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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 and throughout the day in many currency pairs. 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 dealers. Some trades—categorized by the location in which a trade is initiated—are more informative than others. The paper controls for market liquidity and episodes of persistent volatility in exchange rates within and across regional time-zones. The econometric model (Hasbrouck (1991a,b)) utilized in the paper captures the joint behavior of signed trades in each location and foreign exchange returns in an attempt to uncover the price discovery process. This study finds that trades initiated in the U.K. and U.S. contain information useful in predicting exchange rate returns beyond that information available from trades originating in the home country. Trades that occur during overlapping hours between regions are sometimes more informative than those placed during non-overlapping business hours. 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 these models to account for the information and institutions in FX markets may be an important factor. Microstructure models make explicit that the behaviour of market participants impacts on the dynamics of prices 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 have access to the same public information and private information was, until recently, thought to be unlikely. While it is difficult to defend the assumption that private information exists regarding the future release of a public announcement, analysts may differ with respect to their interpretation of a recent public news release. Alternatively, Cao, Evans and Lyons (2006) analyse asymmetric inventory information that is unrelated to fundamentals, but 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. 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 correlated with the exchange rate. In contrast, non-financial customers act as the main liquidity providers in the overnight SEK/EUR foreign exchange market.

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

Since dealers are knowledgeable about the identity of their customers, any private information of customers will find its way into interdealer trades. Consider the simultaneous trade model of Lyons (1997) where customer trades drive strategic interdealer trading. In the interdealer FX market, trading is opaque as individual transactions are only observable to some participants. Only those parties involved will learn about the identities of the counterparties involved in a trade and possess additional information not reflected elsewhere in FX market.

This paper examines whether dealers in one location have an information advantage over dealers in another in three foreign exchange markets: CAD, AUD, and NZD.[2] While FX trading occurs in all industrialized countries, the vast majority of trades in these markets are initiated in Australia, Canada, Japan, New Zealand, U.K. and the U.S. A vector autoregression (VAR) that includes exchange rate returns and signed trades by location is employed to calculate two related measures of the information content of trades in each location. 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 may provide a broader summary measure of the information contained in trade flows.

The empirical literature associated with equities markets literature 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

[2] CAD, AUD and NZD markets are shorthand for USD/CAD, AUD/USD and NZD/USD. 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 quoting behaviour of dealers using the same dataset as Sapp, and finds evidence of price leadership by Deutsche Bank before the announcement of central bank intervention.

The present study finds that Canadian, U.K, and U.S. dealers are asymmetrically informed in the USD/CAD market. In each FX market, a "home country" trade has a larger effect on the exchange rate than most other trades. Though, U.K.-initiated trades have a large impact on all FX markets during Europe hours. Payne (2003) finds strong time-of-day effects regarding the information content of trades for the USD/DEM market. With the exception of Australian trades in the AUD market, the exchange rate impact of a trade occurring outside normal business hours is significantly smaller than that of a trade during 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, and not Japan, support market making operations in all three currency pairs. 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.

Overall, the current study characterizes the information content of trades across geographic location. The results 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 FX market and recent changes in its structure. It also discusses the datasets employed in the paper. Section 3 presents descriptive statistics regarding the time-series and cross-sectional aspects of the data. In Section 4, the paper documents intra- and inter-regional volatility persistence. This section also determines which macroeconomic news is relevant to these markets, and may control for volatility. The VAR methodology is described in Section 5. Section 6 presents the empirical findings from the VAR estimations. Finally, Section 7 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 prices 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 prices 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.

