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Where does price discovery occur in USD/CAD, AUD/USD and NZD/USD foreign exchange markets?

by

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Abstract

Trades in the foreign exchange market are initiated around the world twenty-four hours a day. This paper measures the information content of interdealer trades over a recent and relatively long sample period in three markets: USD/CAD, AUD/USD and NZD/USD. Findings suggest that information asymmetries exist between market participants. Trades initiated in some geographic locations are more informative than those initiated in other locations. Results also suggest that trade informativeness depends on time of day effects and more specifically regional business hours. The econometric model (Hasbrouck (1991a,b)) utilized in the paper captures the joint behavior of foreign exchange returns and order flow in each location across all regional time zones. This study finds that trades initiated in the U.K. and U.S. are informative in predicting exchange rate returns beyond that information available from trades originating in the home country. In the USD/CAD market, during North American business hours, Canadian trades are relatively more informative that U.S. trades suggesting that Canadian-domiciled traders have a comparative advantage in processing fundamental information about the exchange rate.

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1. Introduction

Trades executed in the foreign exchange (FX) market are informative about the future direction of the exchange rate. A number of studies including Evans and Lyons (2002), Payne (2003) and Bjønnes and Rime (2005) provide empirical support for the hypothesis that FX order flow—defined as the number of buyer-initiated trades less seller-initiated trades—is informative. For example, Evans and Lyons (2002) find that order flow explains two-thirds of the daily variation in exchange-rate returns. In contrast, empirical studies such as Meese and Rogoff (1983) illustrate that standard fundamental-based macroeconomic models of the exchange rate perform poorly in explaining and forecasting exchange rate movements. In these models, variables such as interest rate, money supplies, gross domestic products, trade account balances, and commodity prices are the determinants of the equilibrium exchange rate. A random walk usually outperforms these models in out-of-sample forecast comparisons. The failure of macroeconomic models to account for the process in which information is disseminated in FX markets may be an important factor contributing to their poor performance. Microstructure models make explicit that the strategic behaviour of market participants impacts on the joint dynamics of exchange rates and trades (See Glosten and Milgrom (1985)).[1]

The idea that asymmetric information may exist in the foreign exchange market is relatively new to the literature. All active participants are assumed to have access to the same public information, and until recently, private information was thought to be unlikely. While it is difficult to defend the assumption that private information exists regarding the future release of a public news announcements, analysts may differ with respect to their interpretation of a recent public news release. Alternatively, Cao, Evans and Lyons (2006) examine asymmetric inventory information that is unrelated to fundamentals, but may still forecasts future prices. The degree to which participants can be considered heterogenous is an important question and one that is addressed in this study. This paper analyses whether traders in one location have an information advantage over traders in another.

Recent evidence suggests that there are indeed information asymmetries between market participants in the FX market. Froot and Ramadorai (2002), Fan and Lyons (2003) and Mende, Menkhoff and Osler (2006) find that financial customer trades are more informative about the future direction of the exchange rate than non-financial customer trades. Bjønnes, Rime and Solheim (2005) present evidence that financial customer orderflow is positively

[1] In a general equilibrium model of information aggregation, Evans and Lyons (2004) illustrate how transaction flows conveys information about macroeconomic fundamentals.

correlated with the exchange rate. In contrast, non-financial customers act as the main liquidity providers in the overnight Swedish krona/EUR foreign exchange market.

In both the interdealer and customer-dealer spheres of the FX market trading is opaque. In particular, an executed trade is only observable to those participants directly involved in the transaction. For a limited amount of time, these parties will possess information not reflected elsewhere in FX market. Eventually, any fundamental information associated with the trade will be reflected in the exchange rate. This paper examines whether dealers in one location have an information advantage over dealers in another location in any one of three foreign exchange markets: CAD, AUD, and NZD.[2] Dealers will have an informational advantage when forecasting future movements in the exchange rate if they can attract and properly interpret order flow from customers and other dealers. Consider the simultaneous trade model of Lyons (1997) where customer trades drive strategic interdealer trading. Since dealers are knowledgeable about the identity of their customers, any private information of customers will in time find its way into interdealer trades.

The empirical literature associated with equities markets suggest that location does matter. Hau (2005) analyses the German electronic trading system Xetra and finds that traders located outside Germany generate lower trading profits. Further, traders located in Frankfurt, the German financial capital, have superior intraday trading profits compared to those of traders located in other German cities. Coval and Moskowitz (2001) examine the regional investment bias of U.S. mutual funds and find that their local investment generates a higher average return. Grammig, Melvin and Schlag (2005) and Eun and Sabherwal (2003) analyze the data of cross-listed stocks and find that the majority of price discovery occurs in the home market.

In FX markets, Covrig and Melvin (2002) find that Japanese dealers sometimes have superior information over dealers in other locations. In particular, they find that interdealer quotes from Japan lead quotes in the rest of the market. Sapp (2002) investigates how new information is incorporated into intraday quotes for the USD/DEM exchange rate and finds that dealers in a number of locations discover prices before others. Peiers (1997) examines the quoting behaviour of dealers and finds evidence of price leadership by Deutsche Bank before the announcement of central bank intervention.

[2] CAD, AUD and NZD are shorthand for the USD/CAD, AUD/USD and NZD/USD markets. The first currency listed in each pair is the base currency. Therefore USD/CAD is the number of Canadian dollars per U.S. dollar, AUD/USD is the number of U.S. dollars per Australian dollar, and NZD/USD is the number of U.S. dollars per New Zealand dollar.

The present study finds strong evidence that asymmetric information exists across geographic locations in the FX market. The dataset examined in this study disaggregates trades by the location in which the trade is initiated. 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. This paper studies the information content of these market orders. In particular, order flow is calculated for each geographic location at all points in time. A vector autoregression (VAR) that includes exchange rate returns and a number of geographic order flow variables is employed to calculate two related measures of the information content of trades. Hasbrouck (1991a,b) argues that any persistent impact of a trade on the price of a security must arise from asymmetric information signaled by the trade. Alternatively, a decomposition of the long-run variance of exchange rate returns across the different trades may provide a broader summary measure of the information contained in each individual trade flow.

Results suggest that Canadian, U.K, and U.S. dealers are asymmetrically informed in the USD/CAD market. More generally, a "home country" trade (e.g., a Australian trade in the AUD market or a New Zealand trade in the NZD market) has a larger effect on the exchange rate than all other trades during the home country's regular business hours. Across all three currencies pairs, U.S. and U.K. trades have a consistently large impact during their own regional business hours, suggesting that both locations support market making operations in all three currency pairs, and as a result can attract informative order flow. The exchange rate impact of a trade occurring outside normal business hours is significantly smaller than that of a trade during business hours. Payne (2003) also finds strong time-of-day effects regarding the information content of trades in the USD/DEM market. Interestingly, results suggest that during North American hours, Canadian trades are more informative than U.S. trades in the CAD market, suggesting that Canadian dealers have a comparative advantage in processing relevant information associated with this market. Note that since more than 50% of trades in the FX market are cross border trades (BIS, 2005), the information in interdealer trades does not necessarily reflect customer orders in that same location.

Overall, the current study characterizes the information content of interdealer trades across geographic location. The results of this study may be important to policy makers who are interested in learning more about their own domestic financial markets, and the extent to which they are efficient. The study is unique in that it accounts for both the location of initiated trades and regional business hours simultaneously. In addition, it focuses on a number of relatively smaller but mature FX markets–those that are not associated exclusively with "international" or vehicle currencies (e.g., EUR/USD). Unlike existing studies of the foreign exchange market that focus on geography, the dataset employed in the current paper includes trade level data. Last, the dataset spans a more recent period of time which is important given changes in structure of the foreign exchange market over the last decade. In particular, anonymous electronic trading has become an important element of interdealer trading.

The rest of the paper is arranged as follows. Section 2 describes the structure of the FX market and the two datasets employed in the paper. Section 3 presents some descriptive statistics regarding the time-series and cross-sectional aspects of the data. The VAR methodology employed in the study is described in Section 4 while empirical findings are presented in Section 5. Finally, Section 6 concludes.

