE relative to the RMSE of a random walk.

Table 11: In-Sample Fit & Out-of-Sample Forecasting Performance, Replenishment Period

Variable	No Trade Flows	Including Trade Flow Variables
Natural Gas Returns ($a_3 \times 10^{-2}$)	-0.10 (0.24)	-0.92 (0.13)
Non-Energy Returns ($a_4 \times 10^{-2}$)	-4.54 (0.08)	-0.01 (0.98)
Central Bank Trade ($a_5 \times 10^{-6}$)		-4.09 (0.00)
Commercial Client Trade ($a_6 \times 10^{-6}$)		-1.12 (0.00)
Canadian Domiciled Trade ($a_7 \times 10^{-6}$)		-0.10 (0.64)
Foreign Domiciled Trade ($a_8 \times 10^{-6}$)		3.10 (0.00)
Interbank Trade ($a_9 \times 10^{-6}$)		-0.83 (0.66)
$\bar{R}^2$	0.026	0.395
Theil-U: 1-period ahead forecast	1.0199	0.5481
Theil-U: 2-period ahead forecast	1.0152	0.5482
Theil-U: 4-period ahead forecast	1.0045	0.5760
Theil-U: 5-period ahead forecast	1.0055	0.5790
Theil-U: 10-period ahead forecast	1.0030	0.6114
Theil-U: 20-period ahead forecast	1.0280	0.5817
Theil-U: 40-period ahead forecast	1.0048	0.5884
Theil-U: 60-period ahead forecast	0.9607	0.5898

Standard errors are corrected for heteroskedasticity. p-values are listed in parentheses below estimated coefficients. Theil-U statistic is the ratio of the model's RMSE relative to the RMSE of a random walk.

Table 12: OLS Estimates of Reduced Form Equations of Lyon's Model, Intervention Period

	Con.	CB	CB Lags	CC	CC Lags	CD	CD Lags	FD	FD Lags	TRAD	TRAD Lags	$\bar{R}^2$
1	-17.65 (0.00)	-0.35 (0.00)	-0.04 (0.93)	-0.49 (0.00)	-0.04 (0.41)	-0.31 (0.00)	-0.05 (0.72)	-0.41 (0.00)	0.02 (0.80)	0.09 (0.00)	0.01 (0.68)	0.19
2	-9.55 (0.08)	-0.76 (0.01)	0.10 (0.91)	-0.45 (0.00)	0.07 (0.23)	-0.43 (0.00)	0.04 (0.91)	0.38 (0.00)	0.05 (0.23)	0.07 (0.00)	-0.03 (0.23	0.21
3	14.42 (0.00)	-0.35 (0.00)	0.00 (0.85)	-0.48 (0.00)	0.09 (0.12)	-0.20 (0.00)	0.04 (0.40)	-0.20 (0.00)	0.05 (0.06)	0.07 (0.00)	-0.03 (0.08)	0.19
4	4.44 (0.38)	-0.52 (0.03)	0.17 (0.82)	-0.27 (0.00)	0.17 (0.09)	-0.54 (0.00)	-0.04 (0.92)	-0.27 (0.00)	0.00 (0.69)	0.04 (0.00)	0.01 (0.81)	0.10
5	8.91 (0.04)	-0.62 (0.04)	-0.04 (0.43)	-0.35 (0.00)	0.06 (0.13)	-0.24 (0.00)	0.12 (0.45)	-0.13 (0.00)	0.07 (0.18)	0.02 (0.00)	-0.01 (0.48)	0.10
6	-2.90 (0.09)	0.07 (0.87)	0.99 (0.31)	-0.42 (0.00)	0.01 (0.16)	-0.07 (0.27)	0.00 (0.99)	-0.22 (0.00)	0.02 (0.57)	0.01 (0.00)	0.00 (0.85)	0.14
7	-1.86 (0.42)	0.17 (0.78)	0.98 (0.12)	-0.12 (0.01)	0.02 (0.86)	-0.22 (0.10)	0.12 (0.75)	-0.25 (0.00)	-0.07 (0.19)	0.01 (0.03)	0.00 (0.40)	0.07
8	0.60 (0.57)	-1.70 (0.00)	-0.29 (0.90)	-0.12 (0.01)	-0.01 (0.97)	0.01 (0.64)	0.02 (0.79)	-0.12 (0.00)	0.07 (0.83)	0.01 (0.77)	-0.00 (0.62)	0.08

p-values for t-tests (contemporaneous coefficients are zero) and F-tests (lag coefficients are zero) are listed in parentheses below the estimated coefficients.

