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How Do Canadian Banks That Deal in Foreign Exchange Hedge Their Exposure to Risk?

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Abstract

This paper examines the daily hedging and risk-management practices of financial intermediaries in the Canadian foreign exchange (FX) market. Results reported in this paper suggest that financial institutions behave similarly when managing their market risk exposure. In particular, dealing banks do not fully hedge their spot market risk. The results reported 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. While the extent of hedging is found to depend on market volatility and the magnitude of their risk exposure, the uniqueness of the dataset employed in this paper allows for an explicit test of the various sources of comparative advantage that dealing banks in the FX markets have in their role as market-makers. Private information via customer order flow, guaranteed access to liquidity, and the capital-allocation structure of a dealer's financial institution are potential sources of comparative advantage to dealing banks in the FX market. A model with private information and an imperfectly competitive environment is provided to illustrate hedging when informed agents in a multiple security market behave strategically. Empirical results suggest that dealing banks only selectively hedge speculative positions taken in the spot market in the forward market. Findings also suggest that dealing banks share in the risk exposure of the spot market's net position without simultaneously hedging this risk.

JEL classification: F31, G14, G21
Bank classification: Financial institutions; Market structure and pricing; Financial markets

Résumé

L'auteur examine les opérations journalières de couverture et les pratiques de gestion du risque des intermédiaires financiers sur le marché des changes canadien. Les résultats de l'étude donnent à penser que les institutions financières gèrent le risque de marché de façon similaire. C'est le cas en particulier des banques actives sur le marché des changes, qui ne couvrent pas entièrement les risques auxquels elles s'exposent sur le marché au comptant. Les résultats corroborent la thèse soutenue par Stulz (1996) et par Froot et Stein (1998), selon laquelle le degré de couverture dépend de l'avantage comparatif de l'institution à l'égard du risque couru. Bien que l'auteur constate que l'étendue de la couverture est fonction de la volatilité du marché et du degré d'exposition au risque, le caractère unique de l'ensemble de données utilisé dans l'étude autorise l'emploi d'un test explicite des différentes sources d'avantages comparatifs auxquelles les banques ont accès à titre de teneurs du marché des changes. Les sources potentielles d'avantages comparatifs sont : l'information privée recueillie dans le flux d'ordres des clients, l'accès garanti à la liquidité et la structure de répartition du capital au sein de l'institution financière. Un modèle postulant l'existence d'information privée et un cadre de concurrence imparfaite sert à étudier la couverture contractée par des opérateurs informés ayant un comportement stratégique sur un marché de titres multiples. Les résultats empiriques indiquent que les banques actives sur le marché des changes ne couvrent que de manière sélective, sur le marché à terme, les positions spéculatives prises sur le marché au comptant; il semble également qu'elles assument leur part du risque lié au déséquilibre net du marché au comptant sans simultanément le couvrir.

Classification JEL : F31, G14, G21
Classification de la Banque : Institutions financières; Structure de marché et fixation des prix; Marchés financiers

1. Introduction

Exchange rates seem to move inexplicably. This is especially true of their short-term day-to-day movements. In reality, the problem is that current fundamental models of the exchange rate are unable to explain short-term movements in currency prices. This weakness in the international finance literature has motivated this paper. Following Evans and Lyons (2000, 2002) and D'Souza (2002 and Forthcoming), who find that order-flow information explains and forecasts exchange rate movements,[1] this paper approaches the issue from a market microstructure perspective. Specifically, it is presumed that an understanding of how market participants behave, given the institutional structure and information flows in the market, is necessary to understand dynamics in the foreign exchange (FX) market—particularly short-term movements in the exchange rate. This paper seeks to determine how Canadian banks that deal in FX hedge their spot market exposure to exchange rate risk when their inventories diverge from a desired level. 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. This paper suggests that sources of comparative advantage innate to dealing banks will determine the extent of hedging that those banks engage in, which will necessarily have an impact on the behaviour of exchange rates.

The risk-management practices of market intermediaries have recently been investigated by Naik and Yadav (2002a) in U.K. bond markets, and by Naik and Yadav (2001, 2002b) in the U.K. equity market. The authors find that dealing banks actively hedge the duration of their risk exposure with derivatives. Every dealing bank making a market in Canada in the FX market reports net trade flows in each of the spot, forward, and futures markets to the Bank of Canada at the end of each day, which provides an opportunity to empirically investigate the hedging behaviour of market intermediaries for the purpose of risk management. The dataset enables the computation of the exact risk exposures of individual dealing banks, and allows for an investigation into the extent of selective risk-taking by a group of intermediaries who are largely similar in their attributes.

Can companies that face cash-flow risk increase their value by hedging any potential variability with the use of derivatives? Froot and Stein (1998) show that a financial intermediary will always wish to completely hedge its exposure to all risks that can be traded in an efficient market. Stulz

1. Order flow can be considered a measure of net demand or imbalance across the foreign exchange market. One measure of order flow employed in the literature (Evans and Lyons 2002, Hasbrouck 1991a,b) is the difference between buyer- and seller-initiated orders within the interdealer market. Order flow can also be defined as trade between all types of customers and dealers.

(1996) argues that a firm, rather than focusing its corporate risk management on minimizing variance, should spend more time understanding the comparative advantage of bearing certain risks. In particular, firms should not fully hedge risks that they have a comparative advantage in bearing, because a firm that carries no risk will not earn any economic profits.

Dealing banks have a variety of comparative advantages in bearing risk. Reciprocal agreements among dealing banks to quote bid and ask prices guarantee that these market-makers have access to liquidity. Customers, or non-market-making participants in the FX market, do not have this access. Braas and Bralver (1990) find that financial intermediaries can make economic profits solely by “jobbing,” or by buying and selling continuously in small increments and providing 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. Shoughton and Zechner (1999) and D’Souza and Lai (2002) show that a decentralized capital-allocation function can reduce the overall risk of a financial institution that has business lines with correlated cash flows. An optimally designed capital-allocation function should allow intermediaries to bear risk with a higher tolerance than non-financial institution customers.

The market microstructure literature argues that order flow is informative. 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. Order-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 would arguably choose not to hedge their risk exposure completely but to hedge it selectively. Private information gives financial institutions a comparative advantage over shareholders and other FX market participants in taking risks. 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. This paper provides a model that illustrates the role of order-flow information in interdealer strategic trading.