2. The FX Market and the Data Sets

The foreign exchange market is the largest financial market in the world. Average turnover in spot transactions, outright forwards and foreign exchange swaps was U.S. $1.9 trillion in April 2004—an increase of 57% over 2001 levels. In the spot market, trades occur in either customer-dealer or interdealer segments. In the interdealer market, trades are executed either directly or via an interdealer broker (IDB) to insure anonymity. Interdealer trading accounts for between 60% and 80% of the total volumes of trading in the foreign exchange market.

Trading in foreign exchange markets is more decentralized and opaque than in equity markets. Unlike equity exchanges with fixed opening and closing hours, trades in the FX market occur continuously around the clock. In the customer-dealer and direct interdealer segments the market is quote driven while in the brokered interdealer segment a limit order book exists. Dealers provide two-way quotes to both customers and other dealers. Since customers are located in different time zones, trading must be organized in this decentralized fashion.[3] Dealer receive private information through customer orders. Each dealer will know their own customer orders through the course of the day, and will try to deduce the positions of other dealers in the market. Customers are the financial and non-financial corporations that are the end-users of foreign exchange currencies for settling imports or exports, investing overseas, hedging business transactions, or speculating.

Brokers in the FX market match the best orders among dealers. They disseminate dealer

[3] The decentralized nature of the market makes regulation difficult.

quotes to the market without revealing the identity of the dealer. Brokers are pure matchmakers and do not take positions. There are two types of brokers in the FX market, electronic and voice brokers. The two electronic brokers in the interbank market include Reuters (Dealing 3000) and EBS (Electronic Brokering Services). Electronic brokers have taken market share from both voice brokers and direct trading.[4] According to Rime (2003) electronic brokers are the main trading channel in the interbank market. While trading through an electronic broker is anonymous before the trade is executed, after its completion both parties to the trade know the identity of their counterparty. It is in this way that information is partially transmitted across the market. It is also through this channel that traders gradually lose any informational advantage they may have possessed.

In this study, two datasets are utilized. The propriety trade data was made available from an IDB in the FX market. This dataset includes the exact time (GMT) and date that each market order was executed against the limit-order book. In addition to the transacted exchange rate and the associated trade volume of each trade, the dataset is unique since it discloses the geographic location of the trade-initiator (i.e., the country where the market order was entered into the electronic IDB). The dataset includes all market orders in the CAD, AUD and NZD markets executed on the IDB over the two-year period from October 1, 2000 to September 30, 2002. Trade data is then aggregated into 5-minute intervals. The sampling interval is fine enough to minimize any problems associated with contemporaneous endogeneity across trades and exchange rate variables in the econometric analysis below. While there are over 30 possible locations (or countries) where trades may be initiated, most on average comprise less that a handful of trades per day. The analysis below focuses only on trades initiated in Australia, Canada, Japan, New Zealand, U.K., and the U.S. for each exchange rate pair. Australia, Canada, New Zealand and the U.S. are included in the analysis since their own currency is part of at least one of the currency pairs. Japan and the U.K. are included since both Tokyo and London have historically been considered large FX commercial centres.

To determine if a trade was executed at the bid or ask side of the market, intraday quote data for CAD, AUD and NZD exchange rates was obtained from Olsen and Associates over the same sample period. The intraday data provide the bid and ask spot rates at the end of every 5-minute interval over a 24-hour period for each exchange rate.[5] To calculate

[4] Dealing 2000-2 was introduced by Reuters in April 1992 (Rime, 2003).

[5] Olsen and Associates (oanda.com) receives live data from one or more real time data feeds. The data feed vendor should however not be confused with the data source although the real time data collection software is capable of collecting data with several feeds.

order flow, trades must be categorized as either buyer-initiated or seller-initiated. Trades are signed according to the following rule of Lee and Ready (1991): if a transaction occurs above the prevailing mid-quote, it is regarded as buyer-initiated. Otherwise it is designated as a seller initiated trade. If a transaction occurs exactly at the mid-quote, it is signed using the previous transacted exchange rate according to the following tick test: the trade is buyer-initiated if the sign of the last non-zero exchange rate change is positive. Following Evans and Lyons (2002) trades are signed as +1 if foreign exchange is purchased and -1 if foreign exchange if sold.[6] Order flow in each location is then determined by summing-up the signed trades in each 5-minute interval. Midpoints of bid and ask quotes are used to generate a series of exchange rate returns. Returns are continuously compounded returns, defined as 100 multiple by the log difference of the exchange rate determined at the end of each 5-minute interval.

The analysis is completed in Greenwich Mean Time (GMT). Since daylight savings time (DST) has been adopted in Australia, Canada, New Zealand, U.K. and the U.S., the GMT hours corresponding to business hours in some locations shift by one hour twice a year. Further, in each region, the switch to and from DST is not simultaneous across locations. The paper avoids some confusion by looking only at days in which all DST adopters have switched to or from DST. This subset of days can be grouped into four sub-samples:

(i) October 30, 2000 - March 16, 2001 (No DST)

(ii) April 2, 2001 - October 5, 2001 (DST)

(iii) October 29, 2001 - March 15, 2002 (No DST)

(iv) April 8, 2002 - September 30, 2002 (DST)

National holidays and weekends are also excluded from the dataset. Weekends begin on Fridays at 22:00 GMT and end on Sundays at 22:00 GMT. The direct crossing of limit orders occurs on an electronic brokering system when a limit buy order has a quote greater or equal to a limit sell order. In this case, the brokering system automatically matches the two orders. The trade initiator associated with crosses was not provided.[7]

[6]Signing the volume of trades is an alternative measure of order flow. Trades are sighed +(Trade Volume) if foreign exchange is purchased and -(Trade Volume) if foreign exchange if sold.

[7]Crosses could be signed by treating the lastest entering limit order as the aggressor.

3. Descriptive Statistics

The foreign exchange market operates twenty-four hours a day, seven days a week. While many papers have characterized the high-frequency behaviour of the exchange rates and trading in the yen/USD, euro/USD markets,[8] there has been relatively little focus on smaller but well-developed markets such as the CAD, AUD and NZD markets. These markets may be relatively smaller but absolute trading volumes are still large. The objective of this section of the paper is to present some stylized facts regarding the behaviour of the exchange rate and trades in these smaller FX markets. An analysis of daily and intraday frequency data is performed for each market.

Table 1 reports daily summary statistics for each of the three currency pairs. Daily exchange rate returns are presented in percentage amounts and are on average not statistically significantly different from zero in all three markets. Unlike many other exchange rate studies, such as Dacorogna et al. (1993), only the AUD exchange rate exhibits fat-tails or some degree of excess kurtosis. Autocorrelation is detected via a fifth-order Box-Ljung statistic. The asymptotic 5% and 1% critical values for this test statistic are 11.07 and 15.09 respectively. There is no evidence of autocorrelation in returns at the daily frequency. Realized volatility is calculated as the sum off the intraday 15-minute squared returns.[9] Realized volatility across all three currency pairs is autocorrelated. This stylized fact has been documented by many others including Dacorogna et al. Trading volumes and the number of market orders executed on the electronic brokering system are significantly higher in the AUD market.[10] On an average business day there are about 4,000 trades in the AUD market, 1000 trades in CAD market, and about 600 trades in NZD market. Last, while the average trade size is about US$ 2 million in the CAD market, it is 1.7 million in the AUD market and about NZ$ 1.5 million in the NZD market. There is very little variation in the trade size in each market suggesting that trade size is determined by market convention. Table 2 reports daily volumes initiated across the 6 trading locations analysed in the paper.[11] Trading is the CAD market is dominated by trades initiated in Canada, the U.S. and the U.K. These trades make up 75% of all trades in the CAD market. The US and UK are also dominant in the AUD and

[8] See the recent papers by Ito and Hashimoto (2005), Cai, Howorka and Wongswan (2006) and Melvin and Melvin (2003).

[9] Dacorogna et al. (1993) and Guillaume et al. (1995) suggest using samples periods of at least 10 minutes for reliable statistical analysis.

[10] Note that in the CAD/USD market, prices are in terms of US$, while in the USD/AUD and USD/NZD markets, prices are in terms of Australian and New Zealand dollars respectively.

[11] The counterparty to each intiated trade could be located anywhere in the world. The counterparty's location is not available in our dataset.