Table 13: F-Statistics; Reduced Form Equations of Lyon's Model, Intervention Period

	CB=CC	CB=CD		CB=CC	CB=CD		CB=CC	CB=CD		CB=CC	CB=CD
1	1.05 (0.30)	0.07 (0.78)	3	0.69 (0.40)	2.41 (0.12)	5	0.71 (0.39)	1.39 (0.23)	7	0.21 (0.64)	0.35 (0.55)
2	2.01 (0.15)	1.95 (0.16)	4	9.58 (0.00)	15.93 (0.00)	6	1.10 (0.29)	0.10 (0.74)	8	9.95 (0.00)	11.69 (0.00)

p-values for F-tests (contemporaneous coefficients are equal) are listed in parentheses below the estimated coefficients.

Table 14: OLS Estimates of Reduced Form Equations of Lyon's Model, Replenishment Period

	Con.	CB	CB Lags	CC	CC Lags	CD	CD Lags	FD	FD Lags	TRAD	TRAD Lags	$\bar{R}^2$
1	-6.34 (0.55)	1.18 (0.11)	0.83 (0.49)	-0.12 (0.20)	0.09 (0.29)	-0.72 (0.00)	0.77 (0.00)	-0.26 (0.00)	0.03 (0.76)	0.03 (0.05)	-0.02 (0.47)	0.12
2	0.94 (0.87)	-0.38 (0.49)	0.12 (0.20)	-0.01 (0.69)	-0.28 (0.01)	-0.28 (0.05)	-0.11 (0.78)	-0.15 (0.01)	0.11 (0.12)	0.01 (0.72)	0.01 (0.89)	0.13
3	3.64 (0.69)	-1.06 (0.17)	1.82 (0.21)	-0.42 (0.00)	0.07 (0.76)	-0.55 (0.00)	0.06 (0.89)	-0.13 (0.02)	0.03 (0.58)	0.02 (0.15)	-0.05 (0.53)	0.15
4	-5.67 (0.53)	0.58 (0.37)	0.40 (0.68)	-0.26 (0.10)	-0.05 (0.04)	-0.53 (0.00)	0.17 (0.05)	-0.30 (0.00)	-0.01 (0.96)	0.02 (0.20)	0.02 (0.46)	0.12
5	-4.36 (0.49)	-0.31 (0.60)	-0.64 (0.73)	-0.10 (0.07)	-0.06 (0.53)	-0.31 (0.06)	-0.19 (0.17)	0.06 (0.37)	0.01 (0.89)	0.02 (0.05)	0.00 (0.82)	0.02
6	6.56 (0.49)	-0.73 (0.18)	0.01 (0.93)	-0.50 (0.00)	--0.01 (0.29)	-0.67 (0.01)	-0.28 (0.33)	-0.17 (0.00)	0.04 (0.56)	0.00 (0.59)	0.01 (0.52)	0.09
7	7.85 (0.02)	-0.10 (0.82)	-0.43 (0.84)	-0.24 (0.02)	-0.06 (0.87)	-0.13 (0.87)	0.13 (0.15)	-0.23 (0.00)	0.03 (0.93)	0.00 (0.70)	-0.01 (0.32)	0.02
8	0.09 (0.72)	-1.00 (0.00)	-0.00 (0.98)	-0.00 (0.82)	0.01 (0.39)	-0.01 (0.48)	-0.02 (0.35)	0.00 (0.89)	0.00 (0.93)	0.00 (0.42)	-0.00 (0.92)	0.73

p-values for t-tests (contemporaneous coefficients are zero) and F-tests (lag coefficients are zero) are listed in parentheses below the estimated coefficients.

Table 15: F-Statistics; Reduced Form Equations of Lyon's Model, Replenishment Period

	CB=CC	CB=CD		CB=CC	CB=CD		CB=CC	CB=CD		CB=CC	CB=CD
1	2.97 (0.08)	6.36 (0.01)	3	0.66 (0.41)	0.41 (0.51)	5	0.12 (0.72)	0.00 (0.99)	7	0.05 (0.80)	0.00 (0.97)
2	0.46 (0.49)	0.03 (0.84)	4	1.58 (0.20)	2.88 (0.09)	6	0.16 (0.68)	0.01 (0.91)	8	585.14 (0.00)	590.34 (0.00)

p-values for F-tests (contemporaneous coefficients are equal) are listed in parentheses below the estimated coefficients.