I first attempt to confirm the results of Naik and Yadav (2002a), who use a comprehensive dataset from the Bank of England to study the hedging behaviour of U.K. government bond dealing banks based on information about their end-of-day positions. The authors find that the amount of hedging depends on the efficiency of the hedge instrument, and that hedging is higher when volatility is higher, when spot exposure is high, and when the cost of hedging is lower. These results are consistent with the theory of Froot and Stein. Naik and Yadav also compare the hedging of bonds with different levels of market efficiency and find that there is less hedging when the market offers less-efficient hedging alternatives.

Naik and Yadav’s analysis is extended in this paper. The affect on hedging is considered explicitly from two perspectives: the informational advantage of dealing banks who have access to order flow, and their ability to bear risk given their advantageous position in the market. 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 in the gap between the inventory approach and the information approach in microstructure theory. 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 (2002) to include two parallel markets, the spot and the forward-contract FX markets, in a simultaneous interdealer trading model. 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. It is hypothesized that dealing banks will partially hedge their speculative positions in the spot market in the forward market. Tests of this hypothesis are conducted below.

In contrast, Tien (2001) suggests that order flow is 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. In this paper, it is hypothesized that, because dealing banks have a comparative advantage in bearing this risk, risk-sharing positions will not be hedged, provided dealing banks are compensated for bearing the risk. Dealers will take on this responsibility if they have a higher risk tolerance for day-to-day risk. A higher risk tolerance may arise both from reciprocal agreements negotiated among dealers to provide liquidity to each other and the optimal capital-allocation decisions made within banks that take into account correlated cash flows across business lines.

The rest of this paper is organized as follows. Section 2 presents a number of pertinent institutional details regarding the FX market, a description of the data, and an analysis of spot inventories. Section 3 develops a model of inventory information, extending the framework of Cao, Evans, and Lyons (2002) to parallel spot and forward markets. Section 4 explains how exact risk exposures are measured in spot, forward, and futures markets. Section 5 examines how dealing banks use forward contracts to hedge their risk exposure. Factors that can cause time variations in the extent of hedging are investigated. A brief summary concludes the paper in section 6.

2. Institutional Considerations, Dataset, and Behaviour of Inventories

The FX market in Canada is composed of spot, forward, futures, options, and swap transactions. Because of the limitations of the dataset used in this study, which includes dealer trades in the spot, forward, and futures markets, only these three markets will be described in this section. The spot and forward FX markets are decentralized multiple-dealership markets. There is no physical location, or exchange, where dealing banks meet. Two important characteristics distinguish FX trading from trading in other markets: trades between dealing banks account for most of the trading volume in FX markets, and trade transparency is low. Order flow in the FX market is not transparent because there are no disclosure requirements. Consequently, trades in this market are not generally observable. The implication of a trading process that is less informative is that the information reflected in prices is reduced and private information can be exploited for a longer amount of time.

Players in the FX market include dealing banks, customers, and brokers. Dealing banks provide two-way prices to both customers and other dealing banks. In Canada, the top eight banks handle nearly all the order flow. Dealing banks receive private information through their customer's orders. Their access to the information contained in the 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 learn about market-wide order flow from brokered interdealer trades. When a transaction exhausts the quantity available at the advertised bid/ask, the electronic broker system "displays" this fact to the dealing bank community. This indicates that a transaction was initiated. Although the exact size is not known, dealing banks have a sense of the typical size. Most importantly, this is the only public signal of market order flow in the FX market. Brokers in the FX market are involved only in interdealer transactions and communicate dealer prices to other dealing banks without revealing their identity, as would be necessary in an interdealer trade. Brokers are pure matchmakers; they do not take positions on their own.

Participation in the futures market is largely limited to institutions and large corporate customers. The futures market is a close substitute for the forward market, although there are a number of differences. FX futures contracts are traded on organized exchanges (in particular, the International Money Market at the Chicago Mercantile Exchange), while forward contracts are traded over the counter. Futures contracts mature on standardized dates throughout the year, are written for fixed face values, and are settled between sellers and buyers daily. Moreover, exchanges on which futures contracts are bought and sold serve only to match buyers and sellers and guarantee delivery of currencies. The futures exchange maintains a zero position, providing no liquidity to the market. Customers can buy a futures contact via an order through a dealing bank. The empirical section of this paper examines the extent to which a dealing bank will hedge spot and futures risk exposure with forward contracts.

2.1 Data and descriptive statistics

The primary source of data in this paper is the Bank of Canada's daily FX volume report. The report is coordinated by the Bank and organized through the Canadian Foreign Exchange Committee. It provides details on daily FX trading volumes by dealer in Canada.

The dataset employed in this paper covers nearly four years of daily data (January 1996 through September 1999), or 941 observations for the eight largest Canadian FX market participants. Trading flows (in Canadian dollars) are categorized by the type of trade (spot, forward, and futures) and the institution type of the trading partners. Specifically, spot transactions are those involving receipt or delivery on a cash basis or in one business day for Canadian/U.S. dollars, while forward transactions are those involving receipt or delivery in more than one business day for Canadian/U.S. dollars. Descriptive statistics are presented in D'Souza (2002). The structure of the market portrayed in these statistics is an important ingredient when modelling the FX market. This is the market microstructure hypothesis. Daily trading volumes and trading imbalances (means, medians, and standard deviations) are presented in aggregate and broken down by type of business transaction and dealer.

2.2 An analysis of spot inventories

Spot inventories show no evidence of mean reversion, which suggests that each dealer may be subjecting their financial institution to significant levels of exchange rate risk. In the subsequent analysis, empirical tests are performed to determine whether dealing banks engage in hedging this risk exposure. This may be surprising, as the spot and forward market-making operations of a financial institution are usually thought to act independently. Specifically, the coordination of joint decisions across desks and the dissemination of information each time a new decision is made are assumed to be both difficult and costly. In recent work, Shoughton and Zechner (1999) and D'Souza and Lai (2002) show that a decentralized capital-allocation function can accomplish this coordination and dissemination by internalizing the externalities of business lines with correlated cash flows.

