Bank of Canada Working Paper 2008-00
April 11, 2008

The Role of Foreign Exchange Dealers in Overnight Liquidity Provision

by

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Abstract

Dealers in foreign exchange (FX) markets provide intraday liquidity to market participants by standing ready to buy and sell currencies at their posted bid and offer quotes. They are also key participants in the provision of overnight, or interday, liquidity. To hold an undesired position, dealers demand compensation in terms of higher exchange rate returns either directly or indirectly via the private information learned from order flow. As intermediaries in the decentralized FX market, they are able to learn about the order flow of various market participants which can be informative about future movements in the exchange rate. Dealers in financial institutions trade in multiple price-correlated markets, and look for opportunities to speculate, or reduce any undesired risky positions, across markets. I illustrate an interdependent relationship between the overnight positions of non-financial customers and dealers across markets. While dealers provide liquidity to foreign financial customers, they are resistant to providing liquidity when central banks intervene. I also provide evidence that individual dealers have very similarly strategies in managing risk and acquiring information.

JEL classification: F31; G21; D82
Bank classification: Foreign Exchange, Market Microstructure, Asymmetric Information

1. Introduction

Liquidity provision is important in financial markets when trading is decentralized and immediacy is a concern. More generally, an illiquid or poorly functioning foreign exchange (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.[1]

Dealers in FX markets are thought of as intraday liquidity providers. They stand ready to buy and sell foreign exchange from their customers at posted rates during the trading day.[2] It is commonly assumed that these market makers hold only limited overnight, or interday, positions. O'Hara (1995) describes how dealers can manage their inventories by adjusting their bid and offer quotes.[3] Studies by Lyons (1995) and Bjonnes and Rime (2005), analyzing the inventory management practices of individual traders, suggest that dealers do not usually hold open positions for a significant amount of time. In contrast, Bjonnes, Rime and Solheim (2005), hereafter referred to as BRS, present evidence that, while the burden of interday liquidity provision falls on non-financial participants in the foreign exchange market, market making financial institutions do provide liquidity overnight, and continue to do so even at the 10-day horizon, though their role gradually diminishes.

In this paper, I examine in greater detail the provision of overnight liquidity in foreign exchange markets. In particular, I analyze the circumstances under which market makers hold overnight positions, and then examine the manner in which they off-load these positions over time, across markets, and across participants. Using data collected by the Bank of Canada from individual FX dealing institutions active in Canada, I study the behavior of groups of FX participants operating in the USD/CAD market and find that dealers play a non-trivial role in the provision of interday liquidity. Similar to BRS, participants are divided into groups of customers, each with distinct foreign exchange demands. Relative to BRS, the data allows for a more complete examination of the role of each participant in both, the taking and supplying of liquidity. I find that market making dealers and non-financial firms work interdependently in the provision of liquidity.

[1] 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] According to Osler (2008), only the currency pairs involving the dollar, the euro, and the yen are liquid throughout the 24-hour day. Liquidity in most other currencies is concentrated during local hours. For example, see D'Souza (2007).

[3] Dealers can quickly adjust their intraday positions through the interdealer market both directly or through an interdealer broker such as Reuters or EBS.

When providing liquidity services, dealers may hold on to a risky FX position based on the information learned from their trades with customers. One way that dealers may be informed about future movements in the exchange rate is by observing order flow—sometimes measured as the aggregate value of buy orders relative to sell orders that have been received. For example, an excess quantity of net buy (sell) orders for the Canadian dollar suggests that other market participants have a positive (negative) impression about the future prospects of the Canadian dollar based on available information. Evans and Lyons (2002a) demonstrate that order flow influences foreign exchange returns.[4] Dealers have a competitive advantage in acquiring order-flow information since they deal directly and privately with their various customers. Generally though, dealers must balance the inventory risk associated with liquidity provision with the expected excess returns generated from speculation.

Certain trades in the FX market are more informative than others. While 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, 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. Unlike BRS, the trades of financial customers in this paper are broken down into those that are initiated in Canada or from abroad. Two additional types of customers are examined in the paper: non-financial customers (resident or non-residents) and the central bank, specifically the Bank of Canada. BRS find that non-financial customers bear the largest burden in terms of the provision of liquidity. While the effectiveness of FX intervention has been studied extensively, to date little is known about the supply of liquidity subsequent to these special operations.[5] Section 2 below provides some background regarding the structure of the FX market. It also describes each participants' needs for foreign exchange.

According to the microstructure view, price and trade dynamics will be affected by the institutional features and information flows in each financial market. It is therefore interesting to examine whether access to private information affects a dealing bank's willingness to supply liquidity. Some researchers (e.g., Lyons 1997) have argued that customer trades are the catalyst for profitable trading strategies, and that valuable private information about the fundamentals that affect the value of the exchange rate are obtained from customer trades. Another line of thought, proposed by Cao, Evans and Lyons (2006), suggests that

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

[5] For example, Fatum (2008) finds that Bank of Canada intervention is effective at changing the direction of the USD/CAD exchange rate and in smoothing exchange rate movements.

dealers use private information about their own inventories, which must be absorbed by the greater marketplace, as a profitable avenue for speculation. This has direct implications for liquidity in the FX market. In particular, providing liquidity to customers affords dealers an opportunity to speculate on future movements in the exchange rate. The more profitable such speculative opportunities are, the more competitive dealers will become in attracting customer orders. I find that the trades of financial firms domiciled outside of Canada are relatively more informed, and more likely to affect the strategic behaviour of dealers.

When prices are correlated, dealers are able to hedge risk or even speculate across markets. This paper examines the positions of market participants across related markets in order to capture any additional factors that may determine liquidity provision. 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. Section 3 outlines a simple theoretical model illustrating how liquidity is determined across price correlated markets.

In Sections 4 and 5 of the paper, I describe the data and then show empirically that dealers as well as non-financial customers are both providers of liquidity, acting in an interdependent fashion. Generally, foreign domiciled financial customers are liquidity takers. Though this is not always the case. These findings suggest that when uninformed domestic financial customers trade, foreign financial institutions provide significant initial levels of liquidity. Canadian-based financial customers must pay an explicit cost for these liquidity services. In contrast, when foreign domiciled financial institutions trade, dealers are key overnight liquidity providers. This may reflect the fact that dealers believe that the information content of these trades is valuable. Results suggest that the positions of market makers can be speculative, especially subsequent to central bank and foreign domiciled financial customer trades. An analysis of individual dealer positions illustrates that most financial institutions behave in a similar manner.

Dealers are active in both spot and derivatives markets jointly. In the last set of results, presented in Section 6, participants' positions in both spot and forward contract markets are examined. In general, market makers and commercial clients jointly manage their positions across markets. While dealers provide immediate liquidity to foreign domiciled financial customers in spot markets, they use this information for speculate purposes. Over time they attempt to balance out their positions depending on the needs of non-financial customers. In contrast to the behaviour of commercial clients, subsequent to a Canadian domiciled financial customer trade shock, dealing banks do not fully hedge their risk at all times.

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, the findings in this paper suggest that market making dealing institutions intermediate in the overall process, and may hold on to risky positions for longer periods of time than suggested by the existing literature. In addition to a dealer's ability to continuously operating in multiple price-correlated markets, there are other sources of comparative advantage that dealing banks have when bearing risk and providing liquidity. First, access to electronic interdealer brokers guarantees that market-makers have access to certain minimum levels of liquidity. Most of their customers do not have this same access. Second, banks allocate capital across business lines in order to diversify risk and return. This allows intermediaries to bear risk with a higher tolerance than the customers at non-financial institutions that may be specialized in relatively few business lines. Hedging versus speculation may depend on the overall risk-bearing capacity of dealers in the market and on each dealer's individual access to order flow.

2. Information and Institutions 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). In FX markets, trades take place between customers and dealers, or just between dealers in the interdealer market. Customers are the financial and non-financial firms that are the end-users of foreign exchange currencies for settling imports or exports, investing overseas, hedging cross-currency business transactions, or speculating. Trading in foreign exchange markets is more decentralized and opaque than trading in equity markets. Individuals and firms that need to buy and sell foreign exchange typically trade with dealers on a bilateral, over-the-counter basis. Further, the results of these bilateral customer dealer trades are known only to the two counterparties rather than to the entire market.

Dealers continuously supply bid and ask 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. While historically these interdealer markets were also 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.[6] In this paper, I study the positions of each group of participants as a whole in their provision of overnight liquidity. So, while dealers may share their inventory exposure with other dealers, as a group they may also provide a certain levels of liquidity to other groups of market participants, such as the financial and non-financial firms that have speculative and hedging needs in FX markets.

Ito, Lyons, and Melvin (1998) find that even in markets like the FX market, where private information should not exist, empirical evidence suggests that it does indeed exist.[7] A number of studies including Evans and Lyons (2002b) and Payne (2003) provide empirical support for the hypothesis that FX order flow, a measure of buying or selling pressure in the market and a key variable in the microstructure literature, can explain up to two-thirds of the variation in exchange-rate returns. Intuitively, a trader that is worried about losing an informational advantage they currently possess will immediately execute a trade against the prevailing bid or ask quote in the market. Order-flow information may provide a strategic motive for dealers to speculate in FX markets. Since market-makers see a large part of the order flow in the market, they would arguably choose not to hedge their risk exposure completely but to hedge it selectively. Private information gives dealers a comparative advantage over other FX market participants when taking risk.

One important characteristic that distinguishes FX trading from trading in other markets is that trade transparency is low. Order flow in the FX market is not transparent because there are no disclosure requirements. The market is generally unregulated. Consequently, trades in this market are not generally observable. A trading process that is less informative will reduce the information content of prices so that private information can be exploited for a longer amount of time. Dealing banks receive private information through their customer's orders. Their access to the information contained in this order flow gives them an 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. Dealing banks also learn

[6]Brokers in the FX market are involved only in interdealer transactions and communicate dealer prices to other dealing banks without revealing their identity. Brokers in the FX market are those intermediaries who match the best buy and sell orders of dealers. Unlike dealers, who sometimes take speculative positions, brokers act as pure matchmakers.