For this study, we use a number of databases. The propriety trade data was made available from a major IDB. The dataset includes the price, trade volume, time (GMT) and date at which each trade was executed, in addition to the location of the trade initiator (i.e., the country). 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 periods. The sampling interval is fine enough to

[3]The decentralized nature of the market makes regulation difficult.
[4]Dealing 2000-2 was introduced by Reuters in April 1992 (Rime, 2003).

minimize the problems of contemporaneous endogeneity across variables in the econometric analysis below. While there are over 30 possible locations (or countries) where trades may be initiated, most on average constitute 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 for obvious reasons. Japan and the U.K. are included since they are both 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. 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] Signed trades are defined as +1 if foreign exchange is purchased and -1 if foreign exchange is sold. Both signed number of trades and signed volume of trades are considered separately in the analysis. Following Lee and Ready (1991), transactions data are signed according to the following rule. 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 transaction price according to the following tick test: the trade is buyer-initiated if the sign of the last non-zero price change is positive. 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 quote data extends from January 1, 1998 to December 31, 2004. This data is also used in conjunction with data on macroeconomic news announcements collected from Bloomberg over the same period to determine what news is relevant in each FX market. These results permit an analysis of exchange rate returns and trades while controlling for the arrival of scheduled macroeconomic news.

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 two times 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

[5] Olsen Data receives live data from one or more real time data feeds. The data feed vendor should however not be confused with the data source. Their real time data collection software is capable of collecting data with several feeds.

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. The direct crossing of limit orders occurs on an electronic brokering system when a limit buy order has a price greater or equal to a limit sell order. In this case, the brokering system automatically matches the two orders. Since it is difficult to argue that one and not the other counterparty is the trade initiator, crosses are ignored in the analysis below.

3. Descriptive Statistics

The foreign exchange market operates twenty-four hours a day and 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,[6] 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 enormous relative to, say, GDP in Canada, Australia and New Zealand.

The objective of this section of the paper is to present some stylized facts regarding exchange rate and trades in these smaller markets, and compare these statistics with the larger yen/USD, euro/USD markets. An analysis of daily and intraday frequency data is performed by market. By examining the statistical properties of the data, it is possible to build more reasonable or consistent models.

Table 1 reports daily summary statistics for each of the three currency pairs. Notice that returns are not significantly different from zero in all three markets and only the AUD exchange rate exhibits a degree of excess kurtosis. While a hypothesis of no autocorreation cannot be rejected for returns, for realized volatility this is not the case. There is a high

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

degree of autocorreation in volatility across days. Actual spreads posted on the electronic brokering order book are relatively tight (8 pips for the CAD market), and exhibit very little variation across days. In fact, judging by the degree of autocorrelation in spreads, spreads may be set according to conventions in the market. Trading volumes and the number of trades executed on the electronic brokering system are significantly higher in the AUD market.[7] On an average business day there are about 4,000 trades in the AUD, 1000 trades in CAD market and 600 trades in NZD. Last, while the average trade size is about 2 million USD in the CAD market, it is 1.7 million AUD in the AUD market and about 1.5 million NZD in the NZD market. There is very little variation in the trade size in each market, again suggesting that trade size is also determined by convention in the market.

Table 2 reports daily trading volumes initiated across the 6 locations that the paper analyses.[8] 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 NZD markets. Japan tends to be a small player in each of these markets. The reason that the sum of trades in the AUD market initiated in the six locations is significantly smaller that the average daily trading volumes reported in Table 1 is that for the AUD market, a large number of trades are the result of a cross in limit orders. Figures 1 to 3 provide an indication of the proportion of crossed trades executed in each market. Crossed trades (trades in which no one counterparty initiates a market order, but limit orders are crossed) make up more than 50% of trades in the AUD and NZD markets. In the CAD market they represent about 10% of trades.

Trading in the foreign exchange market is conducted throughout the day around the world. Figures 4 and 5 illustrate the change in volatility, spreads, trading volumes, number of trades and crosses hourly across the 24-hour clock. In each market, two graphs are presented, one for periods of time when daylight savings (DST) is not operational on the Northern Hemisphere, and the other when the U.S., Canada and Europe have turned the clock back one hour.[9] The horizontal axis on each graph is GMT time. Notice that for the CAD market, volatility peaks after the opening of business hours in N. America, and as business hours wind down in N. America, volatility falls. The same pattern is observable for trading volumes and the number of trades (include crosses). In general, trading starts to increase during the European

[7] 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.