Although non-linearities in mean reversion may exist (such as mean reversion that depends on the inventory level), it is assumed that mean reversion is constant and the desired position of a dealer is zero. The methodology of Madhavan and Smidt (1993) is used to determine the extent of mean reversion in inventories. A dealer's change in inventory is regressed on the dealer's last period's inventory. An intercept term is included in the regression because initial or desired inventories are not observed:

$$I_t - I_{t-1} = \alpha + \beta I_{t-1} + \varepsilon_t . \tag{1}$$

From equation (1) it is clear that the speed of adjustment is related to $\beta < 0$; lower values of β imply more rapid adjustments to the mean inventory level. The speed of inventory adjustment is directly related to the mean-reversion coefficient, β, which represents the fraction of the deviation between actual and desired inventories that is eliminated each day. A useful measure of adjustment speed is the inventory half-life, denoted by hl, defined as the expected number of days required to reduce a deviation between actual and desired inventories by 50 per cent, where

$$hl = \frac{-\ln(2)}{\ln(1+\beta)}, \tag{2}$$

and desired inventories are assumed to be zero. Inventories are calculated as the cumulative sum of trade flows for each dealer in the spot market. Table 1 lists estimates of the inventory half-life for each of the eight dealing banks in the sample, and the aggregate market. On aggregate, the half-life is 1190 days, while individual half-lives range from 940 days to 5736 days (ignoring non-sensible negative half-lives). Few of the estimated slope coefficients are significant. The results indicate that there is little adjustment or mean reversion in inventories, and if there is mean reversion, the adjustment process is extremely long. In section 5, we consider how dealing banks hedge exchange rate risk in these inventories that seem to persist indefinitely.

3. The Model

Ito, Lyons, and Melvin (1998) suggest that, even in markets such as the FX market, where private information should not exist, empirical evidence is incompatible with the lack of information. This section addresses how, if private information exists, intermediaries use the information when deciding on their speculative positions and hedging requirements. A model is used that extends the framework of Cao, Evans, and Lyons (2002) to include multiple risky assets. 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 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 as a group must share in any net imbalance in the 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 when asset returns are correlated across markets. The correlation between asset returns determines the amount (if any) of "hedging" that dealing banks engage in. In reality, this is not hedging but speculation.

Drudi and Massa (2000) consider a different but related model. They examine how dealing banks behave when they have private information and access to two parallel markets with varying amounts of transparency to trade a single asset. The markets they consider are government bond primary and secondary markets. Trade transparency is significantly higher in the secondary market than in the primary market. In Drudi and Massa's model, the predictions of which are borne out in their empirical tests, dealing banks participating in the Italian Treasury bond market exploit private information by trading in both primary and secondary markets and taking advantage of differences in transparency between those markets. Drudi and Massa find that informed traders refrain from trading in the more transparent market to exploit their informational advantage in the less transparent one. Furthermore, they use the more transparent market to manipulate prices. For example, informed dealing banks will place sell orders with other dealing banks at a time when they have an informational advantage, which suggests that the asset is currently undervalued. Simultaneously, they aggressively place bids in the primary market. The strategy generates losses in the more transparent market (secondary market) for the period when the less transparent market is open, and then produces gains once the possibility of affecting the primary market is over.

Like Drudi and Massa's model, the behaviour of dealing banks is now analyzed when dealing banks trade in multiple markets with varying degrees of transparency. In contrast to Drudi and Massa's model, in the environment described in section 3.1, assets are different in the two markets while their fundamental prices are correlated. Risk-averse dealing banks need to consider their speculative positions in light of their future possible hedging opportunities.

3.1 Multiple-dealer 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 n 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

$$\begin{bmatrix} S \\ F \end{bmatrix} \sim N\left(\begin{bmatrix} 0 \\ 0 \end{bmatrix}, \begin{bmatrix} \sigma_s^2 & \sigma_{sf} \\ \sigma_{sf} & \sigma_f^2 \end{bmatrix} \right). \tag{3}$$

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 seven events of the model are illustrated in Figure 1 and they 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. Dealing banks trade with other dealing banks in the forward market
7. Payoffs $\{S, F\}$ are realized

In both rounds, the first event is dealer quoting. Let P_i^k denote the quote of dealing banks 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 market are independent of the payoffs $\{S, F\}$. They occur in period one only and are cleared at the receiving dealer's period-one spot quote, P_i^s. 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:

$$c_i \sim N(0, \sigma_c^2), \tag{4}$$

where

$$c_i \perp S, c_i \perp F, c_i \perp c_j \forall i \neq j. \tag{5}$$

The convention is used that c_i is positive for net customer purchases and negative for net sales. Customer trades, c_i, 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 it is not conditioned on $T_i^{k\prime}$, so $T_i^{k\prime}$ is an unavoidable disturbance to dealer i's position in period t 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_i 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:

$$T_i^s = D_i^s + c_i + E[T_i^{s\prime} | \Omega_{is}], \tag{6}$$

$$T_i^f = D_i^f + E[T_i^{f\prime} | \Omega_{if}], \tag{7}$$

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

$$\begin{aligned}
\Omega_{is} &= \left\{ c_i, \{P_i^s\}_{i=1}^n \right\} \\
\Omega_{if} &= \left\{ c_i, \{P_i^s\}_{i=1}^n, T_i^s, T_i^{s\prime}, V, \{P_i^f\}_{i=1}^n \right\} \\
\Omega_s &= \left\{ \{P_i^s\}_{i=1}^n \right\} \\
\Omega_f &= \left\{ \{P_i^s\}_{i=1}^n, V, \{P_i^f\}_{i=1}^n \right\}.
\end{aligned} \tag{8}$$

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 (6) and (7) show that dealer orders include both an information-driven component, D_i^k, and inventory components, c_i and $E[T_i^{s\prime} | \Omega_{is}]$. 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:

$$V = \sum_j T_j^s. \tag{9}$$

This sum of all outgoing trades, T_j^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 t wealth of dealer i, we have:

$$\max_{\{P_i^s, P_i^f, D_i^s, D_i^f\}} \quad E[-\exp(-\theta W_i | \Omega_{is})], \tag{10}$$

subject to

$$W_i = W_{i0} + [c_i P_i^s + T_i^{s}{}' P_i^s - T_i^s P_i^{s}{}' + T_i^{f}{}' P_i^f - T_i^f P_i^{f}{}' - (c_i + T_i^{s}{}' - T_i^s) S - (T_i^{f}{}' - T_i^f) F], \tag{11}$$

or

$$\begin{aligned} W_i = W_{i0} + [c_i(P_i^s - S) + T_i^{s}{}'(P_i^s - S) - (D_i^s + c_i + E[T_i^{s}{}' | \Omega_{is}])(P_i^{s}{}' - S) \\ + T_i^{f}{}'(P_i^f - F) - (D_i^f + E[T_i^{f}{}' | \Omega_{if}])(P_i^{f}{}' - F)], \end{aligned} \tag{12}$$

where P_i^k is dealer i's round-k quote, a' denotes a quote or trade received by dealer i, and $\{S, F\}$ are the terminal payoffs on the spot and forward-contract risky assets. Notice that end-of-period wealth includes terms that capture the position disturbance from incoming dealer trades. The conditioning information, Ω_k, at each decision note was summarized in equation (8).