[7]Unlike equity markets, where some investors may have more precise information on the business operations and conditions of a company, information about the exchange rate is assumed to be public and simultaneously available to all interested participants. This assumption of market efficiency, which is common in the academic literature, reflects the belief that relevant information about the exchange rate is related to macroeconomic variables such as foreign and domestic nominal interest rates, inflation rates, and output levels. It also reflects the belief that, globally, FX dealers have access to similar, real-time news feeds that broadcast new information about these variables immediately after it is released.

about market-wide order flow from brokered interdealer trades.

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. Bjønnes, Rime and Solheim (2005), Fan and Lyons (2003), Froot and Ramadorai (2002) and Mende, Menkhoff and Osler (2006) find the FX trades of financial institutions to be more informative about exchange rate movements than the trades of non-financial firms. Evans and Lyons (2004) argue that individual customer trades contain little pieces of new information about the underlying macroeconomic fundamentals driving the exchange rate. In aggregate, customer order flow can be an important source of information that accrues to dealers, and that subsequently drives interdealer speculation. Asymmetric information in interdealer FX markets may then be driven by differences in the abilities of dealers to capture customer order flow.

Customer trades can be associated with either private payoff- or non-payoff relevant information. Both sources of information can be used by dealers strategically. Non-payoff-relevant information, such as information about a dealer's inventory risk exposure, is considered in Cao, Evans, and Lyons (2006). Speculation in interdealer markets is then based on a dealer's ability to forecast the inventories of other dealers in the market. This ability helps dealers to forecast prices because it helps them to forecast the market wide compensation for inventory risk.

Market intermediaries may hold undesired inventories of spot FX when executing incoming trades if compensated with a risk premium, or they may hedge this risk in a derivatives market, such as the forward-contract FX market. Alternatively, when prices are correlated across markets, order flow in one market maybe informative about prices in other markets. Spot and forward markets are directly related through the covered interest rate parity or no-arbitrage condition. Any differences in market structure, such as trade and quote transparency that lead to differences in liquidity may allow traders an opportunity to exploit private information across multiple markets. In foreign exchange markets, there are few differences in the level of transparency across spot and forward markets, but there can be large differences in the levels of liquidity across markets at different times of the day. Trading costs may prevent a trader from exploiting private information in a less liquid market, but not necessarily in a more liquid price-correlated market. If exchange rate returns are correlated, but differences in liquidity persist, dealers may develop multiple market trading strategies that generate larger profits. Dealers in financial institutions make markets in multiple price-correlated markets, and hence can look for opportunities to speculate across markets or to off-load undesired positions. To hold an undesired position, dealers demand compensation in terms of higher exchange rate returns, either directly or indirectly via the private information learned from order flow. In the next section, a model is developed that illustrates the role of order-flow information in the trading strategies of dealers across spot and forward markets.

3. Liquidity Provision and Trading Across Markets

Dealers may hold undesired positions in foreign exchange markets if compensated with higher returns either directly through wider spreads, or indirectly through the private information they receive from these trades. Demands may be tempered if customers offer to reduce the undesired position of dealers in that market, or in other price-correlated markets. Dealers have a comparative advantage in the intermediation of trades since they may hedge inventory risk across markets. Trade flow information may provide a strategic motive for dealers to speculate in interdealer markets. Since market-makers see a large part of the order flow in the FX market, they can choose to hedge it selectively.

While private payoff-relevant information in the FX market may seem unlikely, Cao, Evans, and Lyons (2002) develop a model of inventory information that lies somewhere between the inventory approach and the information approach in microstructure theory.[8] Speculation in interdealer trades is not related to payoffs, but to a dealer's inventory. Superior information about inventories helps dealing banks forecast prices, because it helps them forecast the marketwide compensation for inventory risk (the net market position at the end of the day). This paper extends the framework of Cao, Evans, and Lyons to include two parallel markets, the spot and the forward-contract FX markets, in a trading model that illustrates the strategic role of flow information in trading. Asset markets in the model are related because the final payoffs between risky assets are correlated. In this environment, dealing banks must consider the risks of speculating with private information in one asset market and hedging in another, when payoffs are not perfectly correlated. 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. Specifically, exchange rate movements reflect risk premia demanded by dealing banks as a group to absorb the total undesired position of the public.

The model is a simultaneously interdealer trading model in which customer trades serve as a catalyst for interdealer speculative trading. While this information is unrelated to the

[8] See O'Hara for a detailed exposition of the inventory and information approaches in microstructure theory.

payoffs of the risky assets in the model, customer-dealer trades serve as private information to individual dealers that can be used profitably. Because dealers, and certain other market participants, as a group must share in any net imbalance in each market, non-payoff-relevant information can be used to forecast interim prices by forecasting more accurately the marketwide compensation for inventory risk (the net market position at the end of the day). In imperfectly competitive markets, speculative trading can actually look like hedging. In this multiple risky-asset market example, dealing banks who have access to private information in the spot market can exploit this information in the forward market, and vice versa, when asset returns are correlated across markets. The correlation between asset returns in part determines the amount (if any) of hedging that dealing banks engage in. Customer demands for foreign exchange across time are also fundamental determinants of dealers desired holdings of the two assets.

3.1 Model

The multiple-dealer model attempts to capture trading in markets such as the FX and government bond markets, in which superior information about payoffs is unlikely. The model includes dealing banks, who behave strategically, and a large number of competitive customers. All dealing banks have identical negative exponential utility defined over terminal wealth. The model opens with customer-dealer trading in the spot market, and is followed by two rounds of interdealer trading: the first round consists of spot market trading, and the second round consists of forward contract market trading. A key feature of the model is that interdealer trading within a round occurs simultaneously. This constrains dealing banks' conditioning information. Within any one round, dealing banks cannot condition on that period's realization of trades by other dealers. This allows dealing banks to trade on inventory information before it is reflected in prices, which provides room to exploit inventory information.

There are three assets. One is riskless and two are risky: spot FX (s) and forward contract FX (f). The payoffs on the risky assets are realized after the second round of interdealer trading, with the gross returns on the riskless asset normalized to one. The risky assets are in zero supply initially, with a payoff of $\{S, F\}$, where

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

The two risky assets cannot be traded across markets. The distinction between this framework and that of Cao, Evans, and Lyons (2002) will be clear when the budget constraints of individual dealers are described below. The eight events of the model occur in the following sequence:

Round s:

1. Dealing banks quote in the spot markets
2. Customers trade with dealing banks in the spot market
3. Dealing banks trade with other dealing banks in the spot market
4. Interdealer spot order flow is observed

Round f:

5. Dealing banks quote in the forward markets
6. Customers trade with dealing banks in the forward contract market
7. Dealing banks trade with other dealing banks in the forward market
8. Payoffs $\{S, F\}$ are realized

In both rounds, the first event is dealer quoting. Let P_i^k denote the quote of dealing bank i in market $k = s, f$ in round k. There are three rules governing dealer quotes: (i) quoting is simultaneous, independent, and required; (ii) quotes are observable and available to all participants; and (iii) each quote is a single price at which the dealer agrees to buy and sell any amount. The key implication of rule (i) is that P_i^k cannot be conditioned on P_j^k. The rules regarding quotes agree with the facts that, in an actual multiple-dealer market, refusing to quote violates an implicit contract of reciprocal immediacy and can be punished, and that quotes are fully transparent.

Customer market-orders in the spot and forward markets are independent of the payoffs $\{S, F\}$. They occur in both periods, and are cleared at the receiving dealer's spot and forward quotes, P_i^k. Each customer trade is assigned to a single dealer, resulting from a bilateral customer relationship, for example. The net customer order received by a particular dealer is distributed normally about 0, with known variance σ_c^2:

$$c_{ik} \backsim N(0, \sigma_c^2)$$

where

$$c_{ik} \perp S, c_{ik} \perp F, c_{ik} \perp c_{jk} \quad \forall i \neq j.$$

The convention is used that c_{ik} is positive for net customer purchases and negative for net sales. Customer trades, c_{ik}, are not observed by other dealing banks. These customer trades are the private non-payoff information in the model. In FX markets, dealing banks have no direct information about other banks' customer trades.

The model's structure is based on two rounds of interdealer trading, with the trading of spot in round s and the trading of forward contracts in round f. Let T_i^k denote the net outgoing interdealer order of risky asset $k = \{s, f\}$ placed by dealer i; let $T_i^{k\prime}$denote the net incoming interdealer order received by dealer i placed by other dealing banks. The rules governing interdealer trading are as follows: (i) trading is simultaneous and independent, (ii) trading with multiple partners is feasible, and (iii) trades are divided equally among dealing banks with the same quote if it is a quote at which a transaction is desired. Because interdealer trading is simultaneous and independent, T_i^k is not conditioned on $T_i^{k\prime}$, so is an unavoidable disturbance to dealer i's position in period that must be carried into the following period.

Outgoing interdealer orders in each of the two rounds of interdealer trading are two strategic choice variables in each dealer's maximization problem. By convention, T_i^k is positive for dealer i purchases, and $T_i^{k\prime}$ is positive for purchases by other dealing banks from dealer i. Consequently, a positive c_{ik} or $T_i^{k\prime}$ corresponds to a dealer i sale. If D_i^k denotes dealer i's speculated demand in market k, then

$$T_i^s = D_i^s + c_{is} + E[T_i^{s\prime} | \Omega_{is}], \tag{1}$$

$$T_i^f = D_i^f + c_{if} + E[T_i^{f\prime} | \Omega_{if}], \tag{2}$$

where Ω_{is} and Ω_{if} denote dealer i's information sets at the time of trading in each round

$$\Omega_{is} = \{c_{is}, \{P_i^s\}_{i=1}^n\}$$

$$\Omega_{if} = \left\{c_{is}, c_{if}, T_i^k, T_i^{k\prime}, V, \left\{P_i^s, P_i^f\right\}_{i=1}^n\right\}$$

$$\Omega_s = \{P_i^s\}_{i=1}^n$$

$$\Omega_f = \left\{V, \left\{P_i^s, P_i^f\right\}_{i=1}^n\right\}$$

The first two information sets are the private information sets available to each dealer i at the time of trading in each of the two periods. The second two are the public information sets available at the time of trading in each period. Equations (1) and (2) show that dealer orders include both an information-driven component, D_i^k, and inventory components, c_{is} and $E[T_i^{k\prime}|\Omega_{ik}]$. Trades in the first round with customers must be offset in interdealer spot trading to establish the desired spot position, D_i^s. Dealing banks also do their best to offset the incoming dealer spot order, $T_i^{s\prime}$ (which they cannot know ex ante, owing to the simultaneous trading). In round two, inventory control has one component: it offsets the incoming forward-contract order, $T_i^{f\prime}$.