NZD markets. Japan tends to be a small player in each of these markets.[12]

Trading in the foreign exchange market is occurs throughout the day. Figures 1 to 3 illustrate the intraday pattern in the number of trades, the trading volume, bid-ask spreads and volatility hourly across the 24-hour clock. For each market, two sets of graphs are presented, one set describes the hourly variation when daylight savings time (DST) is not in effect in the Northern Hemisphere. The other set describes the hourly variation once the U.S., Canada and Europe have all turned the clock back one hour.[13] The horizontal axis on each graph is GMT time which does not account for daylight savings. Notice that for the CAD market, the number of trades, trading volumes, and volatility peak after the opening of business hours in North America. As business hours wind down in North America, all three variables falls. Spreads follow a similar but opposite pattern. They fall dramatically with the start of European business hours, and remain low until the end of the North American business day. When daylight savings time is in effect the graphs have a similar shape, except the pattern described above begins one hour earlier. In the AUD market (Figure 2), there are at least two peeks in trades, trading volumes, and volatility. These peaks are associated with morning trading in London and New York. A third smaller peak occurs during Asian hours. A similar pattern is observed for the NZD market (see Figure 3).

Since there are times when some financial centers are open while others are closed, an analysis of the joint dynamics of exchange rates and trades must be performed separately across a variety of time periods. These periods are defined by which trading locations are open for business and which are closed. Based on an examination of trading volumes initiated around the world, this paper adopts the breakdown of regions proposed by Cai, Howorka and Wongswan (2006) for the euro/USD and USD/yen markets[14]:

- No Daylight Savings Time, Regional time zones:
    - (i) Asia trading hours: 22:00-07:30 GMT (9 1/2 hours)
    - (ii) Asia-Europe overlapping hours: 07:30-09:00 GMT (1 1/2 hours)
    - (iii) Europe trading hours: 09:00-12:30 GMT (3 1/2 hours)

[12] Crossed trades are trades in which neither counterparty executes a market order. Instead, limit buy and sell orders are crossed and automatically executed by the IDB. Crosses make up more than 50% of trades in the AUD and NZD markets. In the CAD market they represent about 10% of trades.

[13] Periods of time when some countries have switched to or from DST and others have not yet switched are not considered in the paper.

[14] Melvin and Peiers-Melvin (2003) and Ito and Hashimoto (2005) also have a similar definitions of business hours in each region.

(iv) Europe-N. America overlapping hours: 12:30-17:00 GMT (4 1/2 hours)

(v) N. America trading hours: 17:00-22:00 GMT (5 hours)

- Daylight Savings Time, Regional time zones:

  (i) Asia trading hours: 21:00-06:30 GMT (9 1/2 hours)

  (ii) Asia-Europe overlapping hours: 06:30-08:00 GMT (1 1/2 hours)

  (iii) Europe trading hours: 08:00-11:30 GMT (3 1/2 hours)

  (iv) Europe-N. America overlapping hours: 11:30-16:00 GMT (4 1/2 hours)

  (v) N. America trading hours: 16:00-21:00 GMT (5 hours)

4. Empirical Methodology

This section illustrates an approach widely employed in the literature to determine the informational content of trades. The methodology has been utilized across all financial markets when examining the joint behaviour of trades or orders and the return on financial assets[15]. The impact of each order flow (characterized by the location in which a trade is initiated) cannot be determined from a single regression. All variables are endogenous, and causality between the different order flow variables, and between exchange rates and order flows, may occur in many and multiple different directions. For example, while an unexpected purchase of foreign exchange by a trader may lead to a change in the exchange rate, the causality may also work in the other direction: an unexpected increase in the exchange rate could influence the purchases of foreign exchange. Alternatively, trades initiated in the U.K. may serve as a catalyst for trades initiated in the U.S., while trades initiated in U.S. may serve as a catalyst for trades initiated in the Canada. The methodology of Hasbrouck (1991a,b) is robust to modelling assumptions while at the same time it is able to characterize the dynamics by which all types of trades and exchange rates returns interact.

A vector autoregression (VAR) is constructed in this section to determine both the sources of exchange rate variations and whether those variations are permanent or transitory. A VAR is a linear specification in which each variable is regressed against lags of all variables. The model captures the dynamic relationships between all variables. It also allows for lagged

[15] Hasbrouck (1988, 1991a,b 1993) focuses on U.S. equity markets, Payne (2003) looks at the spot USD/DEM exchange rate market, while Chordia et al. (2005) examine linkages between stock and bond markets.

endogenous effects. Two different statistics are examined with the estimated VAR: an impulse response function is used to determine the permanent exchange rate impact of each order flow variable, while a variance decomposition is employed to determine the relative importance of all order flow variables in explaining the variation in exchange rate returns.

Theoretically, exchange rates can be thought of as being composed of two elements: an informationally efficient price and a transitory element reflecting frictions in the trading process. While new fundamental information will lead to a permanent revision in the market expectations of the exchange rate, microstructure effects will be short-lived and transient. Specifically, the long-run response of the exchange rate to a trade will depend on the whether that trade was initiated by an informed trader with private fundamental information. In order for trades to be informative, traders on the passive side of a transaction must be able to update their beliefs regarding the future direction of exchange rates. In an electronic brokering system, limit orders are anonymous, but once a market order is executed both the initiator and receiver receive information on the counterparty. Statistically, the extent of asymmetric information in trades can be measured by the explanatory power of each order flow variable in accounting for exchange rate variation. While the transitory effects of a trade may drive the current exchange rate away from the informationally efficient level, over a short period of time these effects will dissipate. The VAR methodology employed below allows for an examination of the relationship between trades initiated in different locations and exchange rate returns.

In situations where it is difficult to have a theoretical prior about which variable is affecting which, or which variables are exogenous and which are endogenous, it is useful to consider a more general time series model such as a VAR and include the whole vector of time series. Let z_t denote the column vector of all variables,

$$z_t = \left[x_{1t}, ...x_{nt}, r_t\right].$$

The VAR specification can be written as:

$$z_t = A_1 z_{t-1} + A_2 z_{t-2} ... + A_k z_{t-p} + \nu_t, \tag{1}$$

where the $A's$ are coefficient matrices, p is the maximum lag length, and ν_t is a column vector of serially uncorrelated disturbances (the VAR innovations) with variance-covariance matrix Σ. The variables x_{it} are the various order flows calculated from trades initiated in the n locations, while r_t is the percentage exchange rate return over the 5-minute interval. Estimates of VAR coefficients and associated variance-covariance matrices can be obtained from least-squares estimation.[16] The model is estimated over a number of different subsamples. In particular, to judge the robustness of these estimates, the model is re-estimated with the 20% most volatile days and the top 20% largest trading days across each region. Payne (2003) finds the information content of orderflow to be related to the supply of liquidity in the market.

VARs are sensitive to lag length, or p in equation (1) above. The Schwartz Information Criterion defined as

$$SIC = \ln \left| \widehat{\Sigma}_u \right| + \frac{k \times \ln T}{T} \tag{2}$$

is employed to determine the lag length of the VAR, where k is the number of regression coefficients in the system, T is the sample size, and $\widehat{\Sigma}_u$ is an estimate of the residual covariance matrix. The order of the VAR, p, is determined by minimizing (2).

Impulse response functions are usually more useful to study than the estimated VAR coefficients when characterizing the behaviour of the estimated system of equations. Impulse response functions represent the expected future values of the system conditional on an initial disturbance, v_t, and can be computed recursively from equation (1).

The vector moving average representation (VMA) provides the elements needed to calculate the impulse response function. Since the variables in the present model are either flows or changes in variables from one period to the next, it is useful to consider cumulative quantities. The accumulated response function of one variable to a shock in another can be determined from the Ψ_k matrices in

$$E\left[z_t + z_{t+1} + ...z_{t+k} | v_t\right] = \Psi_k v_t.$$

An important component of the accumulated response function is the long-run impact of an innovation on the cumulative exchange rate return. This quantity measures the fundamental information content of an innovation in a variable. While microstructure effects may lead to transient effects on cumulative returns, any persistent impact will reflect new payoff information. In terms of the accumulated response coefficients, the cumulative return implied by a particular disturbance may be written as

$$E\left[r_t + r_{t+1} + ... | v_t\right] = \Psi_{\infty,r} v_t$$

[16] See Judge et al. (1988) and Hamilton (1994) for a discussion of vector autoregressions.

where $\Psi_{\infty,r}$ is the row of Ψ_{∞} matrix that corresponds to the log exchange rate return. If the VAR representation is invertible, this may be estimated by $\Psi_{n,r}$ where n is large enough to approximate convergence.