Table 16: Significance of Block Exogeneity Tests

	Exchange Rate Returns						Implied Volatility					
	FD		**IB**		$\sqrt{TRAD}$		**FD**		**IB**		$\sqrt{TRAD}$	
	Sample		**Sample**		**Sample**		**Sample**		**Sample**		**Sample**	
	1	**2**	**1**	**2**	**1**	**2**	**1**	**2**	**1**	**2**	**1**	**2**
Aggregate	*	*	*	*	*	*	*	*	*	*	*	*
Dealer 1	*	*	*	*	*	*	*	*	*	*	*	*
Dealer 2	*	*	*		*	*	*	*	*		*	*
Dealer 3	*	*	*	*	*	*	*	*	*		*	*
Dealer 4	*	*	*	*	*	*	*	*	*	*	*	*
Dealer 5	*	*	*	*	*	*	*	*	*	*	*	*
Dealer 6	*	*	*	*	*	*	*	*	*		*	*
Dealer 7	*	*	*	*	*	*	*	*	*		*	*
Dealer 8	*		*	*	*	*	*		*	*	*	*

Likelihood ratio test statistics have a χ^2 distribution with degrees of freedom equal to the number of restrictions placed on the VAR. * indicates a rejection of the null hypothesis of block Exogeneity at the 95% level.

Table 17: Variance Decomposition of Returns, Sample: Jan 1996 to Aug 1998

Intervention Period	Agg.	1	2	3	4	5	6	7	8
CB	21.02	13.62	15.24	14.47	17.72	13.07	7.85	5.65	0.27
FD	13.63	7.05	8.43	2.44	1.86	2.72	14.82	4.13	0.19
IB	0.08	0.22	0.39	0.56	0.52	3.60	0.01	0.88	0.14
TRAD	0.30	1.60	1.12	3.26	3.57	3.02	1.81	5.64	7.29
Exchange Rate Returns	64.97	77.50	74.80	79.26	76.32	77.59	75.51	83.70	92.09

Table 18: Variance Decomposition of Returns, Sample: Sep 1998 to Aug 1999

Replenishment Period	Agg.	1	2	3	4	5	6	7	8
CB	28.55	12.09	6.91	15.21	7.72	15.05	5.17	7.29	3.19
FD	16.07	4.51	17.07	12.41	4.16	0.21	29.11	2.88	0.21
IB	0.52	4.04	0.09	10.45	7.36	0.58	2.37	4.13	0.29
TRAD	4.31	0.21	0.24	0.12	1.88	1.36	0.34	1.32	2.64
Exchange Rate Returns	50.52	79.16	75.68	62.08	78.88	82.79	63.08	84.36	93.67

Table 19: Variance Decomposition of Returns, Sample: Jan 1996 to Aug 1998

Intervention Period	Agg.	1	2	3	4	5	6	7	8
CB	3.55	4.29	0.61	3.51	3.59	1.72	2.00	0.13	0.34
FD	0.21	0.01	0.09	0.81	0.21	0.71	1.44	0.10	0.25
IB	1.01	0.19	0.10	0.15	0.00	1.20	1.41	0.79	0.18
TRAD	0.21	0.14	0.39	0.04	0.14	0.12	0.11	0.17	0.23
Volatility,%change	95.00	95.35	98.79	95.48	96.04	96.25	95.03	98.81	98.99

Table 20: Variance Decomposition of Returns, Sample: Sep 1998 to Aug 1999

Replenishment Period	Agg.	1	2	3	4	5	6	7	8
CB	0.59	0.86	0.46	0.42	0.04	0.21	0.64	0.19	0.19
FD	1.59	1.31	1.84	2.05	0.09	0.40	0.91	0.77	0.06
IB	1.49	0.92	3.46	0.97	2.06	0.87	0.71	0.40	0.38
TRAD	0.61	0.80	0.67	0.34	1.49	1.24	0.51	0.79	1.29
Volatility,%change	95.69	96.11	93.57	96.22	95.92	97.27	97.23	97.83	98.07

Table 21: Variance Decomposition of Returns, Sample: Jan 1996 to Aug 1998

Intervention Period	**Agg.**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
CC	9.73	5.34	1.21	0.38	3.52	2.47	1.15	1.22	0.19
FD	19.67	10.13	13.08	5.23	2.29	3.01	20.22	3.82	0.11
IB	0.04	0.53	0.83	0.63	1.43	3.39	0.07	0.79	0.16
TRAD	0.36	2.76	1.03	3.73	6.58	4.88	1.98	6.75	7.27
Exchange Rate Returns	70.15	81.22	83.84	90.01	86.17	86.25	76.57	87.41	92.25

