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by Chris D'Souza

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## Abstract

This paper illustrates that dealers in foreign exchange markets not only provide intraday liquidity, they are key participants in the provision of overnight liquidity. Dealing institutions receive compensation for holding undesired inventory balances in part from the information they receive in customer trades. These flows can be used to forecast future movements in the exchange rate. Findings suggest that Canadian dealers, as a group and individually, are more likely to provide interday liquidity to foreign rather than Canadian financial customers. Financial institutions operating in multiple price-correlated markets manage their risky positions across markets. An interdependent relationship is revealed between the supply of liquidity provided by non-financial firms and dealing institutions across time, and across markets.



*JEL classification: F31, G21, D82*
*Bank classification: Exchange rates; Market structure and pricing; Financial markets*



## Résumé

Comme l'auteur le montre, les institutions actives sur les marchés des changes ne font pas qu'assurer la liquidité durant la journée : elles jouent aussi un rôle important dans la fourniture de liquidité au-delà d'un jour. Les coûts liés au maintien de positions non désirées sont contrebalancés en partie par l'information tirée des transactions avec la clientèle. Cette information peut en effet aider à prévoir les variations du taux de change. D'après les résultats présentés, les cambistes canadiens seraient, tant collectivement qu'à titre individuel, plus enclins à procurer de la liquidité au-delà d'un jour à leurs clients lorsque ceux-ci sont établis à l'étranger. Les institutions financières assurant la tenue de multiples marchés dont les cours sont corrélés gèrent leurs positions risquées sur plusieurs marchés à la fois. L'auteur met en lumière l'interdépendance des activités d'apport de liquidité des institutions financières et des entreprises non financières, aussi bien dans le temps que sur les différents marchés.



*Classification JEL : F31, G21, D82*
*Classification de la Banque : Taux de change; Structure de marché et fixation des prix; Marchés financiers*

# 1. Introduction

Dealers in foreign exchange (FX) markets are intraday liquidity providers. They stand ready to buy and sell foreign exchange at their posted bid and offer quotes throughout the trading day. It is commonly assumed that these market making institutions hold only limited overnight, or interday, FX positions. Studies by Lyons (1995) and Bjonnes and Rime (2005), analyzing the inventory management practices of individual traders, show that dealers do not usually hold open positions for a significant amount of time. In contrast, Bjonnes, Rime and Solheim (2005, and hereafter referred to as BRS) present preliminary evidence that, while the burden of interday liquidity provision falls on non-financial participants in the foreign exchange market, market making financial institutions provide liquidity overnight, and continue to do so for longer periods of time.

Liquidity provision is important in financial markets where trading is dispersed and immediacy is a concern to certain participants.[1] This paper studies in greater detail the dynamics associated with the provision of overnight liquidity in foreign exchange markets. In particular, it examines the circumstances in which market making institutions hold overnight positions, and the manner in which they off-load these positions over time, across markets, and across participants. Using data collected by the Bank of Canada, obtained from individual FX dealing institutions operating in the US-dollar/Canadian-dollar FX market in Canada, this paper finds that dealers play a non-trivial role in the provision of interday liquidity.[2] Similar to BRS, participants are divided into types of customers, each with distinct foreign exchange demands. Unlike many studies, the analysis of market making behaviour focuses on entire dealing financial institutions rather than individual dealers. Empirical research analysing the behaviour of individual traders may not reflect the norm across all trading desks. Further, in comparison to BRS, the data allows for a more complete examination of the role of each type of FX participant in both the taking and supplying of liquidity. Findings suggest that market making institutions and non-financial firms work interdependently in the provision of liquidity.

In addition to a spread, dealers may hold a risky FX position in return for information learned from the corresponding trade.[3] In particular, dealers may be informed about future

[1] More generally, an illiquid or poorly functioning FX market imposes additional costs on companies engaged in international trade or involved in foreign investments. As well, it may hinder the speed in which information is reflected in prices. Typically, a liquid financial market is characterized as one in which traders can rapidly execute large transactions with only a small impact on prices.

[2] The US-dollar/Canadian-dollar FX market is the fourth largest currency market. USD/CAD will hereafter be used to represent the exchange rate or FX market.

[3] Dealers that provide liquidity may be left with an undesired inventory position. A bid-offer quote spread

movements in the exchange rate by observing order flow—sometimes measured as the volume of buy orders relative to sell orders. For example, an excess quantity of net buy (sell) orders for the Canadian dollar suggests that market participants may have a positive (negative) impression about the future prospects of the Canadian dollar. Evans and Lyons (2002a) demonstrate that order flow predicts future foreign exchange returns.[4] Since dealers have a comparative advantage in acquiring order-flow information from their privately dealings with customers, they must balance the inventory risk associated with providing liquidity with the expected excess returns generated from informed speculation.

Evans and Lyons (2004) and Osler (2008) have suggested that customer trading in the FX market is the catalyst for profitable dealer trading since it is a valuable source of relevant information about exchange rate fundamentals. Further, certain trades in the FX market are more informative than others. BRS, as well as Fan and Lyons (2003), Froot and Ramadorai (2005), and Mende, Menkhoff, and Osler (2006) find the trades of financial firms to be more informative than those of non-financial firms. Unlike BRS, the trades of financial customers in this paper are broken down into those that are initiated in Canada, and those that initiated from abroad. D'Souza (2007) finds that dealers operating from the largest FX commercial centers in the world, such as the London and New York are also asymmetrically informed. Results in this paper suggest that overnight liquidity dynamics will depend on the type of customer demanding liquidity and the information content of those trades. Section 2 provides some background regarding the institutional structure of the FX market. It also describes each participant's fundamental needs for foreign exchange.

Trading dynamics are affected by the flow of information in financial markets, but not all relevant information in the FX market is associated with macroeconomic variables. Cao, Evans and Lyons (2006) suggest that dealers use private information about their own inventories as a profitable avenue for speculation since any undesired inventories must be absorbed elsewhere in the marketplace. This has direct implications for the supply of liquidity in the FX market. In particular, providing liquidity to customers affords dealers an opportunity to speculate on future movements in the exchange rate. If this is the only source of information then all types of customer trades should have the same impact on the behaviour of dealers. On the contrary, findings in this paper suggest that the trades of financial firms domiciled outside of Canada are more likely to induce dealers to provide liquidity. In Section 3, the

is applied to compensate for inventory risk. O'Hara (1995) describes how dealers can manage their inventories by adjusting their bid and offer quotes.

[4] Hasbrouck (1991a,b) and Brandt and Kavajecz (2004) find similar evidence in equity and fixed-income markets, respectively.

Cao, Evans and Lyons (2006) model is extended to allow for both payoff and inventory information to affect the trading strategies of dealers. The equilibrium of the model provides a set of testable implications.

The data used in this study is described in Section 4 of the paper. Causality tests indicate that the trades of foreign-domiciled financial customers motivate other participants in the market to trade. Employing time-series methods, Section 5 illustrates that dealers as well as non-financial customers are both interday providers of liquidity, acting in an interdependent fashion. Long-run cointegrating relationships between the positions of market participants and exchange rates are identified. Unlike foreign-domiciled financial customers, Canadian-based financial customers generally pay a price for liquidity services. Judging by the intensity or speed with which dealers off-load these positions, dealers consider Canadian-based financial customers trades to be less relevant in forecasting the future level of the exchange rate. They are less concerned if this source of private information is quickly revealed to the rest of the market. Similar exercises are performed with disaggregated bank-by-bank dealer and customer positions. Findings suggest that individual dealing institutions behave in a similar manner.

This paper also examines the positions of market participants across correlated FX markets, and whether these positions affect dynamics in the supply of overnight liquidity. When prices are correlated, dealers are able to hedge risk, and even speculate, across markets. Naik and Yadev (2003) provides empirical evidence suggesting that U.K. government bond dealers hedge their spot exposure in derivatives markets. Drudi and Massa (2005) illustrate how dealing banks participating in the Italian Treasury bond market exploit private information by simultaneously trading in both primary and secondary markets. The appendix to the paper extends the Cao, Evans and Lyons model to include correlated asset markets.

In Section 6, participants' positions in both spot and forward contract markets are examined. In general, market making institutions jointly manage their positions across markets. While dealers provide immediate liquidity to foreign-domiciled financial customers in spot FX markets, they take a partially offsetting position in the forward market. The total speculative position across spot and forward markets, which falls across time, may be associated with the dispersion of relevant information in to the market. Again, the positions of the various market participants are interrelated. For example, non-financial customers, increasingly provide liquidity over time in forward markets as dealers reduce their exposure. Last, consistent with the earlier findings, dealing banks quickly hedge their overall position across forward and spot markets subsequent to a Canadian-domiciled financial customer trade shock.

Taken together, these results suggest that the role of market makers in overnight liquidity provision should not be discounted. While BRS find support for the view that non-financial firms are the main providers of liquidity, findings in this paper suggest that market making dealing institutions intermediate in the overall process. They may hold on to risky positions for longer periods of time than suggested by the existing literature. The overall results support arguments by Stulz (1996) and Froot and Stein (1998) that the amount of hedging will depend on a firm's comparative advantage in bearing risk. In the FX market, a dealing institution's source of comparative advantage stems from their role as intermediaries in the intraday market and their ability to observe customer and market-wide order flow.

## 2. Information and Participants in FX Markets

The foreign exchange market is the largest financial market in the world. Average daily turnover in spot transactions, outright forwards and foreign exchange swaps was U.S.$1.97 trillion in April 2004, up from U.S.$1.15 trillion in 1995 and 1.42 trillion in 2001 (BIS, 2005). The largest individual FX markets involve currencies that are extensively used in international trade transactions. The US-dollar/euro, US-dollar/Japanese yen, and US-dollar/British pound sterling markets account for 27 per cent, 13 per cent, and 12 per cent, respectively, of total trading in all currency markets (BIS, 2007). In terms of total trading volumes, the Canadian and Australian dollars, along with the Swiss franc, make up the next tier of currencies involved in FX transactions. The US-dollar/Canadian-dollar market represents approximately 4 per cent of total FX currency volumes throughout the world.

Dealers in FX markets continuously supply bid and offer quotes to both customers and other dealers. Through the course of the day, they stand ready to buy and sell foreign exchange, thus providing liquidity to the market. Given the unpredictable inventory shocks that dealers face in their trades with customers, interdealer markets have developed to facilitate inventory management and risk-sharing.[5] In 2005, interdealer flows in the US-dollar/Canadian-dollar market represented more than 70 per cent of total trading volumes (CFEC, 2006). While dealers in the FX market may share their inventory exposure with other dealers, as a group they provide certain levels of liquidity to other market participants that have speculative and hedging needs.

[5] While historically these interdealer markets were direct and bilateral in nature, the introduction of interdealer brokers (IDBs), such as Reuters and EBS, has significantly reduced the role of direct interdealer trading. Brokers in the FX market are only involved in interdealer transactions, and communicate dealer prices to other dealing banks without revealing their identity. Unlike dealers, brokers act as pure matchmakers.