In this paper, hypothetical disturbances will be used to study the impact of particular trades. The VAR disturbances may be written as $v_t = Bu_t$, where u_t is a vector of mutually uncorrelated structural disturbances, and B is a lower-triangular matrix with ones on the diagonal computed by factoring the VAR disturbance covariance matrix Σ, subject to the desired ordering of the variables.[17] Since the ordering of variables may affect the results, the analysis below reports the maximum and minimum response of accumulated returns to a shock in each trade variable across all possible orderings of the order flow variables in the system.

This paper tests whether trades initiated in different locations have similar impacts on exchange rate returns. Unless, traders in one location have a comparative advantage in collecting and processing pertinent information relevant to the future movements of the exchange rate, the effects of a trade should be similar. The hypothesis is tested by comparing the average accumulated price impact implied by the response function corresponding to different trade flow innovations. Impulse response functions of exchange rate returns are computed for each sample subsequent subject to each trade shocks. As noted above, the long-term cumulative exchange rate return subsequent to a trade flow shock is interpreted as the informational content of the order.

In addition to assessing the effect of a particular trade innovation on exchange rate returns, it is also of interest to consider a broader summary measure of the informational contained in each trade flow. Again, the measure must be computed over an interval long enough that transient effects can be neglected. Suppose that the innovation in the random walk or permanent component of an asset price is denoted as w_t. Its variance, σ_w^2, is a measure of the variation in the permanent component of exchange rate returns, and can be computed using the VMA coefficients from the VAR estimates :

$$\sigma_w^2 = var\left(E\left[r_t + r_{t+1} + ...|v_t\right]\right) = \Psi_{\infty,r}\Omega\Psi'_{\infty,r}.^{18} \tag{3}$$

and measures the variation in the permanent component of fundamental returns. The disturbance covariance matrix will not be diagonal, therefore the right-hand side of (3) will

[17] This is called a Choleski decomposition of the variance-covariance matrix, Σ.
[18] See Hasbrouck (1991b) for an explict derivation.

typically involve terms reflecting the contemporaneous interaction of the disturbances. It is not generally possible to identify a component of σ_w^2 that measures the contribution of each type of innovation. Assumptions must be made about the structure of the innovations which diagonalizes Σ, so that the variance of the random walk component of the exchange rate can be written as

$$\sigma_w^2 = \sigma_{x_1}^2 + \sigma_{x_2}^2 + ...\sigma_{x_N}^2 + \sigma_r^2.$$

Each variable on the right-hand side reflects an incremental contribution relative to the variables that precede it in the ordering. For example $\sigma_{x_k}^2$ corresponds to the incremental contribution of the k'th order-flow variable. The incremental explanatory power of each is measured by adding the variables sequentially to the specification. Relative contributions of each trade variable to explaining the total variance in the random walk component of exchange rate returns are calculated by diving these values by σ_w^2, so that

$$1 = \frac{\sigma_{x_1}^2}{\sigma_w^2} + \frac{\sigma_{x_2}^2}{\sigma_w^2} + ...\frac{\sigma_{x_N}^2}{\sigma_w^2} + \frac{\sigma_r^2}{\sigma_w^2} = R_{x_1}^2 + R_{x_2}^2 + ...R_{x_N}^2 + R_r^2.$$

Again, as with the impulse response functions, the ordering of variables may affect the analysis. In particular, putting a variable earlier in the ordering will increase its information share. The results below report both the maximum and minimum variance decompositions across all possible orderings of the variables in the system.

In summary, the VAR is capable of capturing the dynamic relations among order flows and exchange rate returns. Impulse response function analysis is one useful way of characterizing a VAR by constructing the implied price changes associated with the various types of order flows. A second characterization of the exchange rate return specification in the VAR involves decomposing the sources of the long-run exchange rate return variation among the order flow variables. Since returns are ultimately driven by changes in information, the analysis are useful in attributing information effects and the channels through which they operate.

5. Results

In this section, the informativeness of trades across multiple locations is characterized by utilizing the estimates of a vector autoregression. VARs are estimated for each regional time zone across the trading day and for each currency pair. Table 3 presents relevant information associated with the specification of each VAR. In general, for each currency pair and each subsample, one, two or three lags minimized the Schwarz information criterion. The table also provides p-values of an F-test under the null hypothesis that all lagged coefficients for each order flow variable in the exchange rate returns equation are jointly zero. In general, if a country has regular business hours during the regional time zone examined, then trades in that country have an affect on, or Granger cause, exchange rate returns.

VAR estimated coefficients are not reported in the paper. Instead two summary measures of trade informativeness for each currency pair are discussed: the long-run accumulated impulse response of each order flow on exchange rate returns and the variance decomposition of returns at a long-run horizon (20-periods or 100 minutes is sufficient). Since there are few Canadian-based trades during Asia and Asia-Europe hours, and very few New Zealand-based trades during Europe, Europe-North America and North America hours, either Canadian or New Zealand order flow is omitted from the VAR specification depending on which regional time zone is examined.

Tables 4, 5 and 6 characterize the informativeness of trades in the CAD, AUD, and NZD markets, respectively.[19] For each currency pair, impulse response functions are computed subsequent to an innovation in each trade variables (i.e., a trade in Australia, Canada, Japan, New Zealand, U.K., and U.S.). Since the ordering of each VAR may impact on the results, all possible orderings of trade variables were considered. Both the lowest and highest long-run cumulative exchange rate impact are reported for each type of trade, and in each region. Impulse response functions are presented in terms of percentages (e.g., 0.10 represents a 0.10 % long-run change in the exchange rate). Standard errors of each estimate are shown in parenthesis. Note that across all three tables lows and highs are very similar suggesting that order flows are not very correlated across locations. More importantly, this results suggests that ordering need not be an important consideration with respect to model specification issues. The sampling of trades and exchange rate returns data at 5-minute intervals may have created this favourable effect.

The impulse response results of Tables 4, 5 and 6 can be summarized as follows: The largest impact on the CAD exchange rate occurs as a result of Canadian, U.K, and U.S. trades. The size of the impact is largest during normal business hours in each country. A buyer-initiated trade (or a US$ 2 million purchase) innovation by a Canadian trader has a long-run effect of between 0.658% and 0.737% on the USD/CAD exchange rate during North American hours.[20] A U.S. trade during these same hours has an effect on the USD/CAD

[19] If orderflow is defined as the volume of buyer initiated trades less the volume of seller initiated trades the results are very qualitively and quantatively similar. Since trades are usually executed in conventional amounts ($US 2 million in the CAD market) there will be little difference in the information contained in trades and trade volumes. These results are available from the author.

[20] These ranges may be adjusted to account for the standard errors listed below each number in parenthesis.

exchange rate between 0.411% and 0.570%. Last, for a U.K. trade during European hours, the size of the effect is somewhere between 0.740% and 0.832%. During Asian hours, Australian and Japanese trades have a slightly smaller impact on the exchange rate. Interestingly, during the Asian-European overlapping periods U.K. trades become more potent until the beginning of the North American days when Canadian and U.S. have a larger long-run exchange rate impact.

The variance decomposition results for the CAD market mirror that of the impulse response functions. This is comforting since the two measures attempt to capture similar aspects. During Asian hours, Australian and Japanese trades explain about 10% and 7%, respectively, of the variation in the USD/CAD exchange rate. During the Asia-European and European region time zones, U.K. trades explain more that 40% of the variation in the exchange rate. Once North America opens up for trading, Canadian and U.S. trades explain more than 60% of the variation in the exchange rate. Interestingly, Canadian trades are unambiguously more informative than U.S. trades during North American hours.