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. That the common price is $E(S)$ (i.e., 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_i 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 $P^f = E(F) + \lambda V$.

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 i in a symmetric linear equilibrium is:

$$\begin{array}{ll} T_i^s = \beta_1 c_i & \beta_1 > 0, \beta_2 < 0 \quad if \quad \sigma_{sf} > 0 \\ T_i^f = \beta_2 c_i & \forall i \in 1, \ldots, n \end{array} . \tag{13}$$

The values of the β coefficients are given in Appendix A. Recall that the quoting rules for $\{P^s, P^f\}$ 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 the risk exposure that they took on to manipulate round-two prices via market-observed order flow and round-s outgoing trade.

4. Spot, Forward, and Futures Risk Exposure

To study the hedging behaviour of FX intermediaries, exact measures of risk exposure in all markets must be calculated. A dealer with a long position in terms of their spot inventory of Canadian dollars can hedge by taking a short forward position, also called a short hedge. In this situation, if the Can$/US$ exchange rate falls, the dealer does not fare well on the sale of Canadian dollars in the future, but makes a gain on the short forward position. A forward-contract hedge reduces risk by making the overall outcome more certain. Hedging may work less than perfectly in practice; for example, when the spot price increases by more than the forward-contract price. For currencies, basis risk tends to be fairly small,[2] because arbitrage arguments

2. See Hull (1999) for a more detailed account of basis risk.

lead to a well-defined relationship between the forward-contract price and the spot price of an investment asset. The basis risk for currencies arises mainly from uncertainty regarding the level of the risk-free domestic and foreign interest rates.

The futures market provides a more transparent alternative to the forward market, yet for the Canadian-dollar market the forward market is more liquid. Market prices of forward and futures contracts are very similar for short-term contracts, but as the life of a futures contract increases, the difference between it and forward contracts is liable to become significant, because of the marked-to-market nature of futures contracts. In general, though, as the maturities of the forward and futures contracts converge, forward and futures prices also converge.[3] For Canadian-dollar forward and futures contracts, Cornell and Reinganum (1981) find very few statistically significant differences between the two prices. For practical purposes, therefore, it is customary to assume that forward and futures prices are equivalent.

In this paper, spot, forward, and futures exposures are calculated for each dealer's inventory position at the end of each business day. Risk exposure is measured by the amount a dealer stands to gain or lose on their inventory position in each of these markets from a 1 per cent change in the spot exchange rate. It is assumed, given the average length of forward contracts negotiated by dealing banks, that there is no risk associated with changes in the foreign and domestic risk-free asset. In particular, the value of both the forward and futures exposure of each dealer is calculated using the covered interest rate parity condition:

$$S_t = \frac{F_{t,T}(1 + R_T')}{(1 + R_T)}. \tag{14}$$

An arbitrage agreement that leads to a well-defined relationship between spot and forward-contract prices, where S_t is the spot price of a U.S. dollar in Canadian dollars in t, $F_{t,T}$ is the price of a forward or futures contract on t for delivery in T days from t, and R_T and R_T' are the Canadian and U.S. risk-free rates on demand deposits.

3. The main difference between forward and futures contracts is that the profit or loss is realized at maturity with a forward contract, whereas for a futures contract the profit or loss made on the change in the futures price is settled at the end of each trading day by the brokerage house with whom the account is held. A futures contract can be regarded as a series of one-day forward contracts. Only when the interest rate is non-stochastic will futures and forward prices be equal. While forward and futures prices can also differ for other reasons (tax treatment, transactions costs, or margin rules), empirical evidence indicates that even when the price difference is statistically significant, the magnitudes are small and may not be significant economically. See Chow, McAleer, and Sequeira (2000) for an extensive survey.

Suppose that a financial institution has a long exposure in Canadian dollars and a short exposure in Canadian-dollar forward contracts. The overall exposure to this position is:

$$Exp_P = \Delta S + h\Delta F, \tag{15}$$

which has variance

$$Var(Exp_P) = \sigma^2_{\Delta S} + h^2\sigma^2_{\Delta F} + 2h\rho\sigma_{\Delta S}\sigma_{\Delta F}. \tag{16}$$

To minimize risk,

$$h = -\rho\frac{\sigma_S}{\sigma_F}. \tag{17}$$

If $\rho = 1$ and $\sigma_S = \sigma_F$, the optimal hedge ratio is $h = -1$, while if $\rho = 1$ and $\sigma_S = 2\sigma_F$, the optimal hedge ratio is $h = -2$, because the spot price changes by twice as much as the forward-contract price. Table 2 lists variances and correlations between the returns on spot and forward contracts. Correlations are extremely close to one, and standard deviations are identical, which suggests that if a financial institution was interested in minimizing its overall risk across the spot and forward market, it would choose a hedge ratio equal to -1.

Section 5 examines the time-series evolution of these exposures to infer the attitude of dealing banks towards risk management.

5. Estimation of Hedge Ratios

Full-cover hedging occurs when the forward risk exposure of a dealer is equal and opposite to the amount of spot risk exposure. A less restrictive version of full-cover hedging, which allows for a fixed directional level of risk exposure, occurs when the change in the forward risk exposure of any dealer is exactly opposite to the change in the spot risk exposure. It is assumed that dealing banks hedge spot and futures in the forward markets. The forward market is far more liquid, and therefore dealing banks would use this cheaper market to hedge risk.