Unlike equity markets, where some investors may have more precise information regarding the business operations and conditions of a company, information about the exchange rate is typically assumed to be public and simultaneously available to all interested participants.[6] Despite this, Ito, Lyons, and Melvin (1998) find empirical evidence of private information in the FX market. Furthermore, a number of studies including Evans and Lyons (2002b) and Payne (2003) find that market wide order flow, a measure of buying or selling pressure in the FX market, can explain up to two-thirds of the variation in exchange-rate returns. Intuitively, a trader that is worried about losing private information they currently possess will immediately execute a trade against the best prevailing ask or bid quotes in the market.

One important characteristic that distinguishes FX trading from trading in equities is the lower level of trade transparency publicly available to the market. There are no disclosure requirements. Individuals and firms that need to buy and sell foreign exchange typically trade with dealers on a bilateral over-the-counter basis. These trades are only known to the two counterparties involved in the transaction so that any private information collected from trading may be exploited for a longer period of time. Cheung and Wong (2000), in survey evidence, find that dealing banks list a larger customer base and better order-flow information as two sources of comparative advantage. Each dealer will know their own customer orders through the course of the day, and will try to deduce from the order flow the net imbalance in the market.[7]

In FX markets, the customers of dealers are the financial and non-financial firms that are the end-users of foreign exchange for settling imports or exports, investing overseas, hedging cross-currency business transactions, or speculating. Evans and Lyons (2004) argue that individual customer trades contain pieces of new information about the underlying macroeconomic fundamentals driving the exchange rate. In aggregate, each type of customer order flow may be an important source of information that accrues to dealers, and that subsequently drives interdealer speculation. The analysis below distinguishes between various types of customer flows. Commercial client business captures FX transactions related to commercial, or trade related, activity while investment flows (foreign and domestic) emphasize the investment, or capital, flow nature of those transactions. During the period studied (e.g., 2000-2005), central bank flows in Canada were not associated with intervention (i.e., to have an impact on exchange rates) but with the replenishment of FX reserves. Dealers were aware

[6] According to the traditional monetary model of the exchange rate, the determination of the exchange rate is related to macroeconomic variables such as foreign and domestic nominal interest rates, inflation rates, and output levels. FX dealers have access to similar, real-time news feeds that broadcast new information about these variables immediately after they are released.

[7] Dealing banks also learn about market-wide order flow from brokered interdealer trades.

of this policy. In the next section, a model is developed that illustrates the role of private information in the trading strategies of dealers.

## 3. Model

Participants operating in foreign exchange markets may hold undesired and risky inventory positions over a given period of time. In particular, liquidity suppliers will absorb an imbalance in the market, but will expect to be compensated in terms of higher returns. Generally, returns will reflect a risk premium associated with this source of non-diversable risk, though the overall price of liquidity may be affected by the level of competition amongst liquidity providers. Dealers can generate higher expected returns through speculation. Their trading strategies will use the private information available from customer trades.

In the model laid out in this section, two assumptions are required to generate these predictions. Participants, including dealing institutions, must be risk averse, and trade transparency in FX markets cannot be perfect. Together, these ingredients reduce the information content of trades and prices in the short-run, and allow for trading that is based on differences in individual forecasts of future prices. Permitting some level of opacity in trades is realistic in the short-run, especially between customers and dealers, reflecting the over-the-counter nature of this segment of the market.

The simultaneous trade model presented in this section is based on Lyons (1997, 2001) and Cao, Evans, and Lyons (2006). The model incorporates many realistic features and institutions of the FX market including a multiple dealer structure in which market makers are required to provide firms quotes. Further, dealers may manage their inventories through interdealer trading. This large and essential part of the trading process in FX markets is also the avenue through which dealers can exploit private information.

The model includes a number of simplifying assumptions. First, dealers in the model must quote and trade in a simultaneous manner in the multiple rounds of quoting and trading.[8] In reality, dealers trade with one another in a more sequential and immediate manner. When a dealer's inventory is perturbed, quotes are adjusted immediately so as to elicit an incoming trade, or alternatively, a dealer may hit or take another dealer's quote.[9]

[8] All the rules governing quotes and trades are listed in Lyons (1997). They are based on the actual conventions adopted in the FX marketplace.

[9] Instead of modelling bid-ask spreads, the model allows for only a single price at which dealers agree to buy and sell any amount.

Simultaneity is introduced by Lyons (1997) to constrain a dealer's conditioning information. Each individual dealer cannot place an order conditional on an incoming order of another dealer. This would give the dealer an unfair advantage. Lastly, while the model was originally intended to illustrate the trading behaviour of participants across a single day, it can also be characterized as a model of interday trading. Generally, the length of a period should correspond to the amount of time that it take for all private relevant information to be fully revealed in prices.

There are multiple rounds of quoting and trading in each period of the model, but the catalyst for all trading is the demand for liquidity by customers at the beginning of each period. Once customers trade with dealers, two rounds of interdealer trading take place. Information about market-wide order flow is revealed to the market in-between interdealer trading rounds. Dealers are able to trade strategically in the earlier interdealer trading round using their private information. Once this information is partially revealed through order flow, and reflected in prices, dealers may reduce their speculative position. At the end of the period, a final round of trading occurs between dealers and liquidity suppliers. Suppliers may include all types of participants in the FX market, including the trading desks of financial institutions. The only requirement is that participants are compensated sufficiently for their risky inventory positions. Tien (2001) suggests that flows are a statistically important variable in the determination of exchange rates, not because of informational asymmetries but because risk sharing exists in the FX market.

In the Cao, Evans, and Lyons model, speculation in interdealer trades is not related to payoffs, but to inventory information.[10] Customer-dealer trades serve as the main source of private information accrued to dealing banks in forecasting future prices. In particular, these trades help dealers forecast the net undesired inventory position in the market, and hence the market-wide compensation that must be paid for bearing exchange rate risk. The model developed below extends the Cao, Evans, and Lyons environment to allow for the utilization of payoff-relevant information in dealer strategies. Since the data used in this paper is disaggregated by type of customer, comparisons in dealer behaviour across trades can be made. If payoff-relevant information is absent, then all types of customer trades should have a similar impact on the dynamics of liquidity provision and exchange rates.

The model includes $n$ dealing banks whose traders behave strategically. Liquidity demanding customers are assigned to individual banks and have an exogenous demand for FX. Each dealer's customer base includes investors, speculators, corporate treasurers, liquidity

[10] See O'Hara (1995) for a comparison of the inventory and information approaches in microstructure theory.

traders, and central banks. A large number of liquidity suppliers (including dealing banks and their customers) exist, and must be induced to absorb an FX inventory position. There are two assets, a risk-free bond and risky FX.[11] The risky asset is in zero supply initially, and has a payoff $S$, where $S$ is independently and normally distributed with mean 0 and variance $\sigma_s^2$. Gross returns on the riskless asset are normalized to one. Quoting and trading by dealers in the model is discrete and characterized by a series of four rounds of trading.

The model opens with an initial round of customer-dealer trading. Let $c_i$ denote the net value of all customer FX orders received by dealer $i$ (positive for customer purchases). This variable is private information to dealer $i$. In particular, customer trades are not observed by other dealing banks. Customer orders are not independent of the payoff to the risky asset, $S$. Since we allow for the possibility of payoff-relevant information in these trades, $c_i$ is decomposed into a common component correlated with the value of the risky assets, $c$, and a private component that is idiosyncratic and specific to the each dealer, $x_i$

$$c_i = c + x_i$$

$$c = S + v$$

where $x_i$ and $v$ are independently and normally distributed with mean 0 and variance $\sigma_x^2$ and $\sigma_v^2$, respectively. Let $T_{ik}$ denote the net outgoing interdealer order of FX in the $k$th round of interdealer trading placed by dealer $i$ (where $k = 2, 3$) and let $T'_{ik}$denote the net incoming interdealer order received by dealer $i$ placed by other dealing banks. $T_{ik}$ is positive for dealer $i$ purchases, while $c_{i1}$ and $T'_{ik}$ are positive for purchases by customers and other dealing banks from dealer $i$, respectively. At the end of round two, dealing banks observe the first round of interdealer order flow

$$V = \sum_j T_{j2}.$$

This sum of all outgoing trades, $T_{i2}$, is net demand—the difference in buy and sell orders in the market.[12] In the last round of trading, liquidity suppliers absorb the net position in the market once all uncertainty is resolved. Dealing institutions may hold a non-zero FX position at the end of each period, and are assumed to compete with other participants in the provision of liquidity service.

The eight events of the model occur in the following sequence:

[11] In the appendix, the model is extended to allow for multiple correlated risky assets.
[12] In the FX market, $V$ is the information on interdealer order flow provided by interdealer brokers.

**Round 1: Dealer quoting and customer-dealer trading**

Dealers quote to customers, $P_{i1}$

Dealers receive net customer orders, $c_i$

**Round 2: Interdealer quoting and trading**

Dealing banks quote to each other, $P_{i2}$

Dealing banks trade with other dealing banks, $\{T_{i2}, T'_{i2}\}$

Interdealer order flow is observed at the end of the round, $V$

**Round 3: Interdealer quoting and trading**

Dealing banks quote to each other, $P_{i3}$

Dealing banks trade with other dealing banks, $\{T_{i3}, T'_{i3}\}$

Payoff on the risk asset is realized, $S$

**Round 4: Dealer quoting and trading with liquidity suppliers**

Dealers quote to liquidity suppliers, $P_{i4}$

Dealers trade with liquidity suppliers, $\sum c_i$

Outgoing interdealer orders in each of the two rounds of interdealer trading are two strategic choice variables in each dealer's maximization problem. If $D_{ik}$ denotes dealer $i$'s speculative demand in interdealer round $k$, then

$$T_{i2} = D_{i2} + c_i + E[T'_{i2}|\Omega_{i2}] \tag{1}$$

$$T_{i3} = D_{i3} - D_{i2} + c_i + E[T'_{i3}|\Omega_{i3}] - E[T'_{i2}|\Omega_{i2}]. \tag{2}$$

Let $\Omega_{ik}$ and $\Omega_k$ denote dealer $i$'s private and public information sets at the in round $k$

$$\begin{array}{cc}
\Omega_{i1} = \{\{P_{i1}\}_{i=1}^{n}\} & \Omega_1 = \{\{P_{i1}\}_{i=1}^{n}\} \\
\Omega_{i2} = \{c_i, \{P_{i1}, P_{i2}\}_{i=1}^{n}\} & \Omega_2 = \{\{P_{i1}, P_{i2}\}_{i=1}^{n}\} \\
\Omega_{i3} = \{c_i, T_{i2}, T_{i2}, V, \{P_{i1}, P_{i2}, P_{i3}\}_{i=1}^{n}\} & \Omega_3 = \{V, \{P_{i1}, P_{i2}, P_{i3}\}_{i=1}^{n}\} \\
\Omega_{i4} = \{c_i, \{T_{ik}, T_{ik}\}_{k=2}^{3}, V, \{P_{i1}, P_{i2}, P_{i3}, P_{i4}\}_{i=1}^{n}\} & \Omega_3 = \{V, \{P_{i1}, P_{i2}, P_{i3}, P_{i4}\}_{i=1}^{n}\}.
\end{array}$$

Equation (1) illustrates that dealer $i$'s Round 2 outgoing order includes both information-driven components, $D_{i2}$ and $c_i$, and inventory components, $c_i$ and $E[T_{i2}|\Omega_{i2}]$. Trading in the first round with customers must be offset in interdealer trading in the second round to establish a desired inventory position, $D_{i2}$. Dealing banks also do their best to offset the incoming dealer order, $T'_{i2}$, which they cannot know ex-ante. In round three, outgoing trade orders (2) will be determined by changes in a dealer $i$'s speculative position, $D_{i3} - D_{i2}$, and inventory management considerations such as a revision in the expected value of incoming interdealer orders, $E[T'_{i3}|\Omega_{i3}] - E[T'_{i2}|\Omega_{i2}]$.