In the AUD market, results are similar to those in the CAD market except that Australian trades have a significantly larger impact on the exchange rate than U.S. and U.K. trades during each country's regular business hours. An Australian trade (or a A$ 1.7 million purchase) during Asian hours has an effect of between 1.240% and 1.285% on the AUD exchange rate. In contrast, a U.K. trade during European hours has a long-run effect of between 1.110% and 1.191% on the AUD exchange rate while a U.S. trade during North American hours has an effect of between 1.026% and 1.186% on the AUD exchange rate. Interestingly, Australian trades have a large long-run exchange rate impact across all time zones. For example, Australian trades have a large impact than Canadian trades on the AUD during North American hours. The largest effect of a trade in the AUD market outside of Asian hours occurs as a result of U.K. trades during European hours and U.S. trades during North American hours. U.K. trades explain more than 50% of the variation in the exchange rate during European hours, while U.S. trades explain more than 25% of the variation during European-North American and North American hours. Notice that Japanese trades have a substantially smaller effect than U.K. trades during the Asia-European overlapping period. During this period, Japanese traders may be closing out their FX position as their business day ends. The rest of the market may realize that there is little fundamental information in these liquidity-based trades.

In the NZD market, New Zealand trades have the largest impact on NZD exchange rate during Asia hours. A New Zealand-based trade (equivalent to a NZD$ 1.52 million purchase) during Asian hours has an effect of between 2.230% and 2.338% on the NZD. In a similar fashion as with CAD and AUD markets, U.K. trades are most informative during European hours while U.S. trades are most informative during North American hours. In fact, while New Zealand trades explain about 7.5% of the variation in the NZD during Asian hours, U.K. trades explain more that 40% of the variation in the NZD during European hours.

Overall, these results suggest that there is a home country bias in terms of the magnitude of the effect of a trade on the exchange rate. The exception is U.K.-initiated trades. During European hours, U.K. trades have a larger impact on all FX markets. This result is consistent with the perception of London as a major FX commercial centre. In fact, the exchange rate impact of a U.K. trade in Europe, is approximately two times that of a Japanese trade in Asia in any one of the markets. The raises the question of whether Tokyo should also be considered a major FX centre.

Tables 4, 5 and 6 also provide evidence that there are strong time of day effects associated with informational content of trades. In particular, the long-run impact of a trade will depend on which financial centers are operating at that moment of time in the day. Generally, trades have the largest long-run price impact during each country's regular business hours. This coincides with regular market making operations, and the time period in which dealers are best able to capture informative orders from customers and other dealers.

Robustness checks are performed in Tables 7 and 8. For each currency pair and for each regional time zone, the top 20% most volatile days and the top 20% trading volume days are each selected. [21] The same analysis conduced above is performed with these restricted samples. Findings are very similar. In particular, none of the results discussed above change significantly. There were a few interesting patterns. In particular, on highly volatile days, Australian trades in the CAD market during Asian hours were more informative (i.e., they had a larger long-run exchange rate impact and explained a large proportion of the variability in exchange rate returns) while Japanese trades during the Asian-European overlapping period were less informative. Volatility seems to have little effect of the degree to which trades are informative. On the largest trading days the following trades are found to be more informative: Australian trades in the CAD market during Asian hours, Japanese trades in the AUD market during Asian-European hours, U.K. trades in AUD and NZD markets during European hours, U.S. trades in the NZD market during European-North American hours, and Canadian trades in the NZD market during North American hours. Intuitively, market makers on high volume days are able to capture a larger number of trades, which

[21] More than 50% of the high volatile days coincide with the release of macroeconomic new announcements.

may improve the accuracy of their exchange rate forecasts.

6. Summary, Conclusion and Future Work

Overall the results of this paper suggest that trades initiated in Canada, the U.S. and the U.K. are the most informative in CAD market. In the AUD market, trades in Australia, the U.S. and the U.K. are important, while in the NZD market, trades in New Zealand, the U.S. and the U.K. are important. In general, traders in the U.S. and U.K. are the most informed about all three currency pairs during their own regular business hours. When U.S. and U.K markets are closed, trades in other regions are more informative. There is one exception. In the CAD market, during North American hours, Canadian trades are found to be more informative than U.S. trades.

There is a belief that since traders around the world have access to similar real-time news feeds trades in one location cannot be more informed that trades in another location. The results of the paper, suggest that this is not the case. The ability of dealers to capture order flow from other dealers and customers will determine the extent that their own trades are informative. This ability will be affected by the hours of operation of each dealer. Overall, the results of the paper suggest that not only does location matter, but that location and time matter jointly. Trades at the end of the day or during non-business hours may less related to fundamentals and more related to liquidity and noise trades.

This paper extends the analysis of Payne (2003) and addresses how price discovery depends on where the trade is initiated. The results of the paper suggest that while the FX market operates 24-hours a day in theory, it is important to account for the fact that traders and dealers in each region have regular business hours. Future work will examine in greater depth the price dynamics associated with trades occurring during overlapping periods. Anecdotal evidence suggests that FX trades close-out their position at the end of the day. A structural model of exchange rate determination will be employed to disentangle liquidity and information effects of order flow and exchange rates.

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Table 1: Daily Summary Statistics for Exchange Rate Quotes and Trades[22]

	Returns (percent)	Realized Volatility (percent)	Gross Volume (millions)	Gross Trades (number)	Average Trade Size (millions)
USD/CAD					
Mean	0.013	0.176	2014.66	981.71	2.04
Median	0.023	0.160	1985.00	974.00	2.02
Std.Dev.	0.360	0.078	709.16	323.19	0.15
Skewness	0.001	1.874	0.70	0.86	0.34
Kurtosis	2.709	8.617	4.01	5.18	2.95
Autocorr.	6.045	46.076	22.18	29.64	43.22
AUD/USD					
Mean	0.014	0.784	7092.93	4137.11	1.71
Median	0.000	0.684	6960.00	4131.00	1.69
Std.Dev.	0.706	0.434	2520.72	1374.96	0.11
Skewness	0.630	3.255	0.40	0.31	0.60
Kurtosis	5.529	23.985	3.60	4.04	3.44
Autocorr.	1.267	96.604	30.90	30.76	104.12
NZD/USD					
Mean	0.045	1.765	968.92	631.68	1.52
Median	0.036	1.567	920.50	603.00	1.51
Std.Dev.	0.757	0.965	376.30	220.87	0.12
Skewness	0.172	1.167	0.72	0.59	0.52
Kurtosis	3.428	4.221	4.03	4.10	4.04
Autocorr.	3.825	87.848	16.73	21.53	3.24

[22] Table 1 presents daily descriptive statistics for exchange rate quotes and trades. Returns are defined as the log difference in the midpoint of the bid and offer quotes across periods multiplied by 100. Volatility is realized volatility calculated as the sum of the intraday 5-minute squared returns. Gross volumes and gross trades are the sum of trade volumes and the number of trades across the day. Last, the average size of each trade on a daily basis is determine by diving the daily gross volume by the total number of trades. For each variable the following statistics are presented: mean, median, standard deviation, skewness, kurtosis and the fifth-order Ljung-Box Q-test statistic for autocorrelation. The last statistic is distributed $\chi(5)$ with asymptotic 5% and 1% critical values of 11.07 and 15.09.

Table 2: Summary Statistics of Trading Volume Across Locations[23]

	Australia	Canada	Japan millions	New Zealand	U.K.	U.S.
USD/CAD			($US, millions)			
Mean	51.20	778.15	35.76	0.08	275.55	571.14
Median	42.00	766.00	30.00	0.00	244.00	564.00
Std.Dev.	39.27	318.94	27.88	0.48	158.40	233.87
Skewness	1.77	0.68	2.25	7.44	2.16	0.87
Kurtosis	7.70	3.80	10.62	65.72	11.41	4.91
Autocorr.	15.77	14.57	12.73	3.94	59.88	14.16
AUD/USD			($A, millions)			
Mean	573.44	33.35	59.62	12.32	623.74	422.45
Median	545.00	25.00	51.00	9.00	610.00	417.00
Std.Dev.	229.44	30.44	38.84	12.00	256.88	198.11
Skewness	0.60	2.29	1.24	2.11	0.37	0.57
Kurtosis	3.64	10.85	5.03	9.98	3.54	4.04
Autocorr.	21.87	17.97	90.84	71.80	20.40	8.17
NZD/USD			($NZ, millions)			
Mean	28.35	4.28	2.22	72.30	125.10	54.95
Median	24.50	1.00	1.00	69.00	116.50	45.00
Std.Dev.	16.56	8.16	3.43	37.16	58.45	40.51
Skewness	0.81	3.35	3.13	0.93	0.89	1.85
Kurtosis	3.32	15.79	16.98	4.96	3.92	8.49
Autocorr.	6.26	40.21	9.44	68.25	9.00	26.35

[23] Table 2 reports daily statistics about trading volumes across locations. For each variable the following statistics are presented: mean, median, standard deviation, skewness, kurtosis and the fifth-order Ljung-Box Q-test statistic for autocorrelation.