The last event of round one occurs when dealing banks observe round-one interdealer order flow

$$V = \sum_j T_i^s.$$

This sum of all outgoing trades, T_i^s, is net demand—the difference in buy and sell orders in the spot market. In the spot FX market, V is the information on interdealer order flow provided by interdealer brokers. This is an essential feature of real-time information.

Each dealer determines quotes and speculative demands in each market by maximizing a negative exponential utility defined over terminal wealth. Letting W_i denote end-of-period wealth t of dealer i, we have

$$\max_{\left\{P_i^s, P_i^f, T_i^s, T_i^f\right\}} E[-\exp(-\theta W_i|\Omega_{is})].$$

3.2 Equilibrium

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 1 *A quoting strategy is consistent with symmetric PBE only if the period-one* *spot quote is common across dealing banks with* $P^s = E(S)$*.*

Proofs of all propositions are given in Appendix A. Intuitively, rational quotes must be common to avoid arbitrage, because quotes are single prices, available to all dealing banks, and good for any size. The common price is $E(S)$. An unbiased price conditional on public information is necessary for market clearing in the spot market. Specifically, market clearing requires that dealer demand in period one offset customer demand where Ω_s is public information available for quoting. Since P^s is common, it is necessarily conditioned on public information only. At the time of quoting in period one, there is nothing in Ω_s that helps estimate c_{is} so that $E[c_i|\Omega_s] = 0$. The only value of P^s for which $E[D_i^s(P^s)|\Omega_s] = 0$ is $P^s = 0$, since $D_i^s(0) = 0$ and $\partial D_i^s/\partial P^s < 0$.

Proposition 2 *A quoting strategy is consistent with symmetric PBE only if the period-two quote is common across dealing banks with* $P^s = E(F) + \lambda V$*.*

No arbitrage arguments that establish common quotes are the same as for Proposition 1. Like P^s, P^f necessarily depends only on public information. Here, the additional public information is the interdealer order flow, V. With common prices, the level necessarily depends only on commonly observed information.

Proposition 3 *The trading strategy profile for dealer in a symmetric linear equilibrium is:*

$$\begin{aligned} T_i^s &= \beta_1 c_{is} \qquad && \beta_1 > 0, \beta_2 < 0 \ \mathit{if}\ \sigma_{sf} > 0 \\ T_i^s &= \beta_1 c_{is} + c_{if} \qquad && \forall i = 1,..,n \end{aligned}$$

The values of the β coefficients are given in Appendix A. Recall that the quoting rules for $\left\{P_i^s, P_i^f\right\}$ are linear in $\{E[S], E[F], V\}$. Exponential utility and normality generate trading rules that have a corresponding linear structure. These strategies take into account dealer recognition that their individual actions will affect prices. The trading strategies in Proposition 3 have implications for the role of hedging and private non-payoff information. For example, the coefficient in the period-one trading rule implies that non-payoff-relevant information motivates dealer speculation, but this is offset in round two by the fact that dealing banks are risk-averse and seek to hedge or off-load the risk exposure that they took on to manipulate round-two prices via market observed order flow and round-s outgoing trade.

3.3 Implications of the Model

(i) Dealers in FX market provide overnight liquidity when trades are more informative

(ii) Dealers speculate on the future direction of the exchange rate with order flow information

(iii) Dealers speculate and hedge risk across price-correlated markets

(iv) When dealers do not provide liquidity, commercial clients play the role of liquidity providers

Note that the timing of the model is very stylized. In fact, both types of customer interact with dealers continuously throughout the day. Dealers will hold on to an undesired position in return for adequate compensation. Otherwise they will shade their spreads in order to close out their position. As dealers narrow their quotes, customers will be induced to place orders as their increasingly attractive quotes, and thus absorb some of the excess supply or demand. Quotes will not narrow completely since dealers as a whole are willing to hold their part of the remaining position overnight, or finding an offsetting position in the forward market.

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 individual dealers operating in Canada. In Canada, most FX trades are handled by the top six Canadian banks.[9] The dataset employed in this paper covers a ten year period and includes daily data over the period October 2, 1995 through to September 30, 2005, or more than 2500 observations.[10] The Bank of Canada also provides daily USD/CAD spot closing rates which are used to construct a daily series of foreign exchange returns. Since the foreign exchange rate is quoted as the number of Canadian dollars per U.S. dollar, a rise in the exchange rate indicates a depreciation of the Canadian dollar.

[9] 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

[10] 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.

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.[11] The reported series are in Canadian dollars (CAD), and include trading against all other currencies though most trading is in USD/CAD. Flows are categorized according to customer type: trade with the central bank (Bank of Canada) (CB); commercial client business (CC) includes all transactions with resident and non-resident non-financial customers; Canadian domiciled investment flow business (CD) accounts for transactions with non-dealer financial institutions located in Canada, regardless of whether the institution is Canadian-owned; and foreign domiciled investment business (FD) consists of all transactions with financial institutions, including FX dealers, pension funds, mutual funds and hedge funds, located outside Canada. Interbank transactions between Canadian dealers are not considered in the analysis. These transactions are approximately zero when aggregated across reporting dealers. The paper focuses on the net (purchases less sales) currency positions of each group of customers and the positions of market makers. Participants 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. Canadian-domiciled investment flow business and foreign-domiciled investment business emphasize the investment, or capital, flow nature of those transactions.

Descriptive statistics associated with the daily trading flows (defined as Canadian dollar purchases less sales) of each customer group are presented in Table 1.[12] On average, commercial client and foreign domiciled investment flows are larger and more volatile than Canadian domiciled investment and dealer flows. Further, all individual participant flows exhibit some degree of excess kurtosis relative to a normal distribution. Interestingly, commercial clients, on average, purchase Canadian dollars, while foreign domiciled financial institutions sell Canadian dollars. Spot and forward averages suggest that foreign institutions do not utilize the forward market as intensively as domestic participants, such as Canadian dealers and commercial clients. Since the Bank of Canada does not use the forward market in its operations, no correlation coefficient exists for this category. While the correlations between spot and forward flows are not large for commercial clients, Canadian domiciled investments or foreign domiciled investment participants, this correlation for market making dealers is

[11] Since FX swaps are made up of both a spot and offsetting forward contract legs, they are ignored in the analysis.

[12] Additional descriptive statistics are presented in D'Souza (2002).

negative and large in absolute value, perhaps suggesting that dealing institutions use the two markets jointly to manage their overall FX position.

Table 2 presents correlation coefficients between the various 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: -0.64, spot market: -0.34, forward market: -0.27), between foreign domiciled institutions and market making dealing institutions in spot markets (0.66), and between commercial clients and market making dealing institutions in forward contract markets (0.70). These latter two correlations may suggest that market makers strategically exploit the information learned from certain trades, and then off-load any built-up positions once the information becomes incorporated into prices.

5. Liquidity Provision across FX Participants

In this section, I empirically examine the role of individual groups of FX participants in providing overnight liquidity. I specifically address the following question: when informed and uninformed trades are placed in the market, who holds the offsetting position at the end of the day and, more generally, who holds the offsetting position at all points in time into the future? BRS find evidence that non-financial customers provide liquidity services in the Swedish krona market. Employing a similar dataset covering the Canadian dollar market, I first attempt to confirm those findings. Results suggest that commercial clients are indeed liquidity providers in the Canadian FX market, but so too are market making dealers. They provide significant levels of overnight liquidity under certain circumstances, and at different points in time. I find that market makers are especially involved in providing liquidity services when foreign financial customers initiate trades in the market. These trades are particularly important in terms of their information content, and as such, dealers are willing to accept the risks associated with holding an undesired inventory position. While the Cao, Evans and Lyons (2005) model was developed to explain strategic intraday trading, evidence presented suggests that the model may also describe trading dynamics interday.

To determine causality between variables, I follow the procedure proposed by Toda and Yamamoto (1995) and estimate a vector autoregression in levels. The non-causality hypothesis is tested with a conventional Wald statistic and allows for standard asymptotic inference. The positions (i.e., cumulative trade flows) of commercial clients (CC), Canadian domiciled financial customers (CD), foreign domiciled financial customers (FD), the central bank (CB), and market making dealers (MM) are included along with the logarithm of the end-of-day USD/CAD exchange rate in the vector of endogenous variables that interact across time. This represents a finer grouping of traders than analyzed in BRS.

Table 5 indicates that FD trades have a substantial effect on MM positions in the short-run. These participants are pushers in the market and take a leading role in the price discovery process. Interestingly, FD trades, in addition to CC and CD trades, are influenced by changes in exchange rates. The results may indicate evidence of trend chasing, or simply that traders are continuously rebalancing their portfolios. For example, in response to a exchange rate innovation, commercial clients may adjust their hedge ratio. Lastly, tests statistics indicates that Granger-causality occurs in both directions between CC and MM positions. This can be explained in terms of the theoretical model developed above, and in particular the last period of that model. At the end of the game, groups of participants must negotiate with each other and determine the associated returns required to hold any undesired position in the market. Depending on the day to day values of all non-payoff relevant factors (e.g., relative measure of risk tolerance), CC traders, for example, may decide that the risks associated with holding a large inventory position are too high relative to the compensation offered by the market.