A useful measure of the extent of hedging is the hedge ratio. It is the coefficient on the change in spot risk exposure in a regression, with the independent variable equal to the change in forward risk exposure. If dealing banks engage in full-cover hedging, $h_k = -1$, while if dealing banks engage in selective hedging, $-1 > h_k > 0$. The hypotheses are tested by running the following regression for each dealer:

$$\Delta ForwardExp_{k,t} = \alpha_k + h_k(\Delta SpotExp_{k,t}) + h_{k1}(\Delta SpotExp_{k,t-1}) + \varepsilon_{k,t}, \tag{18}$$

where k indicates the dealer; $\Delta ForwardExp_{k,t}$ is the change in forward exposure of dealer k from the end of day $t-1$ to the end of day t; $\Delta SpotExp_{k,t}$ is the change in spot exposure of dealer k from the end of day $t-1$ to the end of day t; $\Delta SpotExp_{k,t-1}$ is the change in spot exposure of dealer k from the end of day $t-2$ to the end of day $t-1$; h_k is the hedge ratio; and $(\alpha_k, \varepsilon_{k,t})$ are the intercept and error terms, respectively. A lagged spot risk-exposure variable is added into the regression because it is possible that the risk-management process is of a partial-adjustment type.

Results presented in Tables 3 to 7 are disaggregated by dealer, but are also presented for the interdealer market as a whole. Dealing banks are listed according to their activity level, which is measured by a dealer's average daily trading volume in the spot market during the sample period, with Dealer 1 being the most active and Dealer 8 the least active market-maker in the sample. Table 3 illustrates that no dealer engages in full-cover hedging of spot exposure using forward contracts during the same day or over two consecutive days.

All hedge ratios are statistically significant at the 99 per cent level and six of the eight dealing banks' same-day hedge ratios fall into the range between -0.4 and -0.7 (the two outliers are dealing banks 2 and 3, which have hedge ratios of -0.091 and -0.249). Additional hedging takes place during a second day. The aggregate hedge ratio across all eight dealing banks is -0.427 during the same day, and -0.053 during the following day. Both estimates are statistically significant at the 99 per cent level. Interestingly, the individual dealer estimates indicate that larger participants in the spot market take longer to selectively hedge risk that they wish to eliminate. In terms of explanatory power of the regressions, R-square values are high and range from 18.2 per cent to 51.8 per cent. In summary, there is ample evidence in favour of selective hedging and against full-cover hedging among dealing banks, although the results indicate significant differences among dealing banks.

Hedging of risk exposure should be greater the more efficiently risk can be hedged in the forward market. In particular, dealing banks will hedge relatively more when they hold more efficiently hedgeable individual securities. Table 4 shows the hedging behaviour of dealers to both spot and futures exposure. Because there is a higher correlation between forward and futures prices, especially when maturities converge, futures risk should more efficiently be hedged. In addition, futures risk, as opposed to spot market risk, is more efficiently traded on a futures exchange where customers are the majority owners of futures contracts on a day-to-day basis. Thus, dealing banks in Canada do not have a comparative advantage in bearing this risk:

$$\Delta ForwardExp_{k,t} = \alpha_k + h_k^s(\Delta SpotExp_{k,t}) + h_{k1}^s(\Delta SpotExp_{k,t-1}) \\ + h_k^f(\Delta FuturesExp_{k,t}) + h_{k1}^f(\Delta FuturesExp_{k,t-1}) + \varepsilon_{k,t}. \quad (19)$$

Hedge ratios in Table 4 are similar to those in Table 3. There is no full-cover hedging during the same day, and all spot hedge ratios are statistically significant at the 99 per cent level. Furthermore, there is also no full-cover hedging over two days, although additional hedging takes place over the second day. In terms of hedging futures risk, only larger FX market participants hedge futures risk exposure. This could be because these dealing banks account for most FX futures trading among financial institutions in Canada. The top four firms, in terms of trading levels in the spot market, have futures hedge ratios that are statistically significant at the 99 per cent level. They range from -0.511 to -0.934. Interestingly, futures hedging is nearly complete by the end of the second day. In particular, there is evidence of full-cover hedging of futures positions in the forward market. The explanatory power of regressions that include both spot and futures exposure is higher and ranges from 20.5 per cent to 56.5 per cent.

Other variables may also affect a dealer's hedging decision. First, from a risk-minimizing viewpoint, if a dealer does not hedge their spot risk fully but only selectively, the dealer should arguably hedge to a greater extent when the perceived risk is greater. Hence, there should be a higher hedge ratio on days on which the volatility of spot price changes is relatively greater. Stulz (1996) indicates that firms should hedge to avoid lower tail outcomes that could result in bankruptcy. One possible hypothesis is that when exposure levels are high, hedging will increase. Also, when exposure is changing in a direction that increases the magnitude of this exposure, hedging should increase. Table 5 tests all three hypotheses. A regression of the following form is estimated:

$$\Delta ForwardExp_{k,t} = \delta_0 + (h_k + \delta_1 Vol_t + \delta_2 SInv_{k,t} + \delta_3 STrad_{k,t})\Delta SpotExp_{k,t} + \varepsilon_{k,t}, \quad (20)$$

where h_k is the base-level hedge ratio for individual dealer k, and Vol_t is the implied volatility of the FX market. Volatility is measured by implied volatility—a forward-looking measure of perceived future volatility, $SInv_{k,t}$ and $STrad_{k,t}$, is the level and change in level of spot exposure. To control for differences in dealing banks' capitalizations, standardized inventories are calculated by subtracting the sample mean and dividing by the sample standard deviation.

Slope coefficients are restricted to being the same across dealing banks, to maximize estimation efficiency. Base hedge ratios are similar to those shown in Tables 3 and 4. Findings suggest that dealing banks hedge more when perceived spot volatility increases. The result is consistent with that of Naik and Yadav (2002b). In contrast, results indicate that dealing banks engage in less hedging when (standardized) total exposure is high, and when (standardized) change in exposure increases in a direction that increases total exposure. These last two results are puzzling, but may be explained in the next set of regressions.

Table 6 tests the order-flow hypotheses developed by Tien (2001), Cao, Evans, and Lyons (2002) and D'Souza (2002 and Forthcoming). According to these models, hedging should decrease with the change in the market's overall net spot position, because bearing this risk is the cost of making a market. Each market-maker has a comparative advantage in bearing this risk (given its access to liquidity and ability to hedge risk). If dealing banks did not bear this risk, they would not make any economic profits. In addition, hedging should increase with a dealer's customer net trade. This is a source of private information to the dealer, particularly for inventory information. The dealer can use this information to speculate with, knowing that dealing banks in the market will have to share the overall net position. Since this information is only one signal of the overall net market position, it is possible that the dealer's net position is not indicative of the overall market's net position, and therefore the dealer is taking a risky speculative position. There is evidence to support both hypotheses. Dealers reduce their hedge ratio as the net market imbalance in the spot market increases, and they increase their hedge ratio with increased customer purchases of spot FX. The following regression is estimated:

$$\Delta ForwardExp_{k,t} = \delta_0 + \left(h_k + \delta_4\left(\sum_k Trad_{k,t}\right) + \delta_5 CTrad_{k,t}\right)\Delta SpotExp_{k,t} + \varepsilon_{k,t}. \tag{21}$$

The coefficients on the market's net positions and each dealing bank's net customer position have their predicted signs and are significant at the 99 per cent level.