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

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

business day, and decreases with the end of the North American business day. Once daylight savings is adopted the graphs have the same pattern, but increases and decreases begin one hour earlier. Spreads have the opposite reaction. They fall dramatically with the start of European business hours, and remain low until the end of the N. American business day. In the AUD market (Figures 6 and 7), there are at least two peeks in volatility and trading. One peak is associated with N. American hours, the other is associated with European hours, with a third possible peak during Asian hours. A similar pattern is observed for the NZD market (see Figures 8 and 9) except for the volatility graph, where there is a definite decrease in volatility during N. American hours.

Since there are times when some financial centers are open while others are closed, an analysis of exchange rates and trades must be performed separately on a variety of time periods defined by the which locations are open for business and which are closed. Based on an examination of trading volumes initiated around the world, the paper adopts the breakdown of regions proposed by Cai, Howorka and Wongswan (2006) for the euro/USD and USD/yen markets[10]:

- No DST
  - Region 1, Asia: 22:00-07:30 GMT (9 1/2 hours)
  - Region 2, Asia/Europe: 07:30-09:00 GMT (1 1/2 hours)
  - Region 3, Europe: 09:00-12:30 GMT (3 1/2 hours)
  - Region 4, Europe/America: 12:30-17:00 GMT (4 1/2 hours)
  - Region 5, America: 17:00-22:00 GMT (5 hours)
- DST
  - Region 1, Asia: 21:00-06:30 GMT (9 1/2 hours)
  - Region 2, Asia/Europe: 06:30-08:00 GMT (1 1/2 hours)
  - Region 3, Europe: 08:00-11:30 GMT (3 1/2 hours)
  - Region 4, Europe/America: 11:30-16:00 GMT (4 1/2 hours)
  - Region 5, America: 16:00-21:00 GMT (5 hours)

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

4. Volatility Persistence across Regional Time Zones

Before examining the price discovery process a number of issues must be considered. In a number of recent papers, volatility persistence and the effect of macroeconomic news releases on asset markets have been examined. Melvin and Peiers-Melvin (2003) and Cai, Howorka and Wongswan (2006) find evidence of both intraregional ("heat-wave") and interregional volatility ("meteor-shower") clustering in the DM/USD and yen/USD markets, although own-region spillovers are a more dominant feature. Persistence in volatility in the foreign exchange market is puzzling if markets are efficient and prices adjust quickly to new information. One explanation is that the arrival of public information is serially correlated. In particular, relevant news occurs during each region's business hours. This may explain the heat-wave effect, but not the meteor shower effect. One way to explain interregional volatility is if "public information received at one point in time is followed with a lag by a stochastic response" (Melvin and Peiers Melvin, 2003).

This section of the paper attempts to characterize the extent of volatility persistence across regions in the CAD, AUD and NZD markets using high frequency quote data. These results are then compared to Melvin and Peiers Melvin (2003) and Cai, Howorka and Wongswan (2006). Exogenous variables are later constructed to account for the persistent in volatility across regions.

Using 15 minute interval quote data,[11] intraday squared returns are summed across the intervals in each identified region in order to construct a daily measure of integrated volatility. Since regions have different time lengths, these measures of volatility are standardized by the number of time intervals in that region. The paper follows Melvin and Peiers Melvin (2003) and uses the logarithms of volatility which have been shown to be close to normal. The model estimated with these volatility measures specifies that volatility in each region is a function of past volatility in that region and volatility in the other regions. The system has five equations (associated with the five different regions) but note that the right-hand side variables will differ across equations/regions depending on where the region is located relative to the international date line. For example, since Asian hours begin first on each date, the first lag of the other regions will be dated with the previous date. In contrast, during N. American hours, the first lags of the other regions will be dated with the same date as the dependant variable. Thus the only difference in the right hand variables is which lags are appropriate for each dependent variable.