The Johansen method is employed to uncover the dynamic relationship between participant positions and the exchange rate. Like BRS, I test for cointegration across combined spot and forward market positions. 10-year and 3-month interest rate differentials between Canadian and U.S. benchmark government securities are included in the analysis but are treated as exogenous. The two variables are used by BRS to proxy for, or capture, expectations of macroeconomic variables. Before any cointegration analysis can be performed, unit-root tests are conducted on all variables. Panel (a) in Table 3 presents Augmented Dickey-Fuller test statistics and their associated p-values. In all cases, the null of a unit root cannot be rejected at the 10% significance level.

A vector error correction model (VECM) is estimated by maximum likelihood methods.[13] Trace statistics, employed to determine the number of cointegrating relationships (r), are presented in Panel (b) of Table 3, and provide evidence of two cointegrating equations. Based upon the Schwarz Information Criterion (SIC), two lags and a deterministic trend in each cointegrating vector are included in the VECM specification.[14] The two long-run

[13]Maximum likelihood estimation of vector error correction models is discussed in Hamilton (1994) and Johansen (1995).

[14]The choice of r is frequently sensitive to the choice of lag and trend restriction. Banerjee et al. (1993)

relationships are empirically identified. One is associated with price discovery, and describes the long-run relationship between informed cumulative trades flows (or positions) and the exchange rate. The other is associated with overnight liquidity provision, and the relationship between liquidity demand and liquidity supply. These relationships are hypothesized to hold over the longer term, and are therefore estimated as part of the cointegrating system. Results of the cointegration analysis are presented in a similar manner as BRS.

Table 4 summarizes the final version of the estimated model. Panel (a) presents the estimates of the cointegrating vectors. Like BRS, a number of restrictions are imposed on the model to reflect empirical implications of the Evans and Lyons (2002a) model. The cointegrating vector reflecting the price pressure that financial customers and market making dealers put on exchange rates is normalized on the exchange rate. Coefficients associated with the positions of commercial clients (CC), Canadian domiciled financial customers (CD), and central bank (CB) are restricted to zero.[15] The trend in each cointegrating relationship is found to be significant possible reflecting other unobservable variables. The second equation, which accounts for the net imbalance across participant positions, is normalized on CC flows.

Overall, the estimated cointegrating relationships suggest that FD and MM act as aggressive traders, and that CC, MM and FD positions must jointly balance-out in the long-run. Unlike BRS, the estimated model does not impose the extremely restrictive assumption that changes in the positions of financial customers are countered by non-financial commercial clients. Instead, given the increased level of disaggregation in the current dataset, the net positions of all clients are allowed to interact simultaneously. The BRS assumption is especially important to relax since this paper seeks to determine the role of market makers in providing overnight liquidity.

The estimated coefficients associated with the positions of foreign financial customers and market making dealers are significant at the 1% level in the both cointegrating vectors. They also and have their predicted sign. For example, in the first vector, an increase in the Canadian dollar position of foreign domiciled financial institutions is expected to result in a appreciation of the Canadian dollar. D'Souza (2007) suggests that these participants are asymmetrically informed and influential in the price discovery process. Market making dealers, while providing liquidity, also observe order flow. The model developed above suggests that dealers will also speculate with the order flow information they observe while acting as

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warn against omitting cointegrating vectors when test statistics are close to their critical values. Plots of participants' positions provide additional evidence that many series are trend stationary.

[15] Alternatively, CC, CD and CB could be substituted in the first equation rather than FD and MM.

intermediaries.

In the language of BRS, foreign domiciled financial institutors push the exchange rate. It is hypothesized that commercial clients are liquidity providers, and take an off-setting position. Market making institutions play a part in both roles. This result is confirmed in the second identified cointegrating equation. From the perspective of the dealers, when foreign domiciled financial institutions demand liquidity, market makers take partially offsetting positions, as do commercial clients. Panel (b) reports the adjustment coefficients associated with each error correction vector. The adjustment coefficients associated with foreign domiciled financial customers (FD) equation are not statistically different from zero, suggesting that these positions are weakly exogenous.[16] These coefficients are restricted to zero. An LR test of all restrictions cannot be rejected ($\chi^2(4) = 1.42$, p-value$= 0.84$).

Impulse response functions associated with the reaction of each endogenous variables to shocks in the positions of FD, CD, CC, MM groups are computed. A shock to the i-th variable not only directly affects the i-th variable but is also transmitted to all of the other endogenous variables through the dynamic structure of the VECM. Impulse response functions provide a convenient way to fully analyze the time-varying dimensions of liquidity provision given the interdependent nature of these variables. The ordering of each variable in the VECM can be important.[17] A Cholesky decomposition is used to orthogonalize the impulses. Based on the earlier discussion, the following ordering is employed: CD→FD→CB→CC→MM. To illustrate the most conservative estimate of the contribution of MM trades to overnight liquidity provision, MM is entered last.

The response of each endogenous variable to a one standard-deviation innovation in CC, CD, FD and MM is documented in Table 6 at the 5, 10, 20, 100, and 250 day-ahead horizon. Positive values are either associated with increases in the Canadian dollar position of participants, or in the case of the exchange rate, are associated with a depreciation in the Canadian dollar. The exchange rate reaction to each innovation gives an indication of the information content of each type of trade. In particular, FD and MM trades (i.e., the purchase of Canadian dollars) are associated with an appreciation of the Canadian dollar. Generally, these trades can be considered informative about the future value of the exchange rate. In contrast, when commercial clients or Canadian domiciled financial institutions purchase Canadian dollars, the exchange rate depreciates, suggesting that these participants must pay

[16] D'Souza (2007) finds that foreign dealers have private information and are very influential in the price discovery process.

[17] The effect of any common component is attibuted to the variable that is ordered earlier in the system. In general, ordering was not found to make a large difference qualitatively.

a price for liquidity services. This is usually associated with uninformative trades.

Subsequent to a FD trade innovation, both CC and MM provide significant levels of liquidity. While commercial clients dominate in this role, MM traders increase their supply of liquidity across time. Interestingly market makers and commercial clients are liquidity providers to each others . While commercial clients provide larger levels of liquidity to MM earlier on, these amounts fall quite significantly over time. FD traders have only a minor role in the provision of liquidity to all other market participants.

Policy makers tasked with the job of designing effective FX intervention strategies should be concerned with the provision of liquidity during these episodes. In Canada, between 1995 and 1998, the Bank of Canada intervened in the foreign exchange ito reduce the short-term volatility of the USD/CAD exchange rate.[18] The vector error correction model is re-estimated over the period October 2, 1995 and September 30, 1998 with the same structure and restrictions. Figure 1 illustrates that only market makers provide immediate liquidity (i.e., selling of Canadian dollars or buying of U.S. dollars) subsequent to an innovation in which the central bank sell U.S. dollars (or buys Canadian dollars). Overtime, while dealer reduce their exposure, both Canadian domiciled financial customers and the commercial clients of dealers begin to provide liquidity services. Interestingly, foreign domiciled financial customers are liquidity takers, buying CAD, in the aftermath of central bank intervention operations.

These patterns are very similar in to those exhibited in response to a FD innovation. Both FD and CB innovations are thought to contain private information. For example, intervention activities may convey information about the current or future course of domestic monetary policy. Initially, market makers are quick to provide liquidity in an attempt to capture information associated with the future behaviour of the exchange rate. Overtime, dealers will off-load their positions to commercial clients as their private information becomes stale,

[18]On 12 April 1995, the Bank introduced a new set of intervention program guidelines. Dollar sums used for intervention were raised, "non-intervention exchange rate bands" or target zones were widened, and it was decided that non-intervention bands would be rebased automatically at the end of each business day. Officially, the purpose of these new guidelines was to make intervention more effective at reducing exchange rate volatility and more consistent with maintaining orderly markets. 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 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. 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 replensihment of foreign exchange reserves.

or the risks associated with holding these undesired balances become costly.

Overall results are qualitatively similar to BRS. In particular, non-financial customers are found to provide liquidity to financial customers. A disaggregation of participant positions illustrates that this is only true when foreign-domiciled financial customers demand liquidity. Finally, there is significant evidence that dealers as a group are overnight liquidity providers but not to the same extent as commercial clients. The results stands in contrast to anecdotal and empirical evidence of individual dealers that suggest 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, market making dealer positions are now disaggregated by individual financial institutions. The data focuses on the six largest financial institutions in Canada. Dealers as a group share in the provision of liquidity and are able to manage their inventories by trading with each other. In a similar empirical exercise to the one conducted above, each dealer's supply of liquidity is examined. Evidence suggest that most dealers behave in a very similar fashion. Since customers are able to trade with multiple dealers simultaneously, I also examine whether the commercial clients and Canadian domiciled financial customers of each dealer provide similar levels of liquidity.

Before proceeding to an analysis of impulse response functions, I examine whether a common factor exists across trade flows at individual dealing institutions. In Table 7, the maximum likelihood estimates of the loadings, Λ, in a common factor analysis model are documented

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

where x is a vector of the trading flows of individual financial institutions, μ is a constant vector of means and f is the independent standardized common factor. Large loadings across dealers suggest that a common factor exists across flows both from the perspective of each dealer's own inventory and in terms of the trades of their customers. In particular, there is significant evidence that a single factor explain can explain the a large component of the common variation of FD, CC and MM flows. This may be considered preliminary evidence that individual market making dealers provide similar levels of liquidity. A common factor also explains the variation in FD flows across banks. Given the evidence that foreign domiciled financial customers trades are informative, it is likely that dealers compete for these flows. Informed customers may break-up, or spread around, their trading orders amongst multiple dealers to mitigate the risk that any one dealer will exploit the information in these trades. In contrast, there is little evidence that there exists a common factor explains the variation in CD flows across banks.