Table 3: Specification of VAR, Granger Causality tests[24]

	Location of Trades:	Number of Lag	Value of SIC Criteria	p-values: Test of Hypothesis that Trade Coefficients in Exchange Rate Returns Equation are Jointly Zero					
				Australia	Canada	Japan	New Zealand	U.K.	U.S.
USD/CAD	Asian	2	-23.27	0.00		0.00	0.01	0.00	0.00
	Asia-Europe	1	-18.14	0.00		0.00	0.09	0.00	0.07
	Europe	2	-12.88	0.02	0.00	0.05		0.00	0.00
	Europe / N.A.	1	-9.42	0.72	0.00	0.02		0.00	0.00
	N.American	3	-13.33	0.52	0.00	0.27		0.48	0.00
AUD/USD	Asian	1	-11.79	0.00		0.00	0.00	0.14	0.00
	Asia-Europe	1	-6.75	0.01		0.30	0.56	0.00	0.33
	Europe	2	-9.58	0.00	0.55	0.34		0.00	0.31
	Europe / N.A.	2	-5.01	0.00	0.09	0.22		0.00	0.00
	N.American	2	-11.28	0.00	0.00	0.51		0.00	0.00
NZD/USD	Asian	2	-20.20	0.00		0.91	0.00	0.04	0.04
	Asia-Europe	1	-15.73	0.00		0.31	0.00	0.00	0.32
	Europe	2	-22.61	0.53	0.09	0.01		0.00	0.45
	Europe / N.A.	2	-16.81	0.06	0.01	0.00		0.00	0.00
	N.American	2	-23.49	0.00	0.46	0.65		0.00	0.00

[24] Table 3 provides information about the lag length chosen for the estimated VARs under the Schwarz information criterion. It also provides p-values of Granger Causality F-tests under the null that the sum of all coefficients on trades in each location are zero.

Table 4: Summary of VAR results for USD/CAD[25]

USD/CAD	Location:	Australia		Canada		Japan		New Zealand		United Kingdom		United States	
		Low	High	Low	High	Low	High	Low	High	Low	High	Low	High
Accumulated Returns Impulse Response	Asia	0.439	0.483			0.355	0.400	0.069	0.074	0.138	0.151	0.166	0.208
		(0.022)	(0.020)			(0.024)	(0.020)	(0.026)	(0.021)	(0.021)	(0.025)	(0.024)	(0.021)
	Asia-Europe	0.275	0.359			0.321	0.413	-0.095	-0.051	0.678	0.745	0.032	0.120
		(0.069)	(0.067)			(0.064)	(0.065)	(0.077)	(0.064)	(0.070)	(0.058)	(0.071)	(0.082)
	Europe	0.161	0.244	0.410	0.518	-0.004	0.058			0.740	0.832	0.350	0.507
		(0.054)	(0.047)	(0.058)	(0.051)	(0.051)	(0.046)			(0.048)	(0.050)	(0.051)	(0.052)
	European-N.A.	-0.048	-0.015	0.589	0.761	-0.016	0.019			0.104	0.348	0.516	0.720
		(0.075)	(0.067)	(0.067)	(0.055)	-0.065	(0.053)			(0.065)	(0.065)	(0.050)	(0.055)
	N.America	0.050	0.081	0.658	0.737	-0.004	0.030			0.013	0.092	0.411	0.570
		(0.030)	(0.041)	(0.042)	(0.038)	(0.038)	(0.039)			(0.044)	(0.037)	(0.040)	(0.032)
Variance Decomposition 20-Step Ahead Forecast	Asia	0.099	0.120			0.065	0.082	0.002	0.003	0.010	0.012	0.014	0.022
		(0.004)	(0.006)			(0.004)	(0.005)	(0.001)	(0.001)	(0.002)	(0.002)	(0.002)	(0.002)
	Asia-Europe	0.071	0.118			0.098	0.159	0.002	0.008	0.430	0.520	0.001	0.013
		(0.019)	(0.025)			(0.018)	(0.021)	(0.003)	(0.006)	(0.034)	(0.032)	(0.002)	(0.009)
	Europe	0.021	0.048	0.132	0.211	0.000	0.003			0.434	0.562	0.100	0.202
		(0.007)	(0.010)	(0.017)	(0.017)	(0.000)	(0.002)			(0.023)	(0.025)	(0.016)	(0.017)
	European-N.A.	0.000	0.003	0.334	0.594	0.000	0.000			0.013	0.117	0.268	0.520
		(0.001)	(0.003)	(0.026)	(0.033)	(0.000)	(0.001)			(0.007)	(0.017)	(0.027)	(0.029)
	N.America	0.003	0.007	0.487	0.642	0.000	0.001			0.000	0.009	0.202	0.360
		(0.002)	(0.003)	(0.018)	(0.023)	(0.000)	(0.001)			(0.001)	(0.004)	(0.015)	(0.017)

[25] Tables 4-6 summarize the results of the VAR estimation for each currency pair across each of the 5 distinct regional business-hour subsamples: Asia, Asia/Europe, Europe, Europe/N. America, and N. America. For each country initiating trades, the following information is available: the low & high long-run impulse response of exchange rate returns implied by the VAR across possible orderings of the trade variables, and the low & high variance decomposition of exchange rate returns over a 20-step-ahead forecast horizon. Standard errors (in paranthesis) are estimated using a residual based bootstrap of the VAR model with 500 bootstrap replications.

Table 5: Summary of VAR results for AUD/USD

AUD/USD	Location:	Australia		Canada		Japan		New Zealand		United Kingdom		United States	
		Low	High	Low	High	Low	High	Low	High	Low	High	Low	High
Accumulated Returns	Asia	1.240	1.285			0.300	0.511	0.196	0.287	0.159	0.254	0.388	0.479
Impulse Response		(0.063)	(0.049)			(0.058)	(0.059)	(0.054)	(0.053)	(0.050)	(0.062)	(0.056)	(0.060)
	Asia-Europe	0.701	0.902			0.275	0.470	-0.107	0.013	0.961	1.100	0.165	0.273
		(0.190)	(0.168)			(0.181)	(0.153)	(0.160)	(0.169)	(0.152)	(0.179)	(0.187)	(0.149)
	Europe	0.510	0.767	0.115	0.171	0.112	0.230			1.110	1.191	0.175	0.249
		(0.132)	(0.108)	(0.106)	(0.102)	(0.086)	(0.103)			(0.121)	(0.063)	(0.105)	(0.109)
	European-N.A.	0.359	0.619	-0.007	0.218	0.037	0.076			0.774	0.985	0.684	0.926
		(0.105)	(0.103)	(0.096)	(0.098)	(0.073)	(0.090)			(0.097)	(0.089)	(0.109)	(0.072)
	N.America	0.682	0.869	0.505	0.663	-0.062	-0.018			0.440	0.570	1.026	1.186
		(0.067)	(0.063)	(0.073)	(0.078)	(0.060)	(0.075)			(0.064)	(0.072)	(0.074)	(0.068)
Variance Decomposition	Asia	0.459	0.520			0.028	0.079	0.011	0.025	0.008	0.019	0.045	0.070
20-Step Ahead Forecast		(0.015)	(0.013)			(0.005)	(0.009)	(0.003)	(0.005)	(0.003)	(0.004)	(0.006)	(0.007)
	Asia-Europe	0.222	0.351			0.036	0.095	0.000	0.005	0.402	0.538	0.012	0.032
		(0.040)	(0.041)			(0.019)	(0.026)	(0.000)	(0.007)	(0.047)	(0.054)	(0.011)	(0.016)
	Europe	0.125	0.262	0.006	0.013	0.006	0.025			0.544	0.684	0.014	0.030
		(0.022)	(0.039)	(0.005)	(0.008)	(0.006)	(0.010)			(0.026)	(0.032)	(0.007)	(0.012)
	European-N.A.	0.073	0.191	0.001	0.024	0.001	0.003			0.315	0.521	0.253	0.445
		(0.017)	(0.029)	(0.000)	(0.012)	(0.002)	(0.003)			(0.028)	(0.039)	(0.034)	(0.042)
	N.America	0.108	0.173	0.059	0.101	0.000	0.001			0.045	0.075	0.245	0.328
		(0.012)	(0.012)	(0.008)	(0.011)	(0.000)	(0.001)			(0.007)	(0.010)	(0.017)	(0.014)