All participants in the FX market have identical negative exponential utility defined over nominal terminal wealth. Since individual dealers do not hold overnight positions, they solve a one period problem, Letting $W_{i4t}$ denote end-of-period wealth $t$ of dealer $i$. Each dealer determines quotes and speculative demands by solving the following problem

$$\max_{\{P_{ikt}\}_{k=1}^{4}, \{D_{ikt}\}_{k=2}^{3}} E[-\exp(-\theta W_{i4t}|\Omega_{i1})]$$

s.t.

$$\begin{aligned} W_{i4t} &= (W_{i0t} + c_{it}P_{i1t} + T'_{i2t}P_{i2t} + T'_{i3t}P_{i3t} - T_{i2t}P'_{i2t} - T_{i3t}P'_{i3t}) + \\ &\quad (-c_{it} - T'_{i2t} + T_{i2t} - T'_{i3t} + T_{i3t})(P'_{i4t} + S). \end{aligned}$$

A perfect Bayesian equilibrium (PBE) in which Bayes rule is used to update beliefs, and strategies are sequentially rational given those beliefs, is characterized by the following four propositions. Proofs of each proposition are given in Lyons (1997, 2001) and Cao, Evans and Lyons (2006).

**Proposition 1** *A quoting strategy is consistent with a symmetric PBE only if Round 1 and 2 quotes are common across dealing banks with* $P_1 = P_2 = E(S) = 0$.

Prices are common to avoid arbitrage opportunities amongst dealers. In order to ensure that markets clear, prices can only be functions of public information. If dealers expect prices to change from Round 1 to Round 2 (say, to account for $c_i$), then total expected dealer demand cannot be equal to zero. A similar argument explains why prices must also be unbiased in Round 2.

**Proposition 2** *A quoting strategy is consistent with a symmetric PBE only if the Round 3 quote is common across dealing banks with* $P_3 = E(S) + \lambda V$.

The additional public information in Round 3 is interdealer order flow, $V$. Since $V$ is contained in $\Omega_3$, it provides information about the average value of $c_i$. For example, if

$V = \sum T_{i2} > 0$, dealers are on average buying FX in interdealer markets. Given Proposition 4, this implies that customers on average bought FX from dealers in the first round of the model. Since markets must also clear in Round 3, $P_3$ must increases beyond $E[P_4|\Omega_3]$ to provide a temporary premium that induces dealers to hold risky positions until Round 4.

**Proposition 3** *The end-of-period price is a linear function of the aggregate supply of liquidity.*

In the fourth round, dealers may trade with other FX participants in order to reduce their inventory position. Liquidity suppliers (customers and dealing banks) are not willing to absorb a risky inventory position without receiving higher expected returns. The net position that must be absorbed by liquidity suppliers will be equal to the total net FX position demanded by customers in the first round of the model.

**Proposition 4** *The trading strategies of dealer $i$ in a symmetric PBE are linear:*

$$\begin{aligned} T_{i2} &= \beta_1 c_i \qquad \beta_1 > 0, \beta_2 < 0 \\ T_{i3} &= \beta_2 c_i \qquad \forall i = 1, .., n. \end{aligned}$$

These optimal trading strategies take into account dealer $i$'s recognition that individual interdealer trades will affect prices. Private information motivates out-going dealer trades in Round 2 as dealers attempt to manipulate Round 3 prices through order flow, $V$. In Round 3, risk-averse dealers hedge their risk exposure. The qualitative predictions of the model are similar with and without payoff relevant information:

(i) Dealers speculate on the future direction of the exchange rate using the private information learned from their trades with customers.

(ii) Dealers speculate and hedge positions across time.

(iii) Dealing institutions in FX market provide interday liquidity if compensated for risk.

# 4. Data and Descriptive Statistics

The primary source of data is the Bank of Canada's foreign exchange volume report. The report is coordinated by the Bank, and organized through the Canadian Foreign Exchange

Committee (CFEC). It provides details about FX trading flows, both purchases and sales, for all dealing financial institutions operating in Canada. In Canada, most FX trades are handled by the top six Canadian banks.[13] Trades may or may not be initiated by traders working directly for an FX desk. The dataset employed in this paper covers a five-year period and includes daily data over the period October 2, 2000 through to September 30, 2005, or more than 1250 observations.[14] The Bank of Canada also provides daily USD/CAD spot closing rates, and 10-year and 3-month interest rate spreads between Canadian and U.S. government bond yields. Since the foreign exchange rate is quoted as the number of Canadian dollars per U.S. dollar, a rise in the exchange rate represents a depreciation in the Canadian dollar.

Trading is disaggregated by FX market (spot and forward) and by the trading partners of dealers. Spot transactions are those involving receipt or delivery on a cash basis or in one business day for foreign exchange, while forward transactions are those involving receipt or delivery in more than one business day for foreign exchange.[15] The series are reported in Canadian dollars, and include trading against all other currencies, although most trading is in USD/CAD.[16] Net flows, purchases less sales, are categorized according to customer type: commercial client business (CC) includes all transactions of resident and non-resident non-financial customers; Canadian-domiciled investment flow business (CD) accounts for transactions of non-dealer financial institutions located in Canada, regardless of whether the institution is Canadian-owned; foreign-domiciled investment business (FD) consists of all transactions of financial institutions, including FX dealers, pension funds, mutual funds and hedge funds, located outside Canada; and trades of the central bank (CB, i.e., the Bank of Canada). Participants are grouped in this manner in an attempt to distinguish between trade-related and capital-related flows. Net interbank transactions purchases (IB) between Canadian dealers are only considered in the disaggregated bank-by-bank analysis. These transactions are approximately zero when aggregated across reporting dealers.

The paper examines the daily net flows and the currency positions of each type of par-

[13] The largest FX dealers in Canada include the following banks: Bank of Montreal, Canadian Imperial Bank of Commerce, Banque Nationale, Royal Bank of Canada, Scotiabank, Toronto Dominion Bank

[14] The disaggregated data employed in this analysis is not available to market participants. Reporting institutions obtain some statistical summaries of the volume aggregates from the Bank of Canada, but only with a considerable lag.

[15] A forward contract is an agreement between two parties to buy or sell an asset at a specified point of time in the future. Since FX swaps are made up of both spot and offsetting forward contract legs they are not used in the analysis.

[16] In 2005, more than 96% of all spot, forward and FX swap trades, among reporting banks in Canada, included the Canadian dollar in at least one leg of the transaction (CFEC, 2006).

ticipant. At any point in time, position amounts are equal to the cumulative sum of net flows. The flows and positions of market makers as a group and individually, indexed by $i$, are calculated as follows:

$$MM_t = -(CC_t + CD_t + FD_t + CB_t) \tag{3}$$

and

$$MM_{it} = -(CC_{it} + CD_{it} + FD_i + CB_{it}) + IB_{it}. \tag{4}$$

Descriptive statistics associated with the daily net trading flows of each customer group are presented in Table 1. On average, commercial client and foreign-domiciled investment flows are larger and more volatile than Canadian-domiciled investment. Dealer flows are just as volatile as CC and FD flows. Interestingly, commercial clients, on average, purchase Canadian dollars, while foreign-domiciled financial institutions sell Canadian dollars. The magnitude of the means and medians associated with spot and forward flows suggest that foreign institutions do not utilize the forward market as intensively as domestic participants, such as Canadian dealers and commercial clients. Unlike the correlation between spot and forward flows for commercial clients and foreign-domiciled investment flows, the correlation between spot and forward flows for market making dealers is large in absolute value and negative, perhaps suggesting that dealing institutions use the two markets jointly to manage their overall FX position.[17] The Bank of Canada does not use the forward contract market in its operations.

Table 2 presents correlation coefficients between participant flows in spot and forward markets, individually and combined. These statistics indicate a strong negative correlation between commercial clients and foreign-domiciled institutions (combined market: -0.673, spot market: -0.421, forward market: -0.257), between foreign-domiciled institutions and market making dealing institutions in spot markets (-0.698), and between commercial clients and market making dealing institutions in forward contract markets (-0.623). Together these correlations may indicate that while commercial clients are the ultimate source of liquidity to foreign-domiciled institutions, the process is intermediated through dealers. For example, dealers may initially provide liquidity to foreign-domiciled institutions in the spot market. They can then turn around and demand liquidity from commercial clients in the forward contract market.

[17] Empirically, the correlation between spot and forward exchange rates is close to 100%, especially over periods greater and a few minutes (see Akram et al., 2006).

Table 3 displays $p$-values associated with Wald test-statistics calculated under the null hypothesis of no Granger-causality between each pair of variables. Similar to BRS, FD trades are "pushers" in the FX market, influencing both MM and CC flows in the short-run. Findings are consistent with FD customers taking a leading role in the price discovery process, with CC and MM offsetting any changes in the demand and supply of FX. Interestingly, FD, CC and CD trades are all influenced by movements in exchange rates. Participants may be engaged in some kind of trend chasing behaviour, or are simply rebalancing their portfolios as exchange rates adjust to new information and the supply of liquidity.

# 5. Liquidity Provision across FX Participants

This section empirically examines the role of each participant in providing overnight liquidity to the FX market. The following question is addressed: when trades are initiated by a particular type of investor, who holds the offsetting position at the end of the day, at the end of the week, or at any time in to the future? BRS provide evidence that non-financial customers are liquidity suppliers in the Swedish krona market. Those findings are now compared to results from an analysis of the Canadian dollar market. Results suggest that commercial clients (CC) are indeed liquidity providers in the Canadian FX marketplace, but so too are market making financial institutions (MM). Further, market makers are especially involved in providing liquidity services when foreign financial customers (FD) initiate trades in the market.