Vector error correction models are now estimated based on the positions of participants across dealers. The restrictions imposed on the cointegration vectors as well as the adjustment factors are similar to those discussed above.[19] For example, FD flows are still weekly exogenous. Adjustment coefficients in front of the cointegrating vectors associated with the FD equation are restricted to zero. Table 8 describe the response in the position of each institution, and each institution's customers, at the 1-, 5-, 10-, 20-, 100-, 250-day ahead horizon. For brevity, the exercise is only conducted subsequent to a standardized innovation in the market-wide foreign domiciled financial investment position. Results suggest that commercial clients of all six financial institutions are liquidity providers. Similarly, all 6 market makers are found to provide liquidity, though typically in smaller amounts that commercial clients. Not surprisingly, the Canadian domiciled financial customers of each financial institution provide minimal levels of liquidity.[20]

6. Liquidity Provision across Spot and Forward Markets

In this section, the positions of each participant are disaggregated into their individual positions in spot and forward contract markets. Certain 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. Dealers, are market makers in both markets, and can reduce their inventory risk exposure in one market by having an offsetting position in another market. Granger-causality tests, presented in Table 9, indicate that changes in FX market participant positions can have effects across markets. For example, commercial client positions in forward markets have an impact on commercial client positions in spot markets, and vice versa. A similar finding is uncovered for market making dealing institutions. Results also indicate that the spot position of dealers Granger-cause changes in the positions of commercial clients in forward contract markets. In addition, the forward contract positions of commercial clients impacts on the forward contract positions of market makers.

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

[19] Two lags, a deterministic trend, and two cointegrating vectors was found to be the optimal specification.

[20] There is also little evidence that individual foreign domiciled financial institutions provided liquidity. These results are available from the author.

that includes a deterministic trend in each cointegrating vectors and two lags. Estimates of the cointegration vectors and the adjustment coefficients are now summarized. The first cointegrating vector, in which commercial client and Canadian domiciled financial customer flows are restricted to zero, is consistent with earlier findings. Foreign domiciled financial flows are found to push the exchange rate. In particular, when these customers purchase Canadian dollars in either spot or forward market the exchange rate appreciates, or falls in magnitude. Finally, there is little evidence that FD trades are weakly exogenous once positions are disaggregated across spot and forward contact markets.

In Figures 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. After a one-standard deviation innovation in FD, market makers manage a long position in the spot market, but a short position in the forward market. According to the theoretical model presented above, participants speculate based on the information learned from FD trades while taking a partially offsetting, or hedged position, in the forward market. In contrast, commercial clients, who are not privy to FD flows, provide ample levels of liquidity across time in both spot and forward markets. In Figures 3, similar impulse response functions are plotted subsequent to a shock in the spot position of domestic financial customers. Results are considerably different. Market makers and commercial clients each hold nearly offsetting positions across spot and forward markets. While market makers may have a long position in the spot market and a short position in the forward market, the two positions are nearly identical in absolute value. Similarly, the positions of commercial clients are nearly a mirror image of each other across spot and forward 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. In a similar spirit to the stylized model presented earlier, dealers observe order flow while making markets intraday. They may become informed about payoff- and non-payoff relevant factors that affect exchange rate returns. Depending on the information content of trades, dealers may behave strategically by speculating within, and across, markets. Lastly, over time dealers will attempt to off-load part of their inventory positions in a manner that can preserve their informational advantage. In the overall process, they provide and withdraw liquidity. Dealers are well suited to providing overnight liquidity given both their superior position in the intermediation of intraday trading and their ability to operate in multiple markets.

7. Summary, Conclusion and Future Work

Our current understanding of overnight liquidity provision in FX markets is incomplete. Anecdotal evidence, or empirical evidence based on the datasets of individual participants, suggests that dealers in FX market are not involved. This paper has tested a number of hypotheses concerned with the provision of overnight liquidity by dealers, and by other groups of market participants. With a finer disaggregation of trades, both in terms of the groupings of customers that trade with dealers, and a breakdown of position in spot and forward sub-markets, we can better understand if, how, and when, dealers provide this service. Traditionally, it was assumed that dealers end the day 'flat', and only provide intraday liquidity to their customers. This is clearly not the case. I demonstrate that dealers exploit their access to order flow information, obtained in their intraday deals with customers, and take speculative and hedged positions across spot and forward markets. These strategies are executed to generate larger returns as demonstrated in the model developed that is based on Cao, Evans and Lyons (2006).

The disaggregation of positions by type of customer is an important feature of the analysis. Dealers find some customers to be more informative than others. Foreign domiciled financial customer and central bank trades are highly sought after. Domestic financial customers trades are not as informative, and as such market makers are not active in providing overnight liquidity to these participants. When trades are more informative, dealers are willing to act more aggressively in the provision of liquidity. This paper demonstrates that dealers use their own customer trades as a source of private information (non-payoff relevant or payoff relevant), which imparts a temporary profit-making opportunity to dealers speculating in the interdealer market. The strategy is not profitable for long. Once the private information has been utilized and become stale, dealers attempt to off-load any undesired positions to other participants in the market.

Dealing banks in the FX market have many sources of comparative advantages in the intermediation of trades that allows them to engage in strategic interday trading. For example, in the recent past, dealing institutions would negotiate bilateral quoting agreements among themselves that would guarantee access to certain minimum levels of liquidity throughout the day. Electronic trading platforms such as EBS and Reuters now provide dealers with this security. Customers, or non-market-making participants in the FX market, do not have this access. In addition to the flow information that market makers observe that may be used to generate excess returns, financial intermediaries can make economic profits solely by buying and selling continuously in small increments and providing intraday liquidity to the FX market. Furthermore, given their optimally designed capital-allocation functions, financial institutions will generally have a higher tolerance for risk than their customers. D'Souza and Lai (2006) illustrate how market making activities are influenced by the risk-bearing capacity of a dealer, which is itself determined by the amount of risk capital allocated to this activity by each financial institution.

The provision of liquidity is important for well-functioning financial markets. While the results in this paper confirm earlier findings that commercial clients are significant overnight liquidity providers, the role of market makers has previously been undersold. Individually, and as a group, dealers are key participants in the provision of liquidity. But dealers do not provide the service without an expectation of higher returns, either directly through better prices or indirectly through information about market wide order flow. Future work will attempt to measure the actual compensation that dealers receive for this service.

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

Net trades flows for each participant are the difference between purchases and sales of Canadian dollars. Flows (in Canadian dollars) 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; trades by the Bank of Canada (CB) and trading by Canadian dealers (MM). Trading is also disaggregated by the type of trade (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, 1995 - September 30, 2005. Number of daily observations: 2510.

	Participant Category				
	CC	CD	FD	CB	MM
			Total Across Markets		
Mean	156.46	-6.42	-122.93	-0.47	46.06
Median	144.95	-3.20	-107.15	0.00	51.75
Std. Deviation	471.03	212.39	515.92	64.58	484.67
Skewness	-1.25	-0.17	-0.11	6.65	-0.36
Kurtosis	25.93	6.35	6.07	138.41	30.35
			Spot		
Mean	75.54	-36.95	-108.70	-0.47	-57.39
Median	74.10	-23.45	-99.50	0.00	-48.45
Std. Deviation	303.02	149.36	469.28	64.58	500.67
Skewness	-4.75	-2.93	-0.25	6.65	-1.22
Kurtosis	115.22	50.46	6.52	138.41	19.25
			Forward		
Mean	80.91	30.52	-14.22		103.45
Median	60.70	22.20	-9.25		85.40
Std. Deviation	332.46	176.13	170.81		419.97
Skewness	0.24	1.47	-0.23		1.48
Kurtosis	8.58	27.97	11.96		18.74
			Correlation (Spot,Forward)		
	0.097	-0.156	0.105		-0.457

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

Net trades flows for each participant are the difference between purchases and sales of Canadian dollars. Flows (in Canadian dollars) 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; trades by the Bank of Canada (CB) and trading by Canadian dealers (MM). Trading is also disaggregated by the type of trade (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, 1995 - September 30, 2005. Number of daily observations: 2510.

	Participant Category				
	CC	CD	FD	CB	MM
	Total Across Markets				
CC	1.00				
CD	-0.05	1.00			
FD	-0.64	-0.30	1.00		
CB	0.16	0.00	-0.27	1.00	
MM	0.30	0.08	0.32	-0.01	1.00
	Spot				
CC	1.00				
CD	-0.04	1.00			
FD	-0.34	-0.12	1.00		
CB	0.04	-0.00	-0.27	1.00	
MM	0.30	0.16	0.66	-0.10	1.00
	Forward				
CC	1.00				
CD	0.03	1.00			
FD	-0.27	-0.04	1.00		
MM	0.70	0.43	0.22		1.00

Table 3: Unit Root and Cointegration Tests

Augmented Dickey-Fuller unit root test statistics, p-values, with and without trend. Unrestricted cointegration trace statistics with the following assumptions: linear deterministic trend in VAR with two lags. MacKinnon-Haug-Michelis (1999) p-values. Sample: October 2, 1995 - September 30, 2005. Number of daily observations: 2507 after adjustments.

Variable	constant		constant and trend		lags
	t-staistics	p-value	t-staistics	p-value	
log(USD/CAD)	-1.56	0.50	-1.99	0.61	0
Cumulative CC	-0.25	0.93	-1.51	0.83	2
Cumulative CD	-1.07	0.73	-0.73	0.97	1
Cumulative FD	-0.07	0.95	-2.06	0.57	2
Cumulative CB	-0.89	0.79	-1.53	0.82	14
Cumulative MM	-0.87	0.80	-2.17	0.51	1
10-year diff.	-2.46	0.13	-2.40	0.38	0
3-month diff.	-1.56	0.50	-1.99	0.61	0

Hypothesized Number of Cointegrating Equations:	Eigenvalue	Trace Statistic	5% Critical Value	p-value
None	0.022	186.37	159.53	0.001
At most 1	0.018	130.24	125.61	0.025
At most 2	0.015	84.06	95.75	0.242
At most 3	0.008	45.07	69.82	0.829
At most 4	0.006	24.80	47.86	0.924

Table 4: Cointegration Results

Vector error correction model estimated with Johansen method. The VECM models the log of the exchange rate and the positions 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; trades by the Bank of Canada (CB) and trading by Canadian dealers (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 SIC criterion. Estimates of the cointegrating vectors are provided in the panel (a) while adjustment coefficients are presented in panel (b). Standard errors of coefficients are in paranthesis. All cells without standard errors are the results of restriction placed on the model. Sample: October 2, 1995 - September 30, 2005. Number of daily observations: 2510.