Table 6: Summary of VAR results for NZD/USD

NZD/USD	Location:	Australia		Canada		Japan		New Zealand		United Kingdom		United States	
		Low	High	Low	High	Low	High	Low	High	Low	High	Low	High
Accumulated Returns	Asia	1.450	1.649			0.237	0.337	2.230	2.338	0.382	0.429	0.283	0.349
Impulse Response		(0.094)	(0.083)			(0.097)	(0.084)	(0.104)	(0.095)	(0.084)	(0.089)	(0.088)	(0.104)
	Asia-Europe	1.093	1.334			0.345	0.443	1.463	1.750	2.005	2.199	0.241	0.313
		(0.206)	(0.220)			(0.208)	(0.179)	(0.171)	(0.185)	(0.211)	(0.149)	(0.212)	(0.164)
	Europe	0.113	0.291	-0.030	-0.011	0.377	0.459			2.757	2.786	-0.009	0.056
		(0.102)	(0.098)	(0.146)	(0.141)	(0.131)	(0.145)			(0.128)	(0.116)	(0.097)	(0.122)
	European-N.A.	0.130	0.257	0.500	0.682	-0.285	-0.261			2.169	2.379	1.711	1.968
		(0.116)	(0.146)	(0.103)	(0.119)	(0.150)	(0.098)			(0.130)	(0.125)	(0.142)	(0.139)
	N.America	1.118	1.219	0.472	0.568	0.051	0.075			0.918	1.050	2.318	2.389
		(0.164)	(0.145)	(0.110)	(0.123)	(0.141)	(0.139)			(0.135)	(0.126)	(0.148)	(0.114)
Variance Decomposition	Asia	0.032	0.041			0.001	0.002	0.075	0.083	0.002	0.003	0.001	0.002
20-Step Ahead Forecast		(0.002)	(0.002)			(0.000)	(0.000)	(0.004)	(0.003)	(0.001)	(0.001)	(0.000)	(0.001)
	Asia-Europe	0.061	0.091			0.006	0.010	0.111	0.157	0.204	0.247	0.003	0.005
		(0.011)	(0.011)			(0.004)	(0.005)	(0.012)	(0.016)	(0.018)	(0.020)	(0.003)	(0.003)
	Europe	0.001	0.004	0.000	0.000	0.007	0.011			0.402	0.407	0.000	0.000
		(0.001)	(0.002)	(0.000)	(0.000)	(0.002)	(0.003)			(0.014)	(0.014)	(0.000)	(0.000)
	European-N.A.	0.001	0.004	0.014	0.025	0.004	0.005			0.260	0.312	0.162	0.212
		(0.001)	(0.002)	(0.003)	(0.005)	(0.002)	(0.002)			(0.014)	(0.012)	(0.012)	(0.012)
	N.America	0.017	0.021	0.003	0.005	0.000	0.000			0.012	0.015	0.075	0.079
		(0.002)	(0.002)	(0.001)	(0.001)	(0.000)	(0.000)			(0.002)	(0.002)	(0.004)	(0.004)

Table 7: Summary of VAR results: High volatility days

USD/CAD	Location:	Australia		Canada		Japan		New Zealand		United Kingdom		United States	
		Low	High	Low	High	Low	High	Low	High	Low	High	Low	High
Accumulated Returns	Asia	0.472	0.515			0.335	0.380	0.008	0.012	0.171	0.185	0.221	0.270
Impulse Response	Asia-Europe	0.401	0.498			0.243	0.349	0.060	0.104	0.573	0.664	-0.057	0.017
	Europe	0.158	0.278	0.495	0.601	0.036	0.095			0.786	0.893	0.444	0.601
	Europe-N.A.	0.035	0.076	0.544	0.730	-0.004	0.038			0.095	0.351	0.576	0.758
	N.America	0.059	0.100	0.680	0.745	0.050	0.078			0.076	0.154	0.365	0.539
Variance Decomposition	Asia	0.122	0.145			0.061	0.078	0.000	0.000	0.016	0.019	0.027	0.040
20-Step Ahead Forecast	Asia-Europe	0.212	0.330			0.080	0.161	0.005	0.015	0.436	0.587	0.000	0.004
	Europe	0.015	0.047	0.144	0.216	0.001	0.005			0.365	0.482	0.118	0.212
	Europe-N.A.	0.001	0.006	0.283	0.531	0.000	0.001			0.011	0.116	0.320	0.572
	N.America	0.004	0.011	0.505	0.664	0.003	0.007			0.007	0.027	0.158	0.319

AUD/USD	Location:	Australia		Canada		Japan		New Zealand		United Kingdom		United States	
		Low	High	Low	High	Low	High	Low	High	Low	High	Low	High
Accumulated Returns	Asia	1.280	1.317			0.336	0.524	0.257	0.324	0.195	0.283	0.405	0.478
Impulse Response	Asia-Europe	0.788	0.945			0.103	0.277	-0.164	-0.040	0.875	1.019	0.102	0.164
	Europe	0.514	0.865	0.156	0.230	0.300	0.443			1.242	1.350	-0.095	-0.001
	Europe-N.A.	0.351	0.605	0.152	0.379	-0.039	-0.006			0.817	1.004	0.666	0.905
	N.America	0.880	1.083	0.545	0.748	-0.026	-0.001			0.431	0.569	1.122	1.328
Variance Decomposition	Asia	0.322	0.351			0.024	0.054	0.013	0.020	0.007	0.015	0.032	0.045
20-Step Ahead Forecast	Asia-Europe	0.255	0.349			0.006	0.031	0.001	0.010	0.313	0.406	0.004	0.011
	Europe	0.109	0.274	0.009	0.019	0.033	0.078			0.574	0.749	0.000	0.004
	Europe-N.A.	0.064	0.179	0.013	0.070	0.000	0.001			0.327	0.539	0.224	0.419
	N.America	0.156	0.238	0.060	0.112	0.000	0.000			0.038	0.066	0.257	0.361

NZD/USD	Location:	Australia		Canada		Japan		New Zealand		United Kingdom		United States	
		Low	High	Low	High	Low	High	Low	High	Low	High	Low	High
Accumulated Returns	Asia	1.553	1.760			0.264	0.364	2.327	2.416	0.520	0.550	0.347	0.392
Impulse Response	Asia-Europe	0.866	1.079			0.374	0.447	1.211	1.452	1.613	1.762	0.447	0.527
	Europe	0.017	0.220	-0.185	-0.162	0.379	0.465			2.862	2.899	0.322	0.404
	Europe-N.A.	0.277	0.395	0.516	0.712	-0.056	-0.046			2.169	2.401	1.845	2.104
	N.America	1.397	1.501	0.507	0.641	0.128	0.128			1.233	1.377	2.239	2.349
Variance Decomposition	Asia	0.029	0.036			0.001	0.002	0.064	0.069	0.003	0.004	0.001	0.002
20-Step Ahead Forecast	Asia-Europe	0.054	0.082			0.010	0.014	0.107	0.151	0.182	0.219	0.014	0.020
	Europe	0.000	0.002	0.001	0.002	0.007	0.010			0.404	0.412	0.005	0.008
	Europe-N.A.	0.004	0.009	0.015	0.028	0.000	0.000			0.267	0.328	0.192	0.251
	N.America	0.024	0.027	0.003	0.005	0.000	0.000			0.018	0.023	0.061	0.067