Table 22: Variance Decomposition of Returns, Sample: Sep 1998 to Aug 1999

Replenishment Period	**Agg.**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
CC	4.70	5.55	1.26	1.72	0.83	3.56	8.40	4.72	0.74
FD	24.61	4.85	19.10	15.95	4.30	8.25	25.18	3.44	0.15
IB	0.40	4.77	0.16	11.36	7.03	0.63	1.84	3.15	3.48
TRAD	3.84	1.24	0.35	0.14	2.76	2.99	0.17	1.87	2.68
Exchange Rate Returns	66.44	83.59	79.12	70.81	85.08	92.54	64.39	86.89	92.95

Table 23: Variance Decomposition of Returns, Sample: Jan 1996 to Aug 1998

Intervention Period	**Agg.**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
CC	0.10	0.79	0.13	0.01	0.42	0.03	1.46	0.19	0.08
FD	1.76	0.53	0.12	1.35	0.48	0.88	3.06	0.14	0.23
IB	0.57	0.07	0.13	0.07	0.05	1.34	0.67	0.83	0.15
TRAD	0.67	0.21	0.32	0.08	0.10	0.15	0.09	0.13	0.23
Volatility,%change	96.88	98.38	99.29	98.48	98.95	95.59	94.71	98.69	99.30

Table 24: Variance Decomposition of Returns, Sample: Sep 1998 to Aug 1999

Replenishment Period	**Agg.**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
CC	0.10	0.06	0.57	2.33	1.73	0.22	1.11	0.67	0.51
FD	1.72	1.36	1.83	1.40	0.37	0.41	0.62	0.70	0.11
IB	1.53	0.90	2.74	0.62	1.72	0.77	1.09	0.30	0.43
TRAD	1.15	0.77	0.73	0.41	1.50	1.28	0.74	0.76	1.34
Volatility,%change	95.47	96.92	94.11	95.23	94.66	97.31	96.43	97.55	97.60

Table 25: Variance Decomposition of Returns, Sample: Jan 1996 to Aug 1998

Intervention Period	**Agg.**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
CD	0.67	0.06	0.63	0.15	2.31	0.56	1.35	0.28	0.00
FD	26.81	13.20	13.69	5.98	2.84	3.95	20.46	4.11	0.21
IB	0.03	0.11	0.85	0.92	1.61	4.63	0.02	0.84	0.18
TRAD	1.33	1.44	0.99	3.11	6.35	3.75	2.01	6.12	7.28
Exchange Rate Returns	71.14	85.22	83.84	89.22	86.89	87.12	76.16	88.64	92.31

Table 26: Variance Decomposition of Returns, Sample: Sep 1998 to Aug 1999

Replenishment Period	**Agg.**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
CD	2.71	2.99	0.58	2.97	1.34	3.41	1.65	0.18	2.61
FD	26.46	8.02	20.27	15.45	4.94	0.41	30.73	3.81	0.20
IB	0.24	3.34	0.22	10.38	6.45	1.20	2.14	3.97	3.24
TRAD	4.71	0.31	0.20	0.09	2.48	1.67	0.22	1.57	2.89
Exchange Rate Returns	65.89	85.34	78.72	71.10	84.79	93.29	65.24	90.76	91.07

Table 27: Variance Decomposition of Returns, Sample: Jan 1996 to Aug 1998

Intervention Period	**Agg.**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
CD	0.30	0.90	0.04	0.32	0.16	0.03	0.24	0.12	0.01
FD	1.33	0.51	0.13	1.21	0.54	0.89	2.45	0.11	0.28
IB	0.79	0.05	0.08	0.13	0.03	1.33	1.51	0.78	0.14
TRAD	0.41	0.20	0.37	0.05	0.11	0.13	0.13	0.19	0.23
Volatility,%change	97.14	98.34	99.36	98.27	99.16	97.61	95.66	98.81	99.33