Panel A: Cointegration Equation Estimates								
	log(e)	CC	CD	FD	CB	MM	Trend	Const.
Coint.	1.00	0.00	0.00	$8.47 * 10^{-6}$	0.00	$2.66 * 10^{-5}$	yes	yes
Eqn. 1:				$(1.2 * 10^{-6})$		$(4.0 * 10^{-6})$		
Coint.	0.00	1.00	-0.824	2.566	4.085	5.000	yes	yes
Eqn. 2:			(0.581)	(0.338)	(0.685)	(1.009)		

Panel B: Adjustment Coefficients						
	log(e)	CC	CD	FD	CB	MM
Coef.	-0.002	-613.938	151.648	0.000	108.578	-336.921
Eqn. 1:	(0.001)	(149.250)	(84.167)		(24.618)	(161.027)
Coef.	$-5.27 * 10^{-10}$	-0.003	0.001	0.000	0.000	0.001
Eqn. 2:	$(6.7 * 10^{-9})$	(0.001)	(0.000)		(0.000)	(0.000)

Table 5: Granger Causality

Granger-causality tests are employed to determine the direction of causality between each pair of variables. Wald statistics p-value are presented under the null hypothesis that the dependent variable in not affected by the other lagged endogenous variables. The following variables are considered: the log of the exchange rate, 10-year and 3-month interest rate spreads and the positions 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; trades by the Bank of Canada (CB) and trading by Canadian dealers (MM). Lag length was chosen based on the SIC criterion and the approach advocated of Toda and Yamamoto (1995). Sample: October 2, 1995 - September 30, 2005. Number of daily observations: 2510.

	H_0: Excluded Variable					
Dependent Variable	log(e)	CC	CD	FD	CB	MM
log(e)		0.566	0.381	0.534	0.868	0.635
CC	0.000		0.579	0.584	0.067	0.070
CD	0.001	0.579		0.659	0.315	0.619
FD	0.008	0.674	0.069		0.735	0.749
CB	0.420	0.019	0.004	0.045		0.888
MM	0.211	0.039	0.673	0.029	0.550	

Table 6: Impulse Response Functions, Groups of Participants Across FX Markets

Impulse response functions are presented at the 5, 10, 20 100 and 250 day-ahead horizons, subsequent to 1 standard deviation innovations to each trade flow variable. The following variables are considered: the log of the exchange rate, 10-year and 3-month interest rate spreads and the positions of market participants categorized according to customer type: commercial client trading (CC) includes transactions by resident and non-resident non-financial customers; foreign domiciled investment (FD) includes all transactions by financial institutions, including FX dealers, pension funds, mutual funds and hedge funds, located outside Canada; and trading by Canadian dealers (MM). A Cholesky decomposition is employed with the following ordering in variables: log(exchange rate)$\longrightarrow$CD$\longrightarrow$FD$\longrightarrow$CB$\longrightarrow$CC$\longrightarrow$MM. Sample: October 2, 1995 - September 30, 2005. Number of daily observations: 2510.

		Number of Days After Impulse					
Impulse	Response	5	10	20	100	250	∞
CC	CC	444.509	452.731	450.993	446.363	461.851	502.480
	CD	-27.233	-32.551	-42.336	-100.682	-154.056	-193.367
	FD	-54.428	-61.505	-59.727	-49.065	-44.455	-48.680
	MM	-312.239	-307.635	-298.298	-244.960	-201.996	-178.989
	log(e)*10^{-3}	0.158	0.322	0.639	2.430	3.822	4.482
CD	CC	-193.020	-194.437	-197.461	-217.376	-240.070	-263.413
	CD	229.123	224.708	215.716	156.176	87.484	15.817
	FD	-19.020	-14.437	-17.461	-27.376	-20.070	-23.413
	MM	-9.216	-7.709	-4.783	14.743	37.593	61.809
	log(e)*10^{-3}	0.129	0.155	0.208	0.563	0.985	1.442
FD	CC	-501.997	-517.218	-514.781	-500.201	-496.984	-509.610
	CD	8.213	11.775	17.207	48.920	76.479	94.623
	FD	690.341	705.631	704.587	695.646	690.342	690.694
	MM	-134.405	-137.414	-143.157	-175.714	-201.212	-213.642
	log(e)*10^{-3}	–0.050	-0.147	-0.346	-1.470	-2.329	-2.710
MM	CC	-36.059	-32.152	-49.717	-66.342	-172.270	-290.583
	CD	8.812	13.971	24.441	91.461	163.777	233.346
	FD	0.253	-0.634	0.846	12.428	28.332	47.912
	MM	199.462	196.237	190.613	156.353	123.246	96.247
	log(e)*10^{-3}	-0.052	-0.135	-0.289	-1.207	-2.034	-2.624

Table 7: Common Factors, FX Dealing Institutions

Maximum likelihood estimates of the factor loadings associated with the positions of 6 large FX dealers and their customers obtained from a common factor analysis model $x = \mu + \Lambda f + e$ where x is a vector of the trading flows of individual financial institutions, μ is a constant vector of means and f is the independent standardized common factor. Sample: October 1, 2000-September 30, 2002, 5-minutes frequency.

	FD	CD	CC	MM
Dealer 1	0.48	0.27	0.38	0.67
Dealer 2	0.55	0.11	0.36	0.67
Dealer 3	0.47	-0.08	0.44	0.80
Dealer 4	0.52	0.07	0.53	0.47
Dealer 5	0.49	0.10	0.42	0.82
Dealer 6	0.14	-0.09	0.23	0.68
H_0: no common factor	0.00	0.36	0.00	0.00

Table 8: Impulse Response Functions, Dealers and Dealer's Customers Across FX Markets

Impulse response functions are presented at the 5, 10, 20 100 and 250 day-ahead horizons, subsequent to 1 standard deviation innovations in foreign domiciled investment (FD) which includes all transactions by financial institutions, including FX dealers, pension funds, mutual funds and hedge funds, located outside Canada. The following variables are examined: the positions of 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; and trading by Canadian dealers (MM). A Cholesky decomposition is employed with the following ordering in variables: log(exchange rate)$\longrightarrow$CD$\longrightarrow$FD$\longrightarrow$CB$\longrightarrow$CC$\longrightarrow$MM. Sample: October 2, 1995 - September 30, 2005. Number of daily observations: 2510.

	Number of Days After Impulse					
Response	5	10	20	100	250	∞
CC of Dealer 1	-58.54	-60.35	-60.65	-62.00	-72.65	-78.37
CC of Dealer 2	-93.49	-101.20	-109.64	-123.90	-106.81	-83.62
CC of Dealer 3	-91.96	-92.66	-89.12	-80.91	-64.56	-61.01
CC of Dealer 4	-31.38	-33.40	-35.31	-38.75	-37.43	-33.64
CC of Dealer 5	-141.74	-153.54	-167.38	-197.73	-252.73	-262.36
CC of Dealer 6	-82.18	-80.55	-73.44	-58.60	-42.88	-45.40
CD of Dealer 1	2.91	2.66	1.55	-6.89	-15.98	-19.96
CD of Dealer 2	0.81	1.10	1.14	-5.94	-21.41	-30.30
CD of Dealer 3	2.10	1.56	0.63	-0.65	4.01	7.70
CD of Dealer 4	-1.21	-1.63	-2.35	-8.69	-16.49	-20.18
CD of Dealer 5	-8.47	-11.48	-15.67	-39.17	-56.13	-61.32
CD of Dealer 6	-4.05	-4.18	-3.80	-4.51	-9.23	-12.37
Dealer 1 (MM)	-7.80	-9.71	-12.13	-22.37	-34.86	-38.16
Dealer 2 (MM)	-36.90	-29.10	-17.46	-22.48	-51.06	-59.35
Dealer 3 (MM)	-27.53	-29.8	-35.49	-74.29	-101.76	-109.19
Dealer 4 (MM)	-8.74	-6.72	-3.68	-2.24	-6.95	-8.35
Dealer 5 (MM)	-28.86	-25.01	-18.81	-8.36	-10.44	-11.22
Dealer 6 (MM)	-24.77	-28.45	-33.48	-37.34	-31.05	-29.15

Table 9: Granger Causality

Granger-causality tests are employed to determine the direction of causality between each pair of variables. Wald statistics p-value are presented under the null hypothesis that the dependent variable in not affected by the other lagged endogenous variables. The following variables are considered: the log of the exchange rate, and the positions of market participants categorized according to customer type: commercial client trading (CC) includes transactions by resident and non-resident non-financial customers; foreign domiciled investment (FD) includes all transactions by financial institutions, including FX dealers, pension funds, mutual funds and hedge funds, located outside Canada; and trading by Canadian dealers (MM). Lag length was chosen based on the SIC criterion and the approach advocated of Toda and Yamamoto (1995). Trading is also disaggregated by the type of trade (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, 1995 - September 30, 2005. Number of daily observations: 2510.