A vector error-correction model (VECM) is estimated by maximum likelihood methods to uncover the dynamic relationship between participant positions and the exchange rate.[18] Since the positions of all participants in the FX market must sum-up to zero, not all participant positions can be included in the estimation. Market maker inventories are left-out, but their value can be determined using Equations (3) and (4). Unit-root tests are performed on all variables included in the model. Panel A in Table 4 presents Augmented Dickey-Fuller and Phillips-Perron unit-root test statistics and their associated $p$-values. In all cases, the null hypothesis of a unit root cannot be rejected at the 5% significance level. Trace test statistics are employed to determine the number of cointegrating relationships. Results presented in Panel B provides evidence of two cointegrating vectors. Based upon the Schwarz Information Criterion (SIC), two lags and a deterministic trend are included in each cointegrating vector.[19]

[18] Estimation of vector error correction models is discussed in Hamilton (1994) and Johansen (1995).
[19] The trend in each cointegrating relationship is found to be significant.

A number of coefficient restrictions are imposed on the estimated model. They reflect the institutional considerations of the Canadian FX market, the implications of the theoretical model, and the statistical significance of the estimated coefficients. For example, the adjustment coefficients associated with each cointegrating vector in the foreign financial customer and central bank (CB) equations are not statistically different from zero, and are set to zero. Beginning in 1998, the Bank of Canada has chosen FX trading levels to have little or no impact on the exchange rate.[20] In both cointegrating vectors, coefficient estimates on CB are also set to zero. Table 5 summarizes the final version of the estimated model. A likelihood ratio test indicates that the restrictions imposed on the model cannot be rejected ($\chi^2(6) = 7.33$, $p$-value= 0.29).[21]

The estimated cointegrating vectors are presented in Panel A. In the first cointegrating vector, the exchange rate is normalized to one. This equation is associated with price discovery, and describes the long-run relationship between cumulative trade flows (or positions) and the exchange rate. Purchases of Canadian dollars by any one participant result in an appreciation of the Canadian dollar, all else equal. If FD trades are exogenous, the equation captures the long-run quantitative impact of these trades on commercial client positions, Canadian-domiciled financial (CD) customer positions, and the exchange rate. FD trades have the largest impact. D'Souza (2007) suggests that these participants are asymmetrically informed and influential in the price discovery process. The estimated coefficients associated with the positions of foreign financial customers and commercial clients are significant at the 1% level in the first cointegrating vectors.

In the second cointegration vector, the coefficient on the position of foreign financial customers—the "pushers" in the market, is normalized to one. This equation is associated with overnight liquidity provision, and relates liquidity demand and liquidity supply in the long-run. Estimates indicate that CC and FD take partially offsetting positions. Unlike BRS, a restriction that any change in the position of financial customers must be offset by an equal but opposite change in the position of non-financial commercial clients is rejected. Panel B reports the adjustment coefficients associated with each error-correction vector.

[20] With the exception of a coordinated effort by the Bank of Japan, U.S. Federal Reserve, Bank of England, European Central Bank, and Bank of Canada to defend the euro in September 2000, the Bank of Canada has not intervened since 1998. All recent purchases of foreign currencies are associted with the replenishment of foreign exchange reserves.

[21] 10-year and 3-month interest rate differentials between Canadian and U.S. benchmark government securities are included in the model to capture changes in market expectations of macroeconomic variables. They are found to be weakly exogenous. Further, coefficient estimates associated with these variables are not significant in either cointegrating vector.

Impulse response functions provide a convenient way to fully analyze the time-varying dimensions of liquidity provision given the interdependent nature of these variables. A shock to the $i$th variable not only affects the $i$th variable but is also transmitted to all of the other endogenous variables. Impulse response functions associated with the reaction of each variable to shocks in the positions of each customer-type are computed from the estimates of the VECM. Generalized impulse response functions are calculated rather than orthogonalized responses since the ordering of variables can be an important factor.[22] The reaction of each variable to a one standard-deviation innovation (i.e., a purchase of Canadian dollars) in CC, CD, and FD customer trades are documented in Table 6 at the 2-, 5-, 10-, 20-, 40-, and 100-day horizon. Negative values are associated with decreases in the Canadian dollar position of each participant. In the case of the exchange rate, negative values correspond to an appreciation of the Canadian dollar.

The long-run exchange rate reaction to each innovation reflects the fundamental information content of each type of trade.[23] FD purchases of Canadian dollars are associated with an appreciation of the Canadian dollar. Consistent with other findings in the literature, the market interprets net purchases by foreign financial customers as an indication that the dollar is undervalued. The effect of Canadian-domiciled financial institution purchases of Canadian dollars on the exchange rate, while also negative in sign, is not statistically significant at any horizon. While commercial client trades have a statistically significant impact on the exchange rate for up to ten days after the initial shock, results indicate that these customers must pay liquidity suppliers—especially market makers, for supplying this service. In particular, when CC customers demand Canadian dollars, the exchange rate will depreciate over the short-run. Overall, unlike FD trades, CC and CD trades are not informative about the long-run future value of the exchange rate.

Impulses in the positions of each customer type are persistent, and are usually statistically significant even at the 100-day horizon. More interesting is the impact of these impulses on the positions of other participants in the market. The impulse responses presented in Table 6 suggest that market makers provide considerable liquidity services to commercial clients. While CD and FD also take offsetting positions (for up to 40 business days), the magnitudes of these positions are substantially smaller and not statistically significant. In contrast, in response to a CD impulse, CC customers are the predominant liquidity provider. Market making institutions only provide liquidity for up to five days. Subsequent to a FD trade innovation, both CC and MM provide significant levels of liquidity, though commercial clients

[22] See Pesaran and Shin (1997).
[23] See Hasbrouck (1991a).

dominate in this role. CC customers actually increase their supply of liquidity over time as market makers reduce their exposure. There is little evidence of statistically significant liquidity provision by any participant subsequent to a CB shock.[24]

Overall, results are qualitatively similar to BRS. In particular, non-financial customers are found to provide liquidity to financial customers, both foreign and domestic. Findings further illustrate that market making institution are liquidity suppliers subsequent to the trades of non-financial customers. Finally, there is significant evidence that dealing institutions as a group are overnight liquidity providers to foreign domiciled financial traders, though not to the same extent as commercial clients.

These results are consistent with the implications of the theoretical model developed in Section 3 in which payoff relevant information exists in the FX market. Unlike the prediction of the original Cao, Evans and Lyons (2005) model, there is considerable evidence that not all customer trades are equal. The long-run impact on the exchange rate and the behaviour of dealers will depend on which type of participant is initiating a trade. In particular, market makers are quick to provide liquidity to FD customers, possibly in an attempt to capture any fundamental information contained in these trades. Overtime, dealers will off-load their positions to commercial clients as the information becomes stale, or as the risks associated with holding these undesired balances becomes too costly. While the Cao, Evans and Lyons model was developed to explain strategic intraday trading, evidence presented here suggests that the model may also describe price and trade dynamics interday. These results stand in contrast with anecdotal and empirical evidence suggesting that market makers are exclusively intraday liquidity providers.

To further examine the extent to which dealers and commercial clients engage and interact in the supply of liquidity, customer flows are disaggregated by individual dealing institution. The analysis focuses on the six largest financial institutions in Canada. These firms are also the largest domestic market makers in FX. Before directly analysing whether dealers behave similarly in the provision of liquidity, it is useful to first determine if a common factor exists across the customer flows of dealers over time. If dealers receive related customer orders, individually they should behave in a similar manner. Table 7 presents maximum likelihood

[24]This last set of results is not included in the table. With the exception of a coordinated effort by the Bank of Japan, U.S. Federal Reserve, Bank of England, European Central Bank, and the Bank of Canada to defend the euro in September 2000, the Bank of Canada has not intervened since 1998. All recent purchases of foreign currencies are associted with the replenishment of foreign exchange reserves.

estimates of the loadings, $\Lambda$, from a common factor analysis model

$$x = \mu + \Lambda f + e$$

where $x$ is a vector of net trades at individual financial institutions, $\mu$ is a constant vector of means and $f$ is the independent standardized common factor.[25] Large loadings suggest that common factors exist across dealers. Findings point to a single factor that can explain a large component of the common variation in FD and CC flows. Changes in the exchange rate may induce the commercial clients of different market making institutions to behave similarly when providing liquidity. Given earlier findings that foreign-domiciled financial customers trades are informative, it is likely that dealers compete for these flows. If so, informed customers may divide their total order among many dealers to mitigate the risk that anyone may be able exploit the information contained in their trades. There is little evidence that a common factor explains the variation in CD or MM flows across banks.

The amount of liquidity supplied by each individual dealer is analyzed using the same vector error-correction model framework employed above. The commercial client positions of each dealer subsequent to a liquidity demand shock are also examined to determine if these participants behave in a consistent manner across dealers. Again, either commercial client or market making institution positions are not included in the estimation of the model.[26] The restrictions imposed on the cointegration vectors and the adjustment coefficients in each VECM are similar to those discussed above.[27] For example, adjustment coefficients associated with the cointegrating vectors in the FD equations are still not statistically different from zero. For brevity, Table 8 only describes the results of two exercises: the response in the positions of each dealing institution, and each institution's commercial client customers, to a standardized innovation in foreign-domiciled financial investment flows. While the commercial clients of all six financial institutions are significant liquidity providers, so too are all six market makers.[28] Overall, the results are similar to those presented earlier. Market making institutions are key providers of liquidity, but typically in smaller amounts that commercial clients.

[25] See Harman (1976).

[26] CC or MM positions can be determined, ex-post, using Equations (3) and (4).

[27] Two lags, a deterministic trend, and two cointegrating vectors are included in the optimal specification.

[28] Canadian-domiciled financial customers provide some levels of liquidity, but levels are not consistent across financial institutions. There is little evidence that individual foreign domiciled financial institutions provided liquidity. These results are available from the author.

## 6. Liquidity Provision across Spot and Forward Markets

Acting as intermediaries in the FX market, dealing banks have a natural ability in acquiring private customer trade flow information. They also have another important source of comparative advantage in the provision of interday liquidity. Dealing financial institutions operate across asset markets with correlated returns. Naik and Yadav (2003) find that market intermediaries in U.K. bond markets actively use futures to hedge changes in their spot exposure. Drudi and Massa (2001) demonstrate that dealing banks participating in the Italian Treasury bond market exploit private information by trading in both primary and secondary markets, and take advantage of differences in trade transparency between those markets. In the appendix to this paper, the Cao, Evans and Lyons (2006) is further extended to include correlated assets. The model allows for hedging, as well as informed speculation, across markets and over time, as long as differences exist in the speed with which order flow information is made public.