Table 28: Variance Decomposition of Returns, Sample: Sep 1998 to Aug 1999

Replenishment Period	**Agg.**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
CD	0.36	0.03	0.43	0.76	0.42	0.07	5.39	0.71	0.65
FD	1.95	1.38	2.28	1.34	1.41	0.44	1.39	0.74	0.65
IB	1.42	0.79	3.41	1.17	2.01	0.76	0.46	0.31	0.43
TRAD	0.49	0.83	0.63	0.37	1.34	1.22	0.31	0.77	1.41
Volatility,%change	95.77	96.96	93.24	96.35	93.80	97.49	92.49	97.47	97.45

FIGURE 2. Cumulative Change in Returns in Response to Aggregate Shocks, Sample 1

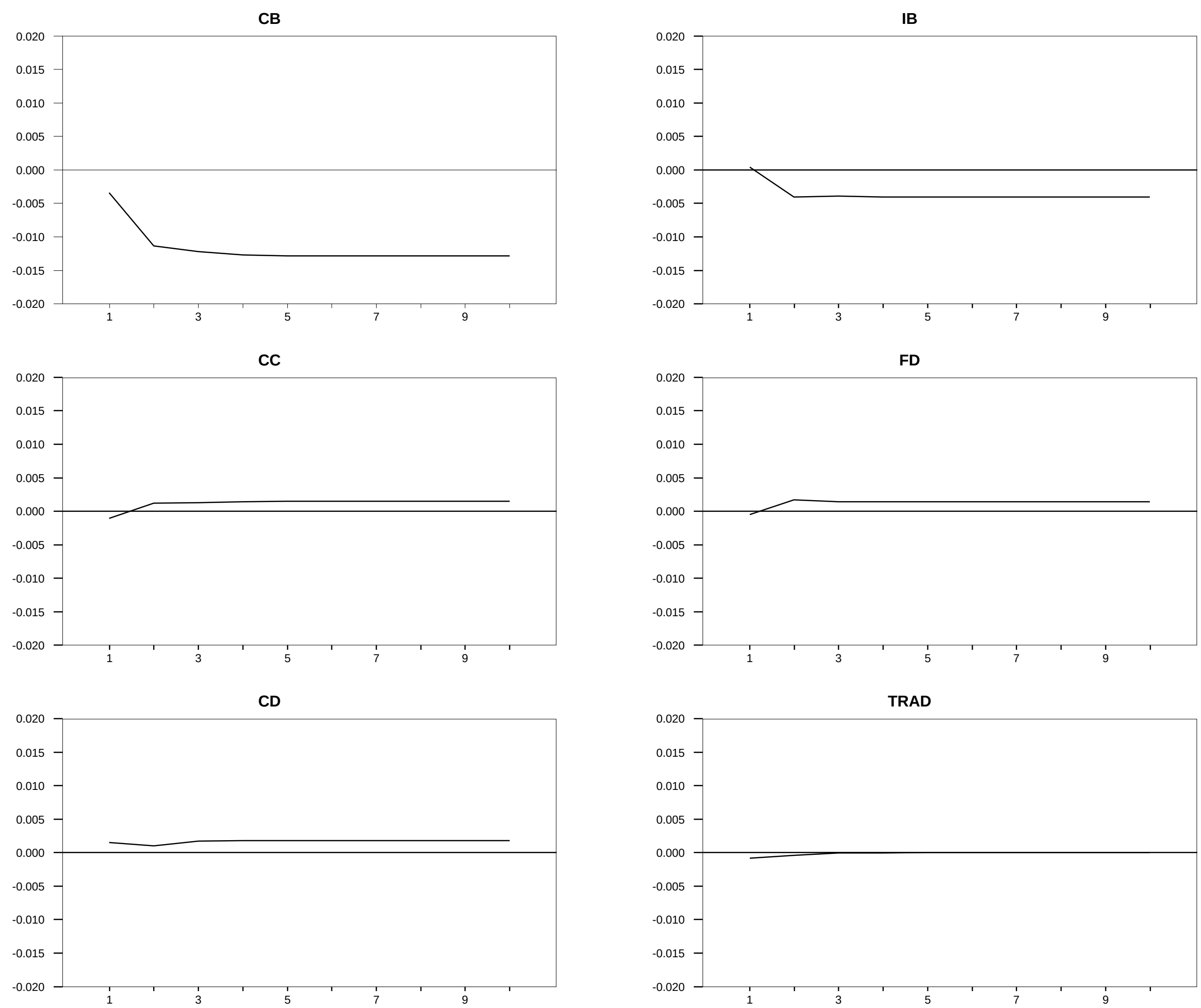

FIGURE 3. Cumulative Change in Returns in Response to Aggregate Shocks, Sample 2