In Table 7, all variables are added into the same regression. The base hedge ratios are similar to previous estimates, and the signs of all coefficients on the slope variables support our hypotheses:

$$\begin{aligned}\Delta ForwardExp_{k,t} = \delta_0 + \Big(h_k &+ \delta_1 Vol_t + \delta_2 SInv_{k,t} + \delta_3 STrad_{k,t} \\ &+ \delta_4\left(\sum_k Trad_{k,t}\right) + \delta_5 CTrad_{k,t}\Big)\Delta SpotExp_{k,t} + \varepsilon_{k,t}.\end{aligned} \tag{22}$$

The volatility and the standardized level of risk-exposure terms are no longer significant. At the same time, the sources of comparative advantage, proxied by customer order flow and the spot market's net overall position, are significant at the 99 per cent level. It may be that the sources of comparative advantage were initially proxied by exchange rate volatility and the level of a dealing bank's risk exposure in the spot market.

6. Conclusion

Results in this paper confirm that FX intermediaries do not fully hedge spot risk but engage in selective hedging. It is important to recognize that not all risks can be hedged in efficient markets. Intermediaries in the FX market have exclusive access to liquidity, in the form of reciprocal agreements with other intermediaries to continuously quote bid and ask prices; have private information, via their own customer trades and interdealer order flow; and have a higher risk tolerance than their customers. These attributes ensure that markets for exchange rate risk are not efficient, and give dealing banks a source of comparative advantage in bearing risk that allows them to make positive economic profits.

If dealing banks are risk-averse, they will attempt to hedge this speculative position in the forward market, while preserving their speculative position. D'Souza (2001) illustrates that, because the forward market is not fully opaque, and any order flow observed in the forward market will reduce the advantage of private information, dealing banks will engage only in selective hedging. In future research, hedging decisions across both spot and forward markets must be analyzed simultaneously, given the existence of customer orders and interdealer trade in both markets. Future research must also consider explicitly the structure of financial institutions, or, more specifically, how capital-allocation decisions within financial institutions affect the hedging behaviour of dealing banks.

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Table 1: Estimates of Spot Inventory Half-Life

	Mean (Can$, millions)	Standard deviation	β *0.001	Half-life
Dealer 1	7597.58	5664.42	-0.248 (0.81)	2797.83
Dealer 2	8459.63	5985.66	1.207 (0.43)	-574.55
Dealer 3	15717.20	11003.42	-0.296 (0.62)	2335.03
Dealer 4	11626.15	6533.06	-0.736 (0.33)	940.82
Dealer 5	6111.73	4377.16	0.268 (0.81)	-2583.44
Dealer 6	4139.61	3656.02	0.851 (0.11)	-815.07
Dealer 7	7404.97	4561.34	0.842 (0.07)	-823.53
Dealer 8	906.24	1144.54	2.909 (0.10)	-238.57
Aggregate	61963.10	41525.01	-0.364 (0.34)	1906.47

Notes: Half-life is based on the coefficient estimates of the mean-revision parameter, β, in equation (1). *p*-values are listed under estimates.

Table 2: Correlations between Spot and Forward Prices

	Can$/U.S.$ spot returns	30-day forward contract	60-day forward contract	90-day forward contract
Standard deviation	0.00315	0.00317	0.00317	0.00318
Correlation with Can$/US$ spot returns	1.000	0.993	0.998	0.997

Note: Returns are calculated daily as the log difference in exchange rates.

Table 3: Changes in Forward Exposures and Changes in Spot Exposures

	α_k	h_k	h_{k1}	$R^2(adj)$
Dealer 1	-9.219 (0.01)	-0.632 (0.00)	-0.043 (0.03)	0.518
Dealer 2	-7.649 (0.03)	-0.091 (0.00)	0.023 (0.07)	0.052
Dealer 3	-19.015 (0.00)	-0.249 (0.00)	-0.061 (0.00)	0.182
Dealer 4	-15.618 (0.00)	-0.660 (0.00)	-0.021 (0.43)	0.390
Dealer 5	-17.820 (0.00)	-0.458 (0.00)	0.017 (0.49)	0.270
Dealer 6	-3.413 (0.03)	-0.554 (0.00)	-0.038 (0.13)	0.346
Dealer 7	3.379 (0.01)	-0.501 (0.00)	0.013 (0.47)	0.436
Dealer 8	2.408 (0.07)	-0.429 (0.00)	-0.035 (0.10)	0.301
Aggregate	-61.503 (0.00)	-0.427 (0.00)	-0.053 (0.00)	0.302

Note: $\Delta ForwardExp_{k,t} = \alpha_k + h_k(\Delta SpotExp_{k,t}) + h_{k1}(\Delta SpotExp_{k,(t-1)}) + \varepsilon_{k,t}$

Table 4: Changes in Forward Exposures and Changes in Spot and Futures Exposures

	α_k	h_k	h_{k1}	h_k^f	h_{k1}^f	$R^2(adj)$
Dealer 1	-9.375 (0.01)	-0.624 (0.00)	-0.050 (0.01)	-0.934 (0.00)	-0.166 (0.08)	0.565
Dealer 2	-8.571 (0.02)	-0.088 (0.00)	0.024 (0.05)	-0.511 (0.00)	-0.357 (0.00)	0.085
Dealer 3	-17.690 (0.00)	-0.243 (0.00)	-0.057 (0.00)	-0.684 (0.00)	-0.307 (0.03)	0.205
Dealer 4	-14.593 (0.00)	-0.676 (0.00)	-0.029 (0.29)	-0.515 (0.00)	-0.165 (0.23)	0.400
Dealer 5	-18.062 (0.00)	-0.458 (0.00)	0.018 (0.46)	0.003 (0.98)	0.149 (0.21)	0.270
Dealer 6	-3.534 (0.021)	-0.531 (0.00)	-0.036 (0.15)	-0.134 (0.00)	-0.008 (0.78)	0.360
Dealer 7	3.381 (0.01)	-0.502 (0.00)	0.014 (0.46)	-1.829 (0.81)	0.088 (0.99)	0.435
Dealer 8	2.397 (0.07)	-0.429 (0.00)	-0.035 (0.10)	-0.024 (0.97)	-0.106 (0.89)	0.300
Aggregate	-61.014 (0.00)	-0.401 (0.00)	-0.053 (0.01)	-0.705 (0.00)	-0.233 (0.01)	0.350