In this section, the positions of each participant in FX spot and forward contract markets are examined. Individual participants may use one market more than the other in their regular business operations. Descriptive statistics presented in Table 1 suggest that foreign-domiciled financial customers trade mostly in spot markets while commercial clients operate across both markets. The correlation between the spot and forward trade flows of market making dealing institutions is large and negative. Dealers, acting as market makers in both markets, can reduce their inventory risk exposure in one market by having an offsetting position in another market. Pairwise Granger-causality tests presented in Table 9 illustrate that trading between market participants is related across markets. For example, commercial client and foreign domiciled financial investment trading in spot markets Granger-cause commercial client trading in forward markets. On the other hand, commercial client trades in forward markets have an impact on market maker trades in spot markets.

A vector error-correction model is estimated once again. In line with the results presented earlier, trace test statistics indicate the presence of two cointegrating vectors in a specification that includes a deterministic trend in each cointegrating vector. Estimates of the cointegration vectors and the adjustment coefficients change only slightly. In particular, once participant positions are disaggregated across spot and forward contact markets there is little evidence that FD trades are still weakly exogenous.

In Figure 2, impulse response functions associated with the positions of commercial clients and market making dealers, in both spot and forward markets, are plotted subsequent to a shock in the spot position of foreign-domiciled financial customers. Recall that these trades are typically treated by the market as been informative about future movements in the exchange rate. After a one-standard deviation innovation in FD, market makers manage a short Canadian dollar position in the spot market, and a long Canadian dollar position in the forward market. The positions are not symmetric. In total, dealers are net liquidity suppliers. They hold a larger negative position in the spot market.

Consistent with the predictions of the theoretical model developed in the appendix, market making institutions attempt to use the information learned from FD trades in the spot market while taking a partially offsetting, or hedged position, in the forward market. In contrast, commercial clients, who are not privy to the information content of FD flows, provide ample levels of liquidity across total spot and forward markets. Over time, as market makers reduce their overall exposure, commercial clients increase their positions. In Figures 3, similar impulse response functions are plotted subsequent to a shock in the spot position of domestic financial customers (CD). Results are considerably different. Market makers hold nearly offsetting positions across spot and forward markets. They sell Canadian dollars in the spot market and buy Canadian dollars in the forward market. The two positions are nearly identical in absolute value, and not statistically different from zero over time. Commercial clients, again, increasingly provide liquidity in both spot and forward markets over time.

Dealers are well suited to provide overnight liquidity in correlated markets given their superior position in the intermediation of intraday trading and their ability to operate across multiple markets. Overall, results suggest that the relationship between the positions of commercial clients and market makers, and the role played by dealers in overnight liquidity provision, has been understated. Depending on the information content of trades, and the demands for liquidity in individual markets, dealers may speculate across markets while simultaneously providing liquidity. Over time, dealers will off-load part of their inventory positions.

# 7. Summary, Conclusion and Future Work

Our current understanding of overnight liquidity provision in FX markets is incomplete. Anecdotal and empirical evidence based on the datasets of individual participants, suggests that dealers in FX market are not involved. This is not the case for Canadian financial institutions operating in the U.S. dollar-Canadian dollar market. This paper considers a number of hypotheses concerned with the provision of overnight liquidity by dealing financial institutions. With a finer disaggregation of trades, both in terms of the types of customers that trade with dealers, and a breakdown of positions across spot and forward contract markets, additional insight is gained on why, when and how dealer financial institutions provide this service.

The possible strategies that dealers engage in are demonstrated in a theoretical model based on Cao, Evans and Lyons (2006). Dealers use their own customer trades as a source of private information that may impart a temporary opportunity to make higher expected returns. Once the private information has been acted upon, or becomes stale, dealers will attempt to off-load any undesired positions to other participants in the market. Unlike domestic financial customers trades, foreign-domiciled financial customer trades are informative about future movements in the exchange rate. When trades are more informative, results presented in this paper suggest that dealers act more aggressively in the provision of liquidity. Consistent with BRS, there is ample evidence of a long-run relationship between the financial and non-financial customers of dealers in the demand and supply of liquidity. This paper finds that market making firms intermediate between these two participants over periods of time longer than a single day.

Dealing banks operating in the FX market have many potential sources of comparative advantage that may allow them to hold risky interday positions. For example, in the past, dealing institutions have negotiated quoting agreements between each other in order to guarantee access to minimum amounts of liquidity throughout the day. Electronic trading platforms such as EBS and Reuters now provide dealers with this kind of insurance. Non-market-making participants in the FX market do not have access to these electronic brokers. Further, since financial institutions allocate risk capital strategically across correlated business lines, financial institutions may have a higher tolerance for risk than other FX market participants. D'Souza and Lai (2006) illustrate how market making is influenced by the risk-bearing capacity of a dealer, which is itself determined by the amount of risk capital allocated to the activity. Future work will attempt to account for, and test, whether these advantages are also important determinants of interday liquidity provision.

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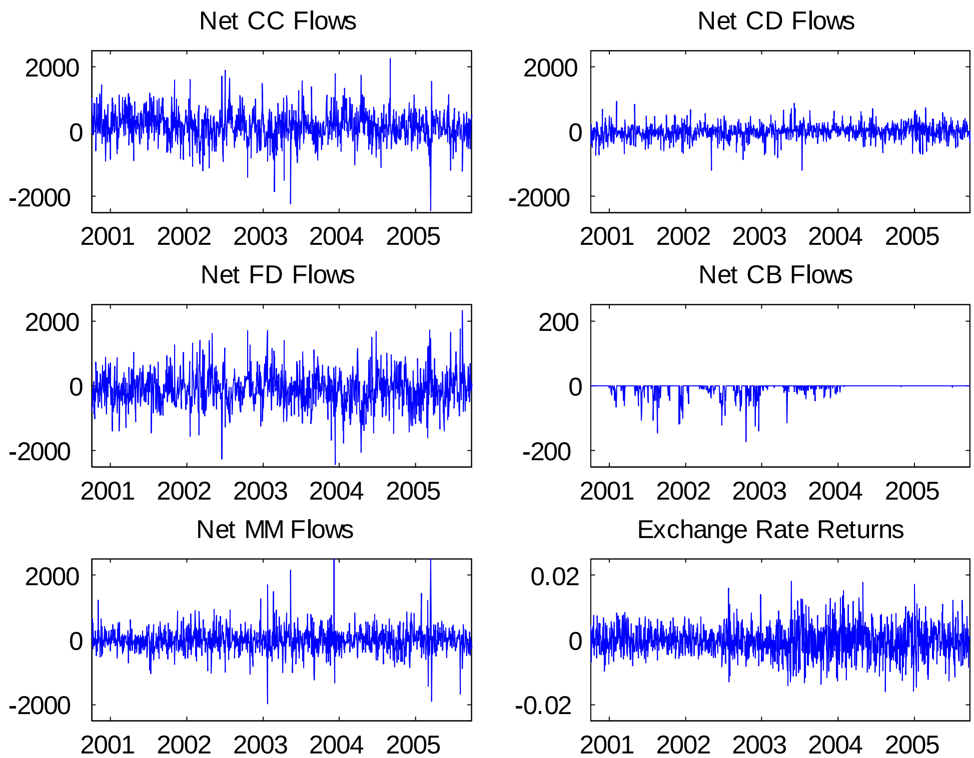


Figure 1: Trade Flows by Participant Type and Exchange Rate Returns, Daily

The net flows of market participants are categorized according to customer type: commercial client trading (CC) includes transactions by resident and non-resident non-financial customers; Canadian-domiciled investment (CD) include transactions by non-dealer financial institutions located in Canada, regardless of whether the institution is Canadian-owned; foreign-domiciled investment (FD) includes all transactions by financial institutions, including FX dealers, pension funds, mutual funds and hedge funds, located outside Canada; central bank flows (CB) include trades by the Bank of Canada; market making flows (MM) include trades by Canadian dealers. Exchange rate returns are calculated as the log difference in the U.S. dollar-Canadian dollar exchange rate. Sample: October 2, 2000 - September 30, 2005

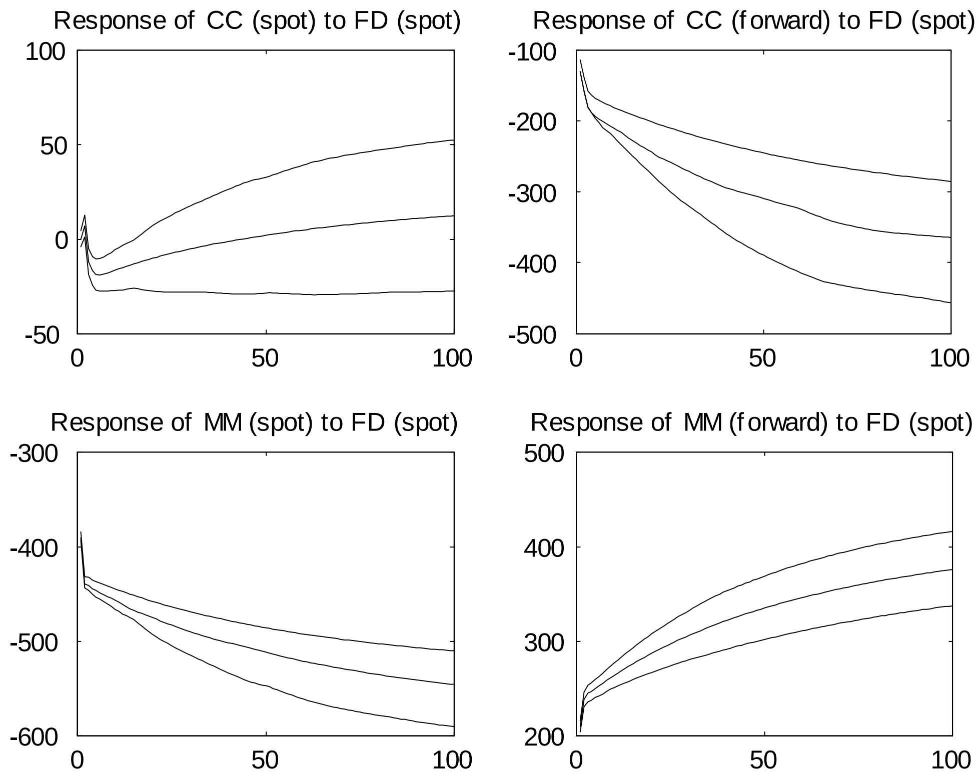


Figure 2: Generalized Impulse Response Functions, FD Innovation in the Spot Market

Impulse response functions are presented subsequent to 1-standard deviation innovation in foreign-domiciled investment (FD) in the spot market. 95% confidence intervals are plotted based on a bootstrap with 200 replications (Efron and Tibshirani, 1993).