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

The model estimated is

$$\sigma_t^2 = A_1\sigma_{t-1}^2 + ... + A_p\sigma_{t-p}^2 + \varepsilon_t \tag{1}$$

where σ_t^2 is a vector containing all five regional volatility measures. The lag length, p, is determined using the Schwarz Information Criterion. The five-equation system is estimated using seemingly unrelated regressions (SUR) and not a vector autoregression since the variables on the right-hand side of the each equation are different. SUR estimation yields more efficient estimates that ordinary least squares equation by equation.

Tables 3-5 report results for the CAD, AUD and NZD currency pairs. Wald test statistics under the null that each variable and its lags are jointly zero are presented along with p-values instead of individual coefficients estimates. The R^2 from each equation are presented at the bottom of each table. Under the null of no heat waves, the diagonal test statistics in the table will not be significant. The off-diagonal elements are associated with the null of no meteor showers. In the CAD, these is evidence of both intra- and inter-regional persistence. For example, there is strong evidence of heat-waves in Asia. There is also strong evidence of persistence in volatility from one region to the next region that subsequently opens, such as from the Europe/N. America region to N. America. Similar evidence is found for the NZD market. In the AUD market there is extensive evidence of both types of persistence across all regions.

In general, these results suggest that, like other foreign exchange markets, the CAD, AUD and NZD markets are characterized by intra- and inter-regional volatility. To control for these effects, the paper now examines which macroeconomic news releases may be the catalyst. Once any relevant news is isolated, this information can be used as control variables in the analysis of the informational content of order flow.

In this section of the paper, five minute quote data is employed. The dates of all scheduled macroeconomic news releases in Canada, Australia, New Zealand, and the U.S. are obtained from Bloomberg. In order to determine which news is relevant to each foreign exchange market, the paper determines which type of announcements have the largest impact on exchange rate returns. The following regression is estimated

$$V_{it} = \alpha_0 + \sum_{t=1}^{23} \alpha_t D_t + \sum_{m=1}^{M} \beta_m D_{mit} + e_t$$

where V_{it} is exchange rate volatility defined as the absolute return on day i in the 5-minute interval t, D_t is a dummy variable used to control for the intraday seasonality in volatility, D_{mit} is a dummy variable that is equal to one if announcement m is made on day i at the beginning of interval t. Table 6 lists the macroeconomic announcements that have a statistically significant impact on returns for each currency. In terms of U.S. news, the results are similar to the results of Ederington and Lee (1993) and Fleming and Remolona (1997). In the empirical analysis regarding price discovery, exogenous dummies will be included to control for relevant macroeconomic news releases.

5. Empirical Methodology

This section illustrates an approach widely employed in the literature to determine the informational content of trades on asset prices.[12] The methodology has been widely utilized across all financial markets to examine the joint behaviour of trades or orders and the return on financial assets.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 trades and exchange rates returns interact. Specifically, the impact of various types of trades (characterized by the location in which a trade is initiated) cannot be determined from a single regression of returns on the trade variables since all variables are endogenous. It is impractical to model all features of the FX market jointly. In particular, causality between variables may occur in many and multiple 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.

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 (usually through the back office).

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 endogenous effects. Two different statistics are examined with the estimated VAR: an impulse

[12] Numerous studies have already examined the dynamics of trades and stock prices such as Hasbrouck, (1988, 1991a,b 1993)).

response function is used to determine the permanent price impact of each trade variable, while a variance decomposition is employed to determine the relative importance of these trade 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. Statistically, the extent of asymmetric information in trades can be measured by the explanatory power of each trade variable in accounting for exchange rate variations. 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. Thus, while a linear regression might give some insight into the expected exchange rate return conditional on a given pattern in trade flows, it will not support inferences about the implied effect of a particular trade.

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:

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

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 exchange rate return over the 5-minute interval. Estimates of VAR coefficients and associated variance-covariance matrices can be obtained from least-squares estimation.[13] Exogenous variables are included in the estimation of the VAR reflecting market liquidity and persistence in volatility across periods. The number of trades executed in the market in the past 30-minutes is one measure of market liquidity. Payne (2003) finds the information content of orderflow to be related to the supply of liquidity in the market. Lagged volatility in each region and in the previously open region are two other exogenous variables constructed with the realized vaolatility measures discused in Section 4.