Note: $\Delta ForwardExp_{k,t} = \alpha_k + h_k(\Delta SpotExp_{k,t}) + h_{k1}(\Delta SpotExp_{k,t-1})$
$+ h_k^f(\Delta FuturesExp_{k,t}) + h_{k1}^f(\Delta FuturesExp_{k,t-1}) + \varepsilon_{k,t}$

Table 5: Hedge Ratios in Different Market Conditions

	δ_0	h_k	δ_1	δ_2	δ_3	$R^2(adj)$
Dealer 1	-1.602 (0.03)	-0.447 (0.00)	-0.031 (0.00)	0.039 (0.00)	0.343 (0.00)	0.466
Dealer 2		-0.101 (0.00)				0.069
Dealer 3		-0.124 (0.00)				0.121
Dealer 4		-0.496 (0.00)				0.329
Dealer 5		-0.280 (0.00)				0.177
Dealer 6		-0.379 (0.00)				0.276
Dealer 7		-0.315 (0.00)				0.374
Dealer 8		-0.242 (0.00)				0.294

Note:

$\Delta ForwardExp_{k,t} = \delta_0 + (h_k + \delta_1 Vol_t + \delta_2 SInv_{k,t} + \delta_3 STrad_{k,t})\Delta SpotExp_{k,t} + \varepsilon_{k,t}$

Table 6: Hedge Ratios in Different Market Conditions

	δ_0	h_k	$\delta_4 \times 10^{-3}$	$\delta_5 \times 10^{-3}$	$R^2(adj)$
Dealer 1	-1.434 (0.05)	-0.640 (0.00)	0.103 (0.00)	-0.074 (0.00)	0.445
Dealer 2		-0.233 (0.00)			0.064
Dealer 3		-0.424 (0.00)			0.187
Dealer 4		-0.687 (0.00)			0.336
Dealer 5		-0.472 (0.00)			0.199
Dealer 6		-0.568 (0.00)			0.288
Dealer 7		-0.500 (0.00)			0.412
Dealer 8		-0.493 (0.00)			0.350

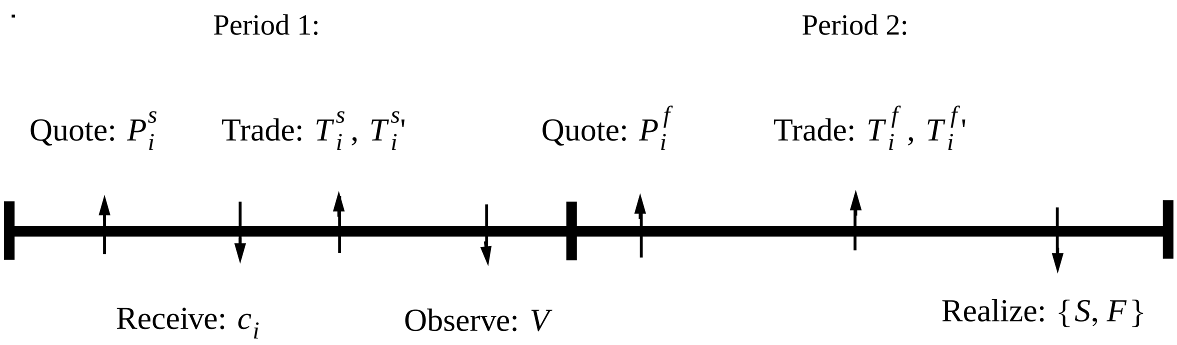
Note: $\Delta ForwardExp_{k,t} = \delta_0 + \left(h_k + \delta_4 \sum_k Trad_{k,t} + \delta_5 CTrad_{k,t}\right)\Delta SpotExp_{k,t} + \varepsilon_{k,t}$

Table 7: Hedge Ratios in Different Market Conditions

	δ_0	h_k	δ_1	δ_2	δ_3	$\delta_4 \cdot 10^{-3}$	$\delta_5 \cdot 10^{-3}$	$R^2(adj)$
Dealer 1	-2.000 (0.01)	-0.589 (0.00)	-0.008 (0.12)	0.012 (0.296)	0.431 (0.00)	0.060 (0.00)	-0.009 (0.00)	0.416
Dealer 2		-0.187 (0.00)						0.018
Dealer 3		-0.368 (0.00)						0.168
Dealer 4		-0.637 (0.00)						0.299
Dealer 5		-0.425 (0.00)						0.152
Dealer 6		-0.521 (0.00)						0.247
Dealer 7		-0.456 (0.00)						0.384
Dealer 8		-0.410 (0.00)						0.300

Note: $\Delta ForwardExp_{k,t} = \delta_0 + \left(h_k + \delta_1 Vol_t + \delta_2 SInv_{k,t} + \delta_3 STrad_{k,t} + \delta_4 \sum_k Trad_{k,t} + \delta_5 CTrad_{k,t}\right) \Delta SpotExp_{k,t} + \varepsilon_{k,t}$

Figure 1: Timing of Simultaneous Trade Model



Information sets:

$$\Omega_{T_1} = \{P_i^s\}_{i=1}^n \qquad \Omega_{T_2} = \left\{V, \{P_i^s, P_i^f\}_{i=1}^n\right\}$$

$$\Omega_{T_{i1}} = \left\{c_i, \{P_i^s\}_{i=1}^n\right\} \qquad \Omega_{T_{i2}} = \left\{V, c_i, T_i^s, T_i^{s}{}', \{P_i^s, P_i^f\}_{i=1}^n\right\}$$