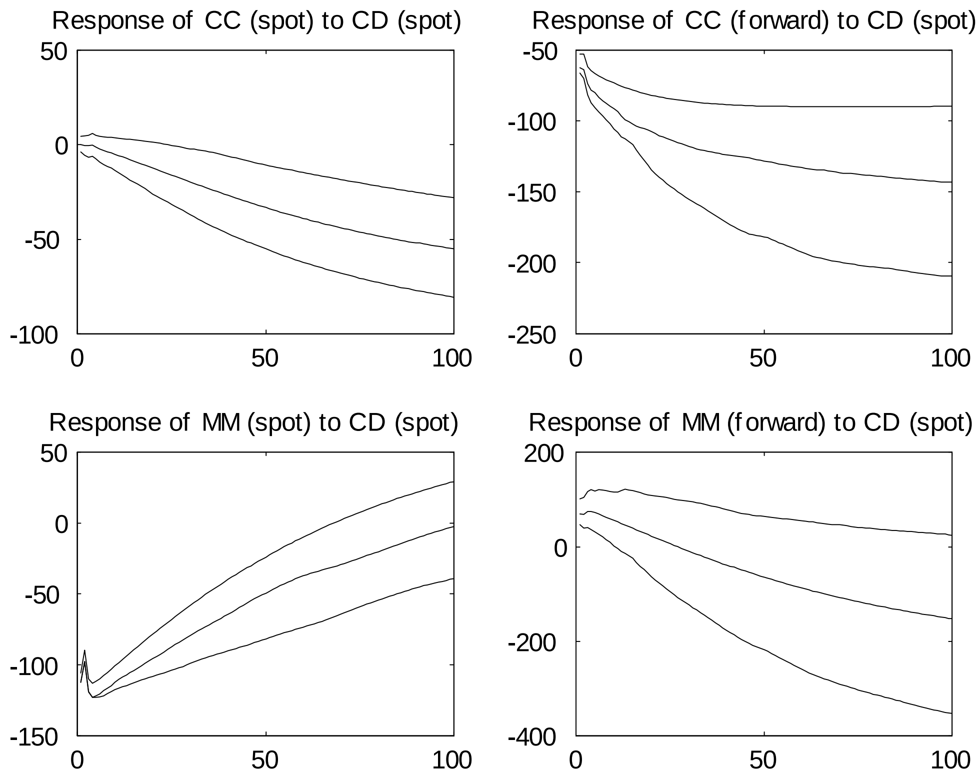


Figure 3: Generalized Impulse Response Functions, CD Innovation in the Spot Market

Impulse response functions are presented subsequent to 1-standard deviation innovation in Canadian-domiciled investment (CD) in the spot market. 95% confidence intervals are plotted based on a bootstrap with 200 replications (Efron and Tibshirani, 1993).

Table 1: Summary Statistics of Net Trade Flows, Spot and Forward Markets, Daily

Net daily trades flows for each participant are the difference between purchases and sales of Canadian dollars. Flows are categorized according to customer type: commercial client trading (CC); Canadian-domiciled investment (CD); foreign-domiciled investment (FD); central bank flows (CB); market making flows (MM) include trades by Canadian dealers. Net daily trading is also disaggregated by FX market (spot, forward). Spot transactions are those involving receipt or delivery on a cash basis or in one business day while forward transactions are those involving receipt or delivery in more than one business day. Sample: October 2, 2000 - September 30, 2005. Number of daily observations: 1255.

| | Participant Category | | | | |
|---|---|---|---|---|---|
| | CC | CD | FD | CB | MM |
| | Total Across Markets | | | | |
| Mean | 153.86 | -12.39 | -104.62 | -5.72 | -6.17 |
| Median | 150.70 | -11.40 | -103.90 | 0.00 | -18.60 |
| Std. Deviation | 463.14 | 229.01 | 532.39 | 17.29 | 402.59 |
| Minimum | -2447.80 | -1202.80 | -2439.90 | -173.07 | -1976.30 |
| Maximum | 2247.10 | 920.90 | 2313.90 | 0.00 | 5766.70 |
| | Spot | | | | |
| Mean | 97.49 | -46.74 | -90.79 | -5.72 | 34.27 |
| Median | 94.70 | -27.50 | -106.10 | 0.00 | 24.90 |
| Std. Deviation | 289.81 | 167.69 | 489.70 | 17.29 | 503.26 |
| Minimum | -2185.90 | -2738.10 | -2546.00 | -173.07 | -1961.20 |
| Maximum | 1469.70 | 714.10 | 1903.80 | 0.00 | 2616.80 |
| | Forward | | | | |
| Mean | 56.36 | 34.35 | -13.82 | | -90.34 |
| Median | 42.40 | 27.00 | -8.50 | | -72.20 |
| Std. Deviation | 338.17 | 200.99 | 181.21 | | 464.57 |
| Minimum | -2539.10 | -987.40 | -1272.00 | | -5335.40 |
| Maximum | 2068.50 | 2707.70 | 1408.40 | | 1779.00 |
| | (Spot, Forward) | | | | |
| Correlation | 0.082 | -0.238 | 0.061 | | -0.485 |

Table 2: Correlation between Net Trade Flows, Spot and Forward Markets, Daily

Net daily trades flows for each participant are the difference between purchases and sales of Canadian dollars. Flows are categorized according to customer type: commercial client trading (CC); Canadian-domiciled investment (CD); foreign-domiciled investment (FD); central bank flows (CB) include trades by the Bank of Canada; market making flows (MM) include trades by Canadian dealers. Net daily trading is also disaggregated by FX market (spot, forward). Spot transactions are those involving receipt or delivery on a cash basis or in one business day while forward transactions are those involving receipt or delivery in more than one business day. Sample: October 2, 2000 - September 30, 2005. Number of daily observations: 1255.

| | Participant Category | | | | |
|---|---|---|---|---|---|
| | CC | CD | FD | CB | MM |
| Total Across Markets | | | | | |
| CC | 1.000 | | | | |
| CD | -0.038 | 1.000 | | | |
| FD | -0.673 | -0.327 | 1.000 | | |
| CB | 0.153 | 0.015 | -0.158 | 1.000 | |
| MM | -0.252 | -0.069 | -0.262 | -0.005 | 1.000 |
| Spot | | | | | |
| CC | 1.000 | | | | |
| CD | -0.050 | 1.000 | | | |
| FD | -0.421 | -0.103 | 1.000 | | |
| CB | 0.112 | 0.010 | -0.135 | 1.000 | |
| MM | -0.174 | -0.215 | -0.698 | 0.027 | 1.000 |
| Forward | | | | | |
| CC | 1.000 | | | | |
| CD | 0.060 | 1.000 | | | |
| FD | -0.257 | -0.029 | 1.000 | | |
| MM | -0.623 | -0.468 | -0.258 | | 1.000 |

Table 3: Granger Causality

Granger-causality tests are used to determine the direction of causality between pairs of variables. Wald test statistic $p$-values are presented under the null hypothesis that the dependent variable in not affected by the lags of each independent variable. The following variables are examined: U.S. dollar-Canadian dollar exchange rate returns, the net flows of market participants categorized according to customer type: commercial client trading (CC) includes transactions by resident and non-resident non-financial customers; Canadian-domiciled investment (CD) include transactions by non-dealer financial institutions located in Canada, regardless of whether the institution is Canadian-owned; foreign-domiciled investment (FD) includes all transactions by financial institutions, including FX dealers, pension funds, mutual funds and hedge funds, located outside Canada; central bank flows (CB) include trades by the Bank of Canada; market making flows (MM) include trades by Canadian dealers; and 10-year and 3-month interest rate spreads between Canadian and U.S. government yields. Lag length are chosen based on the Schwartz Information Criterion. Sample: October 2, 2000 - September 30, 2005. Number of daily observations: 1255.

| | Independent Variable | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Dependent Variable | $\Delta\log(e)$ | CC | CD | FD | CB | MM | 10-year Spread | 3-month Spread |
| Exchange Rate Returns | | 0.38 | 0.67 | 0.98 | 0.66 | 0.13 | 0.21 | 0.34 |
| CC Trade Flows | 0.01 | | 0.54 | 0.08 | 0.83 | 0.13 | 0.82 | 0.94 |
| CD Trade Flows | 0.00 | 0.02 | | 0.83 | 0.20 | 0.03 | 0.86 | 0.34 |
| FD Trade Flows | 0.02 | 0.16 | 0.43 | | 0.95 | 0.24 | 0.50 | 0.68 |
| CB Trade Flows | 0.45 | 0.29 | 0.82 | 0.50 | | 0.71 | 0.00 | 0.14 |
| MM Trade Flows | 0.12 | 0.27 | 0.43 | 0.03 | 0.11 | | 0.50 | 0.63 |
| 10-year Interest Rate Spreads | 0.97 | 0.73 | 0.21 | 0.72 | 0.72 | 0.69 | | 0.15 |
| 3-month Interest Rate Spreads | 0.74 | 0.35 | 0.41 | 0.46 | 0.83 | 0.82 | 0.00 | |

Table 4: Unit Root and Cointegration Tests

Augmented Dickey-Fuller and Phillips-Perron unit-root test statistics and one-sided $p$-values are presented in Panel A. The number of lags is chosen based on the Schwartz Information Criterion. A constant and trend are included. Unrestricted cointegration trace test statistics and MacKinnon-Haug-Michelis (1999) $p$-values are displayed in Panel B. Cointegrating vectors include a linear trend and constant. A lag length of 2 was chosen based on the Schwartz Information Criterion. Sample: October 2, 2000 - September 30, 2005. Number of daily observations: 1255.

| Panel A | | | | | | |
|---|---|---|---|---|---|---|
| Variable | ADF | | PP | PP | | |
| | t-statistic | p-value | lags | t-statistic | p-value | lags |
| log(USD/CAD) Exchange Rate | -2.44 | 0.36 | 0 | -2.41 | 0.37 | 4 |
| Cumulative CC Trade Flows | -2.03 | 0.58 | 2 | -2.08 | 0.55 | 17 |
| Cumulative CD Trade Flows | -2.51 | 0.32 | 1 | -2.47 | 0.34 | 3 |
| Cumulative FD Trade Flows | -1.51 | 0.83 | 2 | -1.61 | 0.79 | 19 |
| Cumulative CB Trade Flows | 0.53 | 0.99 | 5 | 0.73 | 0.99 | 22 |
| Cumulative MM Trade Flows | -1.99 | 0.60 | 0 | -2.03 | 0.58 | 3 |
| 10-year interest rate differential | -1.89 | 0.66 | 1 | -1.89 | 0.66 | 3 |
| 3-month interest rate differential | -1.06 | 0.93 | 0 | -0.98 | 0.95 | 23 |

| Panel B | | | |
|---|---|---|---|
| Hypothesized Number of Cointegrating Equations: | Total Spot and Forward Positions | | |
| | Eigenvalue | Trace Statistic | p-value |
| None | 0.022 | 186.37 | 0.001 |
| At most 1 | 0.018 | 130.24 | 0.025 |
| At most 2 | 0.015 | 84.06 | 0.242 |
| At most 3 | 0.008 | 45.07 | 0.829 |
| At most 4 | 0.006 | 24.80 | 0.924 |