		H_0: Excluded 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		0.49	0.36	0.50	0.31	0.59	0.13	0.58	0.87
CC	spot	0.59		0.78	0.97	0.53	0.08	0.29	0.32	0.09
CD	spot	0.00	0.59		0.59	0.96	0.30	0.25	0.26	0.77
FD	spot	0.03	0.92	0.31		0.98	0.34	0.15	0.03	0.33
MM	spot	0.21	0.78	0.18	0.59		0.06	0.08	0.08	0.02
CC	forward	0.00	0.03	0.75	0.85	0.09		0.17	0.45	0.71
CD	forward	0.00	0.71	0.69	0.62	0.26	0.50		0.06	0.74
FD	forward	0.06	0.71	0.59	0.17	0.60	0.68	0.75		0.39
MM	forward	0.06	0.21	0.62	0.80	0.20	0.01	0.02	0.81	

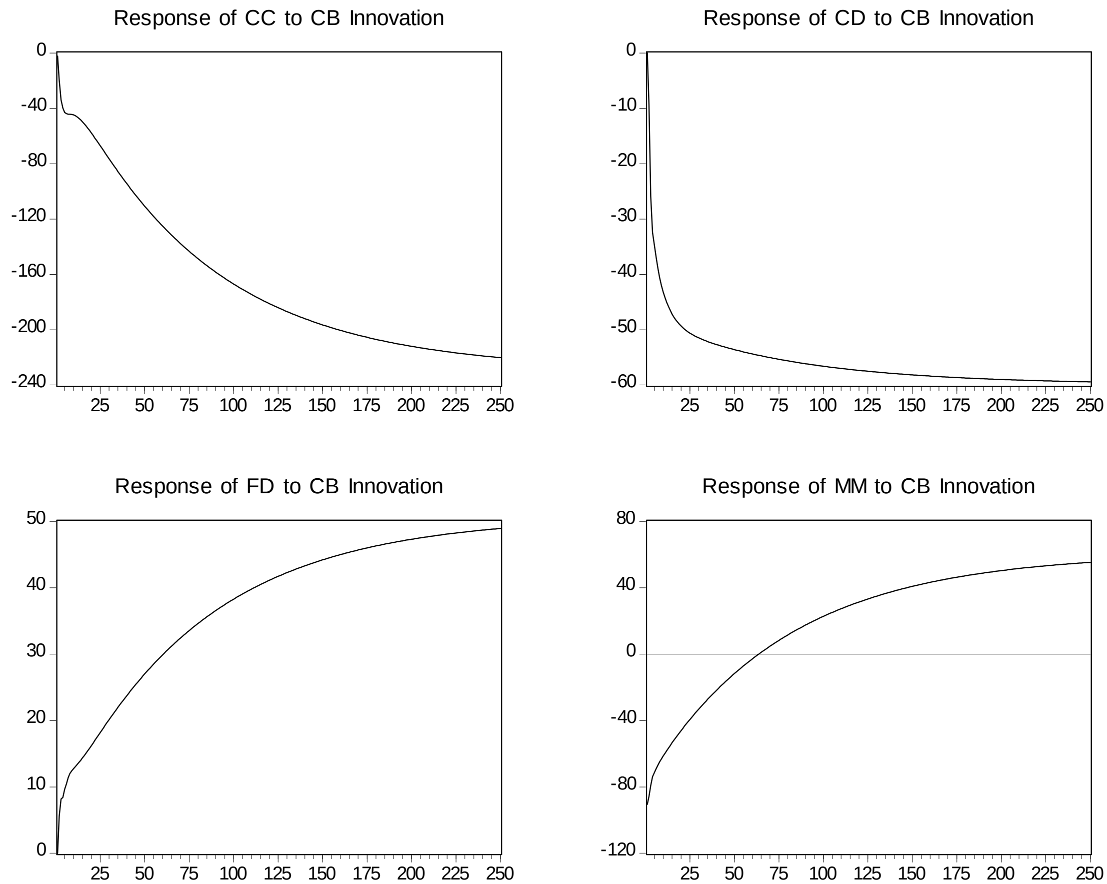

Figure 1: Impulse response functions, CB innovation

Impulse response functions are presented subsequent to 1 standard deviation innovations in trades by the Bank of Canada (CB). The positions of the following market participants are examined: 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; and trading by Canadian dealers (MM). A Cholesky decomposition is employed with the following ordering in variables: log(exchange rate)→CD →FD →CB →CC →MM. Sample: October 2, 1995 and September 30, 1998. Number of daily observations: 2510.

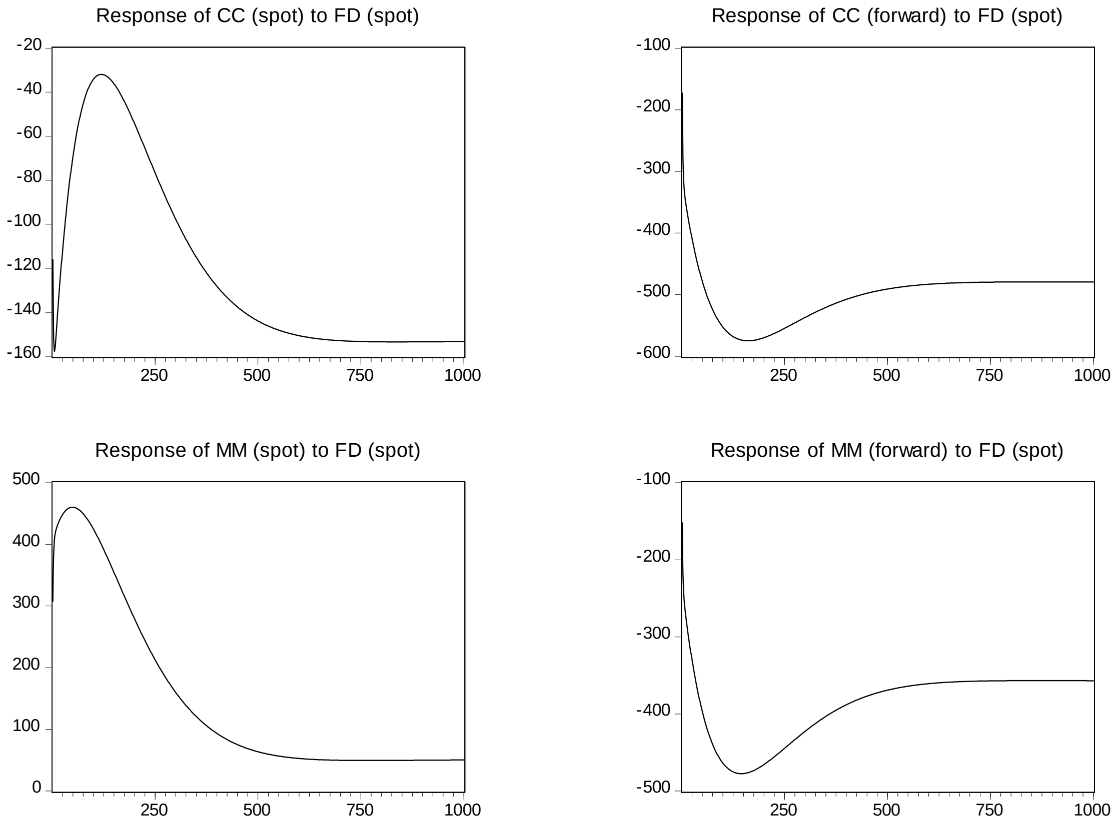

Figure 2: Impulse response functions, FD innovation in the spot market

Impulse response functions are presented subsequent to 1 standard deviation innovation to foreign domiciled investment (FD) in the spot market. The positions of commercial client traders (CC) and Canadian dealers (MM) are illustrated across spot and forward contract markets. A Cholesky decomposition is employed with the following ordering of variables: log(exchange rate) →CD(spot) →CD(forward) →FD(spot) →FD(forward) →CB →CC(spot) →CC(forward) →MM(spot) →MM (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, 1995 - September 30, 2005. Number of daily observations: 2510.

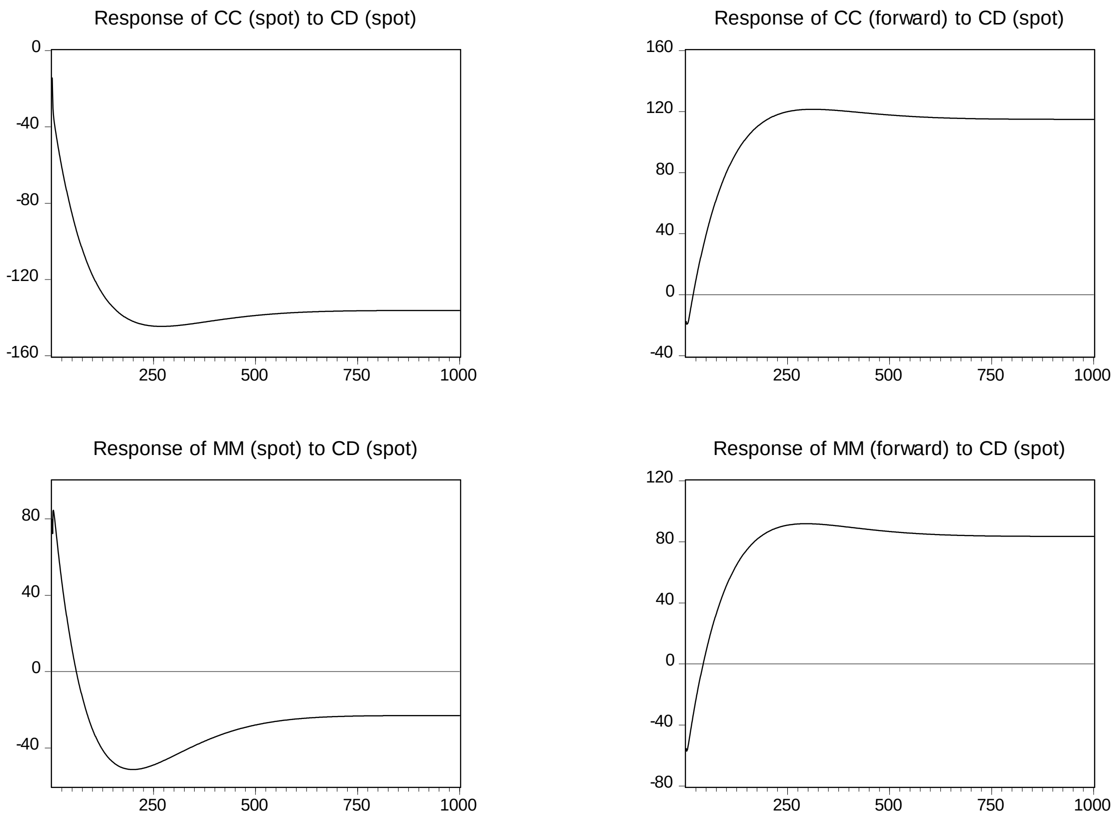

Figure 3: Impulse response functions, CD innovation in the spot market

Impulse response functions are presented subsequent to 1 standard deviation innovation to Canadian domiciled investment (CD) in the spot market. The positions of commercial client traders (CC) and Canadian dealers (MM) are illustrated across spot and forward contract markets. A Cholesky decomposition is employed with the following ordering of variables: log(exchange rate) →CD(spot) →CD(forward) →FD(spot) →FD(forward) →CB →CC(spot) →CC(forward) →MM(spot) →MM (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, 1995 - September 30, 2005. Number of daily observations: 2510.