Appendix A

Proofs of 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

$$\sum_i E[(T_i^s - D_i^s - c_i - E[T_i^{s\prime}|\Omega_{is}])|\Omega_s] = 0, \tag{A.1}$$

or

$$\sum_i (E[c_i|\Omega_s] + E[D_i^s|\Omega_s]) = 0, \tag{A.2}$$

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 $E[(c_i)|\Omega_s] = 0$. The only value of P^s for which $E[D_i^s(P^s)|\Omega_s] = 0$ is $P^s = E(S|\Omega_s) = 0$, since $D_i^s(E(S|\Omega_s)) = 0$ 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:

$$\sum_i E[(T_i^f - D_i^f - E[T_i^{f\prime}|\Omega_{if}])|\Omega_f] = 0, \tag{A.3}$$

or

$$\sum_i E[D_i^f|\Omega_f] = 0. \tag{A.4}$$

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

$$D_i^k = \frac{\mu_k - P^k}{\theta\sigma_k^2}, \tag{A.5}$$

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

$$D_i^f = \frac{\mu_f - P^f}{\theta\sigma_f^2} - D_i^S\frac{\sigma_{sf}}{\sigma_f^2}, \tag{A.6}$$

so that

$$\sum_i E\left[\left(\frac{\mu_f - P^f}{\theta\sigma_f^2} - D_i^S\frac{\sigma_{sf}}{\sigma_f^2}\right)|\Omega_f\right] = 0. \tag{A.7}$$

Since

$$\sum_i E\left[\left(D_i^S\frac{\sigma_{sf}}{\sigma_f^2}\right)|\Omega_f\right] = \frac{\sigma_{sf}}{\sigma_f^2}\sum_i E[-c_i|\Omega_f] = -\frac{\sigma_{sf}}{\sigma_f^2}\sum_i \frac{V}{n\beta_1}, \tag{A.8}$$

$$P^f = \frac{\theta\sigma_{sf}V}{n\beta_1} = \lambda V. \tag{A.9}$$

Proof of 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

$$D_i^f = \frac{\mu_f - P^f}{\theta\sigma_f^2} - (T_i^S - T_i^{s'} - c_i)\frac{\sigma_{sf}}{\sigma_f^2}. \tag{A.10}$$

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

$$\begin{aligned} W_i &= W_{i0} + [c_i P_i^s + T_i^{s\prime} P_i^s - T_i^s P_i^{s\prime} + T_i^{f\prime} P_i^f - T_i^f P_i^{f\prime} - (c_i + T_i^{s\prime} - T_i^s)S - (T_i^{f\prime} - T_i^f)F] \\ &= W_{i0} + [c_i(P_i^s - S) + T_i^{s\prime}(P_i^s - S) - T_i^s(P_i^{s\prime} - S) + T_i^{f\prime}(P_i^f - F) - T_i^f(P_i^{f\prime} - F)] \\ &= W_{i0} + c_i(P_i^s - S) + T_i^{s\prime}(P_i^s - S) - (D_i^s + c_i + E[T_i^{s\prime} | \Omega_{is}])(P_i^{s\prime} - S) \\ &\quad + T_i^{f\prime}(P_i^f - F) - (D_i^f + E[T_i^{f\prime} | \Omega_{if}])(P_i^{f\prime} - F)], \end{aligned} \qquad \text{(A.11)}$$

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

$$\underset{D_i^s}{Max} \quad E_{\{P^f, S, F\}}[-\exp(-\theta(D_i^s - T_i^{s\prime})(S - P^s) - \theta(D_i^f)(F - P^f)) | \Omega_{is}], \qquad \text{(A.12)}$$

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

$$E[(-\theta W_i) | \Omega_{is}] - \frac{Var[(-\theta W_i) | \Omega_{is}]}{2}. \qquad \text{(A.13)}$$

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

$$E_{\{X, Y\}}[-\exp(kX + qY)] = \exp\left(k\mu_x + q\mu_y + \frac{k^2\sigma_x^2}{2} + \frac{q^2\sigma_y^2}{2} + kq\sigma_{xy}\right), \qquad \text{(A.14)}$$

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

$$\underset{D_i^s}{Max} \quad D_i^s E(S - P^s | \Omega_{is}) - D_i^s \frac{\sigma_{sf}}{\sigma_f^2} E(F - P^f | \Omega_{is}) - \left(D_i^s \frac{\sigma_{sf}}{\sigma_f^2}\right)^2 \frac{\theta}{2} \tilde{\sigma}_f^2, \qquad \text{(A.15)}$$

where

$$\tilde{\sigma}_f^2 = var((E(F - P^f | \Omega_{is})) | \Omega_{is}), \qquad \text{(A.16)}$$

and

$$\tilde{\sigma}_s^2 = var((E(S - P^s \big| \Omega_{is})) \big| \Omega_{is}) = 0 \tag{A.17}$$

$$\tilde{\sigma}_{sf} = covar((E(S - P^s \big| \Omega_{is})), (E(F - P^f \big| \Omega_{is})) \big| \Omega_{is}) = 0 \tag{A.18}$$

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

$$\underset{D_i^s}{Max} \qquad D_i^S \frac{\sigma_{sf}}{\sigma_f^2} \lambda(D_i^s + c_i) - \left(D_i^S \frac{\sigma_{sf}}{\sigma_f^2}\right)^2 \left(\frac{\theta}{2} \tilde{\sigma}_f^2\right). \tag{A.19}$$

The first-order condition is

$$2D_i^S \frac{\sigma_{sf}}{\sigma_f^2} \lambda + \frac{\sigma_{sf}}{\sigma_f^2} \lambda(c_i) - \left(2D_i^S \frac{\sigma_{sf}^2}{(\sigma_f^2)^2}\right)\left(\frac{\theta}{2} \tilde{\sigma}_f^2\right) = 0. \tag{A.20}$$

Simplifying,

$$D_i^S = \left(\frac{\lambda \sigma_f^2}{\theta \tilde{\sigma}_f^2 \sigma_{sf} - 2\sigma_f^2 \lambda}\right) c_i. \tag{A.21}$$

Note that

$$D_i^s = (\beta_1 - 1)c_i = T_i^s - c_i \tag{A.22}$$

$$D_i^f = \beta_2 c_i \tag{A.23}$$

where

$$(\beta_1 - 1) > 0, \beta_2 < 0 \qquad \text{if} \qquad \sigma_{sf} > 0, V = 0. \tag{A.24}$$

The second-order condition,

$$2\lambda - \left(\frac{\sigma_{sf}}{(\sigma_f^2)}\right)(\theta \tilde{\sigma}_f^2) < 0 \tag{A.25}$$

ensures that $\beta_1 > 1$.

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