Table 5: Cointegration Results

A vector error-correction model is estimated with the following variables: the log of the U.S. dollar-Canadian dollar exchange rate, the positions of market participants categorized according to customer type: commercial client trading (CC), Canadian-domiciled investment (CD), foreign-domiciled investment (FD), central bank flows (CB), and market making flows (MM). 10-year and 3-month interest rate spreads between Canadian and U.S. government yields are treated as exogenous. The models includes two lags and a trend is included in each cointegrating vector based on the Schwartz Information Criterion. Estimates of the cointegrating vectors are provided in the Panel A while adjustment coefficients are presented in Panel B. Standard errors are in parenthesis. All cells without standard errors are the results of restrictions placed on the model. Sample: October 2, 2000 - September 30, 2005. Number of daily observations: 1252 after adjustments.

| Panel A: Cointegration Equation Estimates | | | | | | | |
|---|---|---|---|---|---|---|---|
| | log(e) | CC | CD | FD | CB | Trend | Const. |
| Coint. | 1.000 | $7.1*10^{-6}$ | $1.2*10^{-5}$ | $1.3*10^{-5}$ | 0.000 | yes | yes |
| Eqn. 1: | | $(2.1*10^{-6})$ | $(7.2*10^{-6})$ | $(1.2*10^{-6})$ | | | |
| Coint. | 0.000 | 0.603 | -1.105 | 1.000 | 0.000 | yes | yes |
| Eqn. 2: | | (0.252) | (0.905) | | | | |

| Panel B: Adjustment Coefficients Across Equations | | | | | |
|---|---|---|---|---|---|
| | log(e) | CC | CD | FD | CB |
| Coef. on | -0.0142 | -693.124 | -1573.319 | 0.000 | 0.000 |
| Coint. 1: | (0.005) | (125.998) | (289.530) | | |
| Coef. on | $9.40*10^{-9}$ | 0.000 | 0.013 | 0.000 | 0.000 |
| Coint. 2: | $(4.2*10^{-8})$ | | (0.002) | | |

Table 6: Generalized Impulse Response Functions, Total Positions Across FX Markets

Impulse response functions are presented subsequent to a one-standard deviation innovation in each trade flow variable. The estimated vector error-correction model includes the log of the U.S. dollar-Canadian dollar exchange rate and the positions of market participants: commercial client trading (CC); Canadian-domiciled investment (CD); foreign-domiciled investment (FD); central bank flows (CB). 10-year and 3-month interest rate spreads between Canadian and U.S. government yields are treated as exogenous. Market maker (MM) positions are calculated using Equations (3). Generalized impulses response functions are described by Pesaran and Shin (1998). A '*' is used to indicate responses that are statistically significant at the 5% level. Bootstrap methods with 200 replications are employed to calculate standard errors. (see Efron and Tibshirani, 1993). Sample: October 2, 2000 - September 30, 2005. Number of daily observations: 1252.

| | | Number of Days After Impulse | | | | | |
|---|---|---|---|---|---|---|---|
| Impulse | Accumulated Response | 2 | 5 | 10 | 20 | 40 | 100 |
| CC | CC | *346.86 | *380.67 | *373.81 | *355.31 | *322.85 | *247.67 |
| | CD | -9.57 | -27.80 | -28.37 | -27.75 | -23.98 | -9.43 |
| | FD | -21.60 | -38.97 | -40.34 | -37.34 | -32.34 | -21.57 |
| | CB | -0.29 | -0.34 | -0.40 | -0.37 | -0.31 | -0.18 |
| | MM | *-315.38 | *-313.55 | *-304.69 | *-289.84 | *-266.21 | *-216.47 |
| | log(e)*$10^{-3}$ | *0.231 | *0.251 | 0.202 | 0.120 | 0.006 | 0.000 |
| CD | CC | *-101.30 | *-131.27 | *-144.31 | *-157.89 | *-159.78 | *-116.54 |
| | CD | *215.16 | *196.88 | *168.48 | *128.51 | *87.56 | 55.83 |
| | FD | -11.00 | 7.18 | 13.91 | 21.79 | 27.80 | 24.86 |
| | CB | -0.10 | 0.17 | 0.28 | 0.35 | 0.40 | 0.34 |
| | MM | *-98.27 | *-72.96 | -38.37 | 7.22 | 44.00 | 35.50 |
| | log(e)*$10^{-3}$ | -0.093 | -0.064 | -0.033 | -0.069 | -0.100 | -0.103 |
| FD | CC | *-234.50 | *-308.89 | *-334.89 | *-374.31 | -445.84 | *-617.57 |
| | CD | *-98.58 | *-106.65 | *-103.55 | -97.10 | -83.59 | -47.42 |
| | FD | *516.04 | *590.75 | *599.46 | *605.38 | *615.67 | *639.85 |
| | CB | 0.30 | 0.83 | 1.05 | 1.14 | 1.27 | 1.56 |
| | MM | *-183.25 | *-176.03 | *-162.07 | *-135.11 | *-87.50 | -23.58 |
| | log(e)*$10^{-3}$ | *-0.054 | *-0.089 | *-0.167 | *-0.305 | *-0.541 | *-1.080 |

Table 7: Common Factors, FX Dealing Institutions

Maximum likelihood estimates of the factor loadings associated with the net trade flows of the 6 largest FX dealers, and their customers, obtained from a common factor analysis model $x = \mu + \Lambda f + e$ where $x$ is a vector of individual financial institution trading flows, $\mu$ is a constant vector of means and $f$ is the independent standardized common factor. Market participants are categorized according to customer type: commercial client trading (CC) includes transactions by resident and non-resident non-financial customers; Canadian-domiciled investment (CD) include transactions by non-dealer financial institutions located in Canada, regardless of whether the institution is Canadian-owned; foreign-domiciled investment (FD) includes all transactions by financial institutions, including FX dealers, pension funds, mutual funds and hedge funds, located outside Canada; central bank flows (CB) include trades by the Bank of Canada. 10-year and 3-month interest rate spreads between Canadian and U.S. government yields are treated as exogenous. Market maker (MM) positions are calculated using Equations (3). Sample: October 1, 2000-September 30, 2005, Number of daily observations: 1255.

| | FD | CD | CC | CB | MM |
|---|---|---|---|---|---|
| Dealer 1 | 0.48 | 0.25 | 0.35 | 0.50 | 0.05 |
| Dealer 2 | 0.62 | 0.17 | 0.60 | 0.29 | -0.03 |
| Dealer 3 | 0.50 | -0.09 | 0.44 | 0.30 | 0.01 |
| Dealer 4 | 0.48 | 0.09 | 0.51 | 0.03 | -0.04 |
| Dealer 5 | 0.56 | 0.05 | 0.32 | 0.03 | -0.02 |
| Dealer 6 | 0.03 | -0.26 | 0.13 | 0.04 | 0.09 |
| $H_0$: single factor | | | | | |
| p-value | 0.80 | 0.65 | 0.32 | 0.18 | 0.63 |

Table 8: Generalized Impulse Response Functions, Commercial Clients and Dealer Positions

Impulse response functions are presented subsequent to a one-standard deviation innovation in foreign-domiciled investment flows (FD). The positions of commercial clients (CC) and market makers (MM) across individual dealers are presented. MM positions are calculated using Equations (3) and (4). Generalized impulses response functions are described by Pesaran and Shin (1998). Sample: October 2, 2000 - September 30, 2005. Number of daily observations: 1252.

| Accumulated Response to | Number of Days After Impulse | | | | | |
|---|---|---|---|---|---|---|
| | 2 | 5 | 10 | 20 | 40 | 100 |
| CC of Dealer 1 | -34.03 | -52.62 | -52.12 | -49.97 | -48.57 | -49.48 |
| CC of Dealer 2 | -54.40 | -99.42 | -101.46 | -100.74 | -100.42 | -101.28 |
| CC of Dealer 3 | -49.78 | -82.19 | -83.15 | -82.31 | -81.74 | -82.09 |
| CC of Dealer 4 | -20.95 | -32.32 | -32.50 | -32.05 | -31.71 | -31.76 |
| CC of Dealer 5 | -85.72 | -144.07 | -145.68 | -142.93 | -141.09 | -142.20 |
| CC of Dealer 6 | -43.43 | -56.48 | -56.27 | -55.06 | -54.42 | -55.37 |
| | | | | | | |
| Dealer 1 (MM) | -19.20 | -18.54 | -16.86 | -15.37 | -14.10 | -13.67 |
| Dealer 2 (MM) | -16.83 | -20.31 | -20.78 | -20.95 | -20.87 | -20.65 |
| Dealer 3 (MM) | -10.35 | -12.50 | -13.19 | -13.73 | -13.91 | -13.73 |
| Dealer 4 (MM) | -24.90 | -24.86 | -23.59 | -21.77 | -20.12 | -20.51 |
| Dealer 5 (MM) | -68.85 | -64.42 | -63.68 | -63.10 | -62.46 | -62.14 |
| Dealer 6 (MM) | -21.98 | -26.22 | -25.95 | -26.01 | -26.19 | -26.37 |

Table 9: Granger Causality across Spot and Forward FX Markets

Granger-causality tests are used to determine the direction of causality between pairs of variables. Wald test statistic $p$-values are presented under the null hypothesis that the dependent variable in not affected by the lags of each independent variable. The following variables are examined: U.S. dollar-Canadian dollar exchange rate returns, the net flows of market participants categorized according to customer type: commercial client trading (CC) includes transactions by resident and non-resident non-financial customers; Canadian-domiciled investment (CD) include transactions by non-dealer financial institutions located in Canada, regardless of whether the institution is Canadian-owned; foreign-domiciled investment (FD) includes all transactions by financial institutions, including FX dealers, pension funds, mutual funds and hedge funds, located outside Canada; central bank flows (CB) include trades by the Bank of Canada; market making flows (MM) include trades by Canadian dealers; and 10-year and 3-month interest rate spreads between Canadian and U.S. government yields. Lag length are chosen based on the Schwartz Information Criterion. Sample: October 2, 2000 - September 30, 2005. Number of daily observations: 1255.