Appendix

Proof. Proposition 1 and 2: Price determination ■

Rational quotes must be common to avoid arbitrage under the proposed quoting rules, trading rules, and risk aversion. With common prices, the level necessarily depends only on commonly observed information. Prices are redundant as conditioning variables because they depend deterministically on commonly observed variables already in the information set. The price a dealer quotes in the first round to the customer must be an unbiased estimate of the next round price, because the dealer has no information about the customer's trade prior to trading, and dealers are risk-averse. In the round that consists of spot market interdealer trading, the expected holding of dealers is still zero conditional on public information, because there is no new public information. The spot market must clear among dealers at a price that will not generate net excess demand.

Market clearing in the round-one spot market implies that

$$\sum_i E\left[\left(T_i^S - D_i^S - c_i - E\left[T_i^{S\prime}|\Omega_{iS}\right]\right)|\Omega_S\right] = 0,$$

or

$$\sum_i \left(E\left[c_i|\Omega_S\right] + E\left[D_i^S|\Omega_S\right]\right) = 0,$$

where Ω_S is public information available for quoting. At the time of quoting in round one, there is nothing in Ω_S that helps estimate c_i, so $E\left[(c_i)\,|\Omega_S\right] = 0$. The only value of P^S for which $E\left[D_i^S\left(P^S\right)|\Omega_S\right] = 0$ is $P^S = E\left(S|\Omega_S\right) = 0$, since $D_i^S\left(E\left(S|\Omega_S\right)\right) = 0$ and $\partial D_i^{S\prime}/\partial P^S < 0$.

In the forward-contract (second) round of interdealer trading, a bias in P^f is necessary for market clearing:

$$\sum_i E\left[\left(T_i^f - D_i^f - E\left[T_i^{f\prime}|\Omega_{if}\right]\right)|\Omega_f\right] = 0,$$

or

$$\sum_i E\left[D_i^f|\Omega_f\right] = 0.$$

Given normality and exponential utility, it is well known that if markets are independent, the round-two desired position is:

$$D_i^k = \frac{\mu_k - P^k}{\theta\sigma_k^2},$$

where μ_k is the unconditional mean and σ_k^2 is the unconditional variance of asset k. When asset prices are correlated, and if D_i^S has already been chosen in round one, the desired demand for D_i^f is

$$D_i^f = \frac{\mu_f - P^f}{\theta\sigma_f^2} - D_i^S\frac{\sigma_{Sf}}{\sigma_f^2},$$

so that

$$\sum_i E\left[\left(\frac{\mu_f - P^f}{\theta\sigma_f^2} - D_i^S\frac{\sigma_{Sf}}{\sigma_f^2}\right)|\Omega_f\right] = 0.$$

Since

$$\sum_i E\left[\left(D_i^S\frac{\sigma_{Sf}}{\sigma_f^2}\right)|\Omega_f\right] = \frac{\sigma_{Sf}}{\sigma_f^2}\sum_i E\left[-c_i|\Omega_f\right] = -\frac{\sigma_{Sf}}{\sigma_f^2}\sum_i\frac{V}{n\beta_1},$$

$$P^f = \frac{\theta\sigma_{Sf}V}{n\beta_1} = \lambda V.$$

Proof. Proposition 3: Optimal trading strategies ■

The derivation of trading strategies is summarized in this section. Dealer i's trading strategy in round two given their actions in round one is

$$D_i^f = \frac{\mu_f - P^f}{\theta\sigma_f^2} - \left(T_i^S - T_i^{S\prime} - c_i\right)\frac{\sigma_{Sf}}{\sigma_f^2}.$$

This equation is then substituted into dealer i's budget constraint before deriving first-order conditions.

Dealer i's trading strategy in round two given their actions in round one:

Omitting terms unrelated to D_i^S in the expected utility function, where

$$\begin{aligned}
W_i &= W_{i0} + \left[c_i P_i^S + T_i^{S\prime} P_i^S - T P_i^{S\prime} + T_i^{f\prime} P_i^f - T_i^f P_i^{f\prime} - \left(c_i + T_i^{S\prime} - T_i^S\right) S - \left(T_i^{f\prime} - T_i^f\right) F\right] \\
&= W_{i0} + \left[c_i\left(P_i^S - S\right) + T_i^{S\prime}\left(P_i^S - S\right) - T_i^S\left(P_i^{S\prime} - S\right) + T_i^{f\prime}\left(P_i^f - F\right) - T_i^f\left(P_i^{f\prime} - F\right)\right] \\
&= W_{i0} + c_i\left(P_i^S - S\right) + T_i^{S\prime}\left(P_i^S - S\right) - \left(D_i^S + c_i + E\left[T_i^{S\prime}|\Omega_{iS}\right]\right)\left(P_i^{S\prime} - S\right) \\
&\quad + T_i^{f\prime}\left(P_i^f - F\right) - \left(D_i^f + E\left[T_i^{f\prime}|\Omega_{if}\right]\right)\left(P_i^{f\prime} - F\right),
\end{aligned}$$

it is possible to write the dealer's problems as:

$$\underset{D_i^S}{Max} \qquad E_{\left\{P^f,S,F\right\}}\left[-\exp\left(-\theta\left(D_i^S - T_i^{S\prime}\right)\left(S - P^S\right) - \theta\left(D_i^f\right)\left(F - P^f\right)\right)|\Omega_{iS}\right],$$

The utility function has the convenient property of maximizing its expectation; when variables are normally distributed, this is equivalent to maximizing

$$E\left[\left(-\theta W_i\right)|\Omega_{iS}\right] - \frac{Var\left[\left(-\theta W_i\right)|\Omega_{iS}\right]}{2}.$$

In addition, if $\{X, Y\}$ are normally distributed with means $\left\{\mu_x,\ \mu_y\right\}$, variances $\left\{\sigma_x^2, \sigma_y^2\right\}$, and covariance σ_{xy},

$$E_{\{X,Y\}}\left[-\exp\left(kX+qY\right)\right]=\exp\left(k\mu_x+q\mu_y+\frac{k^2\sigma_x^2}{2}+\frac{q^2\sigma_y^2}{2}+kq\sigma_{xy}\right),$$

where $\{k,q\}$ are constants, the problem can be written as

$$\underset{D_i^S}{Max}\qquad D_i^S E\left(S-P^S|\Omega_{iS}\right)-D_i^S\frac{\sigma_{Sf}}{\sigma_f^2}E\left(F-P^f|\Omega_{iS}\right)-\left(D_i^S\frac{\sigma_{Sf}}{\sigma_f^2}\right)^2\frac{\theta}{2}\tilde{\sigma}_f^2,$$

where

$$\tilde{\sigma}_f^2=var\left(\left(E\left(F-P^f|\Omega_{iS}\right)\right)|\Omega_{iS}\right),$$

and

$$\tilde{\sigma}_S^2=var\left(\left(E\left(S-P^f|\Omega_{iS}\right)\right)|\Omega_{iS}\right)=0$$

$$\tilde{\sigma}_{Sf}=covar\left(\left(E\left(S-P^S|\Omega_{iS}\right)\right),\left(E\left(F-P^f|\Omega_{iS}\right)\right)|\Omega_{iS}\right)=0$$

After substituting $E\left(P^f|\Omega_{iS}\right)=E\left(\lambda V|\Omega_{iS}\right)=\lambda T_i^S=\lambda\left(D_i^S+c_i\right)$ into the objective function, the problem can be written as

$$\underset{D_i^S}{Max}\qquad D_i^S\frac{\sigma_{Sf}}{\sigma_f^2}\lambda\left(D_i^S+c_i\right)-\left(D_i^S\frac{\sigma_{Sf}}{\sigma_f^2}\right)^2\left(\frac{\theta}{2}\tilde{\sigma}_f^2\right).$$

The first-order condition is

$$2D_i^S\frac{\sigma_{Sf}}{\sigma_f^2}\lambda+\frac{\sigma_{Sf}}{\sigma_f^2}\lambda\left(c_i\right)-\left(2D_i^S\frac{\sigma_{Sf}^2}{\left(\sigma_f^2\right)^2}\right)\left(\frac{\theta}{2}\tilde{\sigma}_f^2\right)=0.$$

Simplifying,

$$D_i^S = \left(\frac{\lambda \sigma_f^2}{\theta \tilde{\sigma}_f^2 \sigma_{Sf} - 2\sigma_f^2 \lambda} \right) c_i$$

Note that

$$D_i^S = (\beta_1 - 1)\, c_i = T_i^S - c_i$$

$$D_i^f = \beta_2 c_i$$

where

$$(\beta_1 - 1) > 0, \beta_2 < 0 \qquad \text{if} \qquad \sigma_{Sf} > 0, V = 0$$

The second-order condition,

$$2\lambda - \left(\frac{\sigma_{Sf}}{(\sigma_f^2)} \right) \left(\theta \tilde{\sigma}_f^2 \right) < 0$$

ensures that $\beta_1 > 1$.