Table 8: Summary of VAR results: High volume days

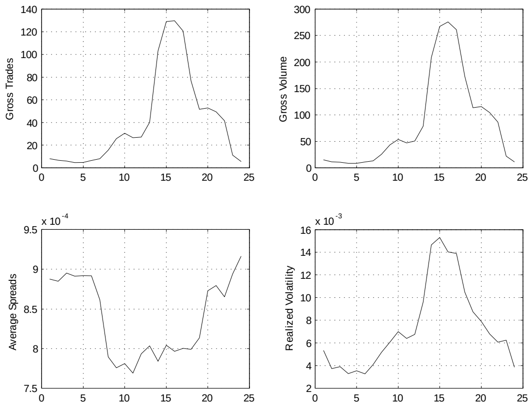
USD/CAD	Location:	Australia		Canada		Japan		New Zealand		United Kingdom		United States	
		Low	High	Low	High	Low	High	Low	High	Low	High	Low	High
Accumulated Returns	Asia	0.487	0.531			0.375	0.419	-0.007	-0.001	0.155	0.167	0.191	0.239
Impulse Response	Asia-Europe	0.277	0.362			0.337	0.428	0.054	0.102	0.666	0.730	0.122	0.220
	Europe	0.164	0.261	0.280	0.375	0.033	0.099			0.809	0.869	0.286	0.436
	Europe-N.A.	-0.047	-0.015	0.439	0.632	-0.042	-0.005			0.205	0.420	0.498	0.682
	N.America	0.040	0.073	0.626	0.709	0.090	0.120			0.008	0.083	0.436	0.577
Variance Decomposition	Asia	0.119	0.141			0.070	0.088	0.000	0.000	0.012	0.014	0.018	0.028
20-Step Ahead Forecast	Asia-Europe	0.074	0.125			0.110	0.178	0.003	0.010	0.424	0.525	0.014	0.046
	Europe	0.023	0.059	0.066	0.117	0.001	0.008			0.545	0.665	0.071	0.160
	Europe-N.A.	0.000	0.003	0.217	0.462	0.000	0.002			0.052	0.196	0.285	0.540
	N.America	0.002	0.006	0.449	0.598	0.009	0.016			0.000	0.008	0.228	0.379

AUD/USD	Location:	Australia		Canada		Japan		New Zealand		United Kingdom		United States	
		Low	High	Low	High	Low	High	Low	High	Low	High	Low	High
Accumulated Returns	Asia	1.267	1.320			0.373	0.558	0.273	0.362	0.184	0.295	0.274	0.356
Impulse Response	Asia-Europe	0.372	0.690			0.664	0.843	-0.234	-0.052	1.216	1.346	-0.019	0.122
	Europe	0.473	0.785	-0.043	0.050	0.082	0.213			1.206	1.288	0.292	0.349
	Europe-N.A.	0.376	0.670	-0.006	0.236	0.048	0.081			0.804	1.052	0.846	1.077
	N.America	0.688	0.890	0.557	0.712	-0.112	-0.031			0.374	0.525	0.999	1.163
Variance Decomposition	Asia	0.411	0.464			0.037	0.080	0.019	0.033	0.009	0.022	0.019	0.033
20-Step Ahead Forecast	Asia-Europe	0.055	0.158			0.151	0.234	0.001	0.018	0.504	0.634	0.000	0.005
	Europe	0.106	0.262	0.000	0.001	0.003	0.019			0.624	0.787	0.037	0.058
	Europe-N.A.	0.065	0.174	0.001	0.022	0.001	0.002			0.274	0.459	0.299	0.483
	N.America	0.132	0.219	0.087	0.143	0.000	0.004			0.040	0.077	0.281	0.383

NZD/USD	Location:	Australia		Canada		Japan		New Zealand		United Kingdom		United States	
		Low	High	Low	High	Low	High	Low	High	Low	High	Low	High
Accumulated Returns	Asia	2.004	2.197			0.357	0.456	2.391	2.559	0.255	0.319	0.353	0.471
Impulse Response	Asia-Europe	1.715	1.964			0.365	0.519	1.712	1.999	2.041	2.285	0.179	0.292
	Europe	0.038	0.188	-0.112	-0.094	0.351	0.411			3.058	3.082	0.139	0.217
	Europe-N.A.	0.065	0.184	0.571	0.757	-0.429	-0.389			2.292	2.550	1.981	2.261
	N.America	1.385	1.483	0.586	0.651	0.071	0.073			1.231	1.348	2.263	2.363
Variance Decomposition	Asia	0.045	0.054			0.001	0.002	0.064	0.073	0.001	0.001	0.001	0.002
20-Step Ahead Forecast	Asia-Europe	0.131	0.172			0.006	0.012	0.130	0.176	0.183	0.230	0.001	0.004
	Europe	0.000	0.002	0.001	0.001	0.006	0.008			0.441	0.445	0.001	0.002
	Europe-N.A.	0.000	0.002	0.018	0.032	0.009	0.011			0.300	0.370	0.222	0.288
	N.America	0.022	0.025	0.004	0.005	0.000	0.000			0.018	0.021	0.059	0.065

Figure 1: Hourly Statistics for USD/CAD across 24-hour Day

Non-Daylight Savings Time Sample



Daylight Savings Time Sample

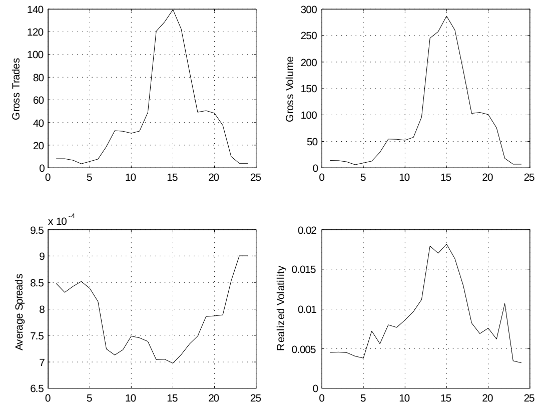
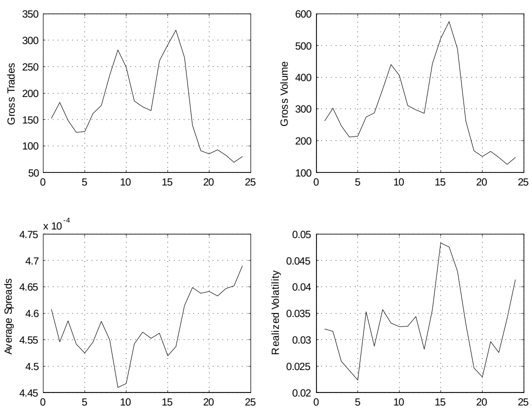


Figure 2: Hourly Statistics for AUD/USD across 24-hour Day

Non-Daylight Savings Time Sample



Daylight Savings Time Sample

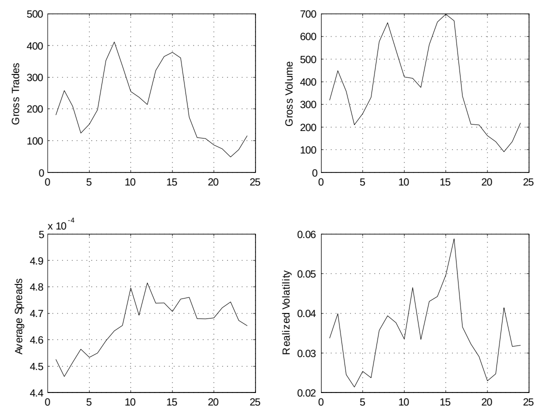
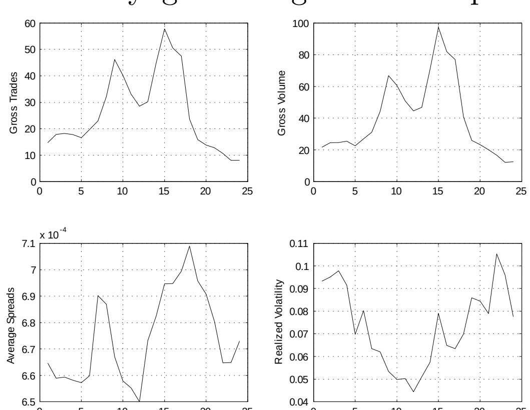


Figure 3: Hourly Statistics for NZD/USD across 24-hour Day

Non-Daylight Savings Time Sample



Daylight Savings Time Sample