| | | Independent Variable | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Dependent | | log(e) | CC | CD | FD | MM | CC | CD | FD | MM |
| Variable | market | spot | spot | spot | spot | spot | forward | forward | forward | forward |
| log(e) | spot | | 0.08 | 0.54 | 0.88 | 0.53 | 0.82 | 0.16 | 0.41 | 0.80 |
| CC | spot | 0.13 | | 0.99 | 0.01 | 0.01 | 0.05 | 0.74 | 0.67 | 0.27 |
| CD | spot | 0.00 | 0.94 | | 0.68 | 0.51 | 0.02 | 0.67 | 0.59 | 0.42 |
| FD | spot | 0.01 | 0.51 | 0.19 | | 0.25 | 0.01 | 0.51 | 0.00 | 0.73 |
| MM | spot | 0.00 | 0.59 | 0.43 | 0.31 | | 0.02 | 0.58 | 0.00 | 0.61 |
| CC | forward | 0.00 | 0.00 | 0.98 | 0.00 | 0.95 | | 0.58 | 0.19 | 0.89 |
| CD | forward | 0.73 | 0.10 | 0.22 | 0.44 | 0.52 | 0.41 | | 0.37 | 0.21 |
| FD | forward | 0.00 | 0.02 | 0.97 | 0.00 | 0.00 | 0.00 | 0.31 | | 0.05 |
| MM | forward | 0.00 | 0.45 | 0.99 | 0.06 | 0.21 | 0.00 | 0.16 | 0.00 | |

# Appendix

### A Simultaneous Trading Model with Correlated Assets

The model developed in this appendix extends the Cao, Evans and Lyons (2006) framework to include multiple risky assets. Two risky assets are considered: FX spot ($s$) and forward contracts ($f$). Any two assets that are correlated in terms of final payoffs may also be considered. A second risky asset is introduced to illustrate how speculative trading and hedging demands may occur across correlated asset markets. As with Cao, Evans and Lyons (2006), the model is a simplification of the actually trading practices employed in FX markets. For example, trading in spot and forward interdealer trading rounds is assumed to occur sequentially. The assumption is motivated by differences in illiquidity and opacity in two markets. Generally, forward FX markets are relatively less liquid and transparent (in terms of order flow information) than spot FX trading. Drudi and Massa (2001) attempt to illustrate the strategies of informed traders operating in "parallel" markets. In this more realistic setting, multiple equilibria exist, and numerical solutions are only available under restrictive assumptions.

The model developed here is able to provide additional insights into the potential trading strategies of dealers and dealing institutions. Participants in the FX market include $n$ dealing banks, liquidity demanding customers, and a large number of liquidity suppliers. The payoffs on the risky assets are realized after the final round of trading. Gross returns on the riskless asset are normalized to one while the risky assets, which are in zero supply initially, have final payoffs

$$\begin{pmatrix} S \\ F \end{pmatrix} \backsim N\left( \begin{bmatrix} 0 \\ 0 \end{bmatrix}, \begin{bmatrix} \sigma_s^2 & \sigma_{sf} \\ \sigma_{sf} & \sigma_f^2 \end{bmatrix} \right).$$

The two risky assets cannot be traded across markets.[29]

Quoting and trading by dealers in the model is discrete, and characterized by a series of three rounds of trading. The total length of time corresponds to the resolution of uncertainty regarding asset payoffs. Customers trade both FX spot and forward contracts with dealers in the first round. Each customer trade is assigned to a single dealer resulting from an existing bilateral customer relationship. Let $c_{ij}$ denote the net value of all customer FX orders received by dealer $i$ (positive for customer purchases) in market $j = s, f$. These variables are private information to dealer $i$. Unlike the model presented in the main text of the paper, customer

[29]n the case of forward and spot FX, $\sigma_{sf} = 1$.

orders are independent of the payoffs of the risky assets, $\{S, F\}$. The net customer order received by dealer $i$ in market $j$ is distributed normally about 0, with known variance $\sigma_c^2$:

$$c_{ij} \backsim N(0, \sigma_c^2) \quad \forall i, j$$

where

$$c_{ij} \perp S, c_{ij} \perp F, c_{ij} \perp c_{kj} \quad \forall i \neq k.$$

The preliminary round of customer-dealer trading is followed by two rounds of interdealer trading. Interdealer trading allows dealing banks to trade based on their private customer information before it is fully reflected in prices. The first and second rounds of interdealer trading are associated with spot and forward contract trading, respectively. Much like quoting, trading is also simultaneous in each round. Let $T_{ij}$ denote the net outgoing interdealer order placed by dealer $i$ in round $j$, while $T'_{ij}$ denotes the net incoming interdealer order received by dealer $i$ in round $j$, placed by all other dealers. $T_{ij}$ is positive for dealer $i$ purchases, while $T'_{ij}$ is positive for purchases by other dealers from dealer $i$.

At the end of the first round of interdealer trading, the market publicly learns about order flow in the spot market—the sum of all net interdealer demand,

$$V_s = \sum_{i=1}^{n} T_{is}$$

where $V_s$ is the information associated with interdealer order flow provided by interdealer brokers in FX markets. In the final round of trading, dealers partially cover their speculative positions. Dealers unwilling to hold a positions at the end of the third round must provide compensation to liquidity suppliers to avoid this risk. Daily closing prices in the market. will then adjust. Unlike Cao, Evans and Lyons, a further round of trading with liquidity suppliers at the end of the period is not modelled. This omission does not change the general implications of the model related to strategic trading across markets.

The eight events of the model occur in the following sequence:

**Round 1: Dealer quoting and customer-dealer trading**
Dealers quote to customers, $P_{ij1} \quad \forall j = s, f$
Dealers receive net customer orders, $c_{ij} \quad \forall j = s, f$

**Round 2: Interdealer quoting and trading in spot FX**

Dealing banks quote to each other, $P_{is2}$
Dealing banks trade with other dealing banks, $\{T_{is2}, T'_{is2}\}$
Interdealer order flow is observed at the end of the round, $V_s$

**Round 3: Interdealer quoting and trading in forward FX**
Dealing banks quote to each other, $P_{if3}$
Dealing banks trade with other dealing banks, $\{T_{if3}, T'_{if3}\}$
Payoffs on the risky assets are realized, $\{S, F\}$

Quoting by dealers in the model is simultaneous, independent, required, and fully transparent. These rules are consistent with the actual behavior in multiple-dealer market. Interdealer trading is simultaneous and independent so that $T_{ik}$ cannot be conditioned on $T'_{ik}$. Outgoing interdealer orders in each of the two rounds of interdealer trading are two strategic choice variables in each dealer's maximization problem. Let $D_{ik}$ denotes dealer $i$'s speculative demand in interdealer round $k$. If $\sigma_{sf} = 1$

$$T_{i2} = D_{i2} + c_{is} + c_{if} + E[T'_{i2} \mid \Omega_{i2}]$$

$$T_{i3} = (D_{i3} - D_{i2}) + (T'_{i2} - E[T'_{i2} \mid \Omega_{i2}]) + E[T'_{i3} \mid \Omega_{i3}]$$

where $\Omega_{i2}$ and $\Omega_{i3}$ denote the information sets of dealer $i$ in rounds two and three, respectively. The public and private information sets available to each dealer $i$ in each of the rounds of trading are

$$\Omega_1 = \{\{P_{is1}, P_{if1}\}_{i=1}^{n}\} \qquad \Omega_{i1} = \{\{P_{is1}, P_{if1}\}_{i=1}^{n}\}$$
$$\Omega_2 = \left\{\{P_{is1}, P_{if1}, P_{is2}\}_{i=1}^{n}\right\} \qquad \Omega_{i2} = \left\{c_{is}, c_{if}, \{P_{is1}, P_{if1}, P_{is2}\}_{i=1}^{n}\right\}$$
$$\Omega_3 = \left\{V, \{P_{is1}, P_{if1}, P_{is2}, P_{if3}\}_{i=1}^{n}\right\} \qquad \Omega_{i3} = \left\{c_{is}, c_{if}, T_{i2}, T_{i2}, V, \{P_{is1}, P_{if1}, P_{is2}, P_{if3}\}_{i=1}^{n}\right\}.$$

Dealers will use their private customer trades to forecast subsequent changes in the price of FX spot and forward contracts. Each dealer determines quotes and speculative demands by maximizing a negative exponential utility defined over terminal wealth. The equilibrium concept of the model is that of a perfect Bayesian equilibrium (PBE). Under PBE, the Bayes rule is used to update beliefs, and strategies are sequentially rational given those beliefs.

**Proposition 5** *A quoting strategy is consistent with symmetric PBE if the Round 1 and 2 spot and forward contract quotes are common across dealing banks and $P_{s1} = E(S)$, $P_{f1} = E(F)$, and $P_{s2} = E(S)$.*

**Proof.** See Cao, Evans and Lyons (2006). ■

**Proposition 6** *A quoting strategy is consistent with symmetric PBE only if the Round 3 forward contract quote is common across dealing banks and* $P_{f3} = E(F) + \lambda V$*.*

**Proof.** $P_{f3}$ can only depend on public information to avoid arbitrate opportunities. Public information includes interdealer spot order flow, $V$ in Round 3. In the forward-contract round of interdealer trading, a bias in $P_{f3}$ is necessary for market clearing:

$$\sum_i E\left[\left(T_{if3} - D_{if3} - E\left[T_{if3}|\Omega_{i3}\right]\right)|\Omega_3\right] = 0,$$

or

$$\sum_i E\left[D_{if3}|\Omega_3\right] = 0.$$

When asset prices are correlated, and if $D_{is2}$ has already been chosen in Round 2, the desired demand for $D_{if3}$ is

$$D_{if3} = \frac{\mu_f - P_{f3}}{\theta\sigma_f^2} - D_{is2}\frac{\sigma_{sf}}{\sigma_f^2},$$

so that

$$\sum_i E\left[\left(\frac{\mu_f - P_{f3}}{\theta\sigma_f^2} - D_{is2}\frac{\sigma_{sf}}{\sigma_f^2}\right)|\Omega_3\right] = 0.$$

Since

$$E\left[D_{is2}|\Omega_3\right] = -E\left[c_{is}|\Omega_3\right] = -\frac{V_s}{n\beta_1},$$

$$P_{f3} = \frac{\theta\sigma_{sf}V_s}{n\beta_1} = \lambda V_s.$$

■

**Proposition 7** *Linear trading strategy profile for dealer i in a symmetric PBE are:*

$$
\begin{aligned}
T_{is2} &= \beta_1(c_{is} + c_{if}) \qquad \beta_1 > 1, \beta_2 < 0 \\
T_{if3} &= \beta_2(c_{is} + c_{if}) \qquad \text{if } \sigma_{sf} = 1
\end{aligned}
$$

$$
\begin{aligned}
T_{is2} &= c_{is} \\
T_{if3} &= c_{if} \qquad \text{if } \sigma_{sf} = 0
\end{aligned}
$$

When $\sigma_{sf} \neq 0$, strategies take into account a dealer's recognition that their individual actions can affect prices. The proposition has implications for the role of hedging and speculation across markets. The positive coefficient associated with Round 2 trading, $T_{is2}$, indicates that non-payoff-relevant information can motivate dealers to speculate. In Round 3, risk-averse dealing banks hedge or off-load part of their risk exposure.

**Proof.** See D'Souza (2002b). ■