VARs are sensitive to lag length, or p in equation (2) above. The Schwartz Information Criterion defined as

$$SIC = \ln \left| \widehat{\Sigma} \right| + \frac{k \times \ln T}{T} \tag{3}$$

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 (3).

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 (2).

The vector moving average representation (VMA) provides the elements needed to calculate the impulse response function. Since most of 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

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

[13]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.[14] 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 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 :

$$\sigma_w^2 = var\left(E\left[r_t + r_{t+1} + ...|v_t\right]\right) = \Psi_{\infty,r}\Omega\Psi'_{\infty,r}.^{15} \tag{4}$$

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 (4) will typically involve terms reflecting the contemporaneous interaction of the disturbances. It is

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

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 trade 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 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.

6. Results

This section presents the results of a number of estimated vector autoregression (VAR) models in terms of summary measures of trading informativeness. VARs are estimated over a number of subperiods within the trading day. Table 9 presents a number of statistics 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. In the columns headed “Sum of Coefficients", p-values of an F-test under the null that all coefficients for each trade variable in the exchange rate returns equation are zero are presented. In general, if a country is open during the regional time zone examined, then trades in that country have an affect on, or Granger cause, exchange rate returns.

Tables 10 to 15 present results of 6 different VARs. The coefficients are not reported. It is more useful to consider the long-run accumulated impulse response of trades on exchange rate returns, the variance decomposition of returns at forecast horizons of 1-period and 20-periods (or 5-minutes and 100 minutes, respectively). This information is reported for each type of trade, in each region, in each table. Since there are extremely few Canadian-based trades during Asia and Asia/Europe hours, and extremely few New Zealand-based trades during Europe, Europe/N.America and N. America hours in any VAR specification there are only 5 trade variables.

Tables 10 and 13 analyze the CAD market, Tables 11 and 14 analyze the AUD market, and Tables 12 and 15 analyze the NZD markets. Tables 10 to 12 consider as order flow, the number of buyer initiated trades less the number of seller initiated trades, across the 6 locations and 5 regional time zones. Tables 13 to 15 consider as order flow, the volume of buyer initiated trades less the volume of seller initiated trades, across the 6 locations and 5 regional time zones. The results are similar whether order flow is defined in numbers of trades or volume of trades. For brevity, the discussion below will only focus on order flow defined in terms of trades, or Tables 10, 11 and 12.

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 the VAR will 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. Units are in terms of percentages or basis points (e.g., 0.10 represents a 0.10 % long-run change in the exchange rate). There are a number of aspects that should be noted in these tables. First, lows and highs across all exchange rate pairs are very similar suggesting that trades are close to uncorrelated across regions, and more importantly, the ordering of the VAR is not a major issue that needs to be dealt with in the specification of the model. The sampling of trade and exchange rate returns data at 5-minute intervals may have had this beneficial effect. Second, results are similar whether order flow is defined over trades or volumes. This result may arise since trades are usually executed in conventional amounts on the electronic brokering screen thus there may be no difference between in the information contained in trades or volumes.

The impulse response results of Tables 10, 11 and 12 can be summarized as follows. The largest impact on the CAD exchange rate occurs from Canadian , U.K, and U.S. trades. The size of the impact is similar in these countries during their normal business hours. Trade impacts of Australian, Japanese and New Zealand trades are significantly smaller, even during Asian hours. In terms of the AUD market, results are similar, except that Australian trades have a significantly larger impact on the exchange rate than U.S. and U.K. trades. Interestingly, Australian trades have a large long-run exchange rate impact across all time zones. In the NZD, New Zealand trades have a large impact on exchange rate during Asia hours. Overall, these results suggest that there is some home country bias in terms of the magnitude of the effect of a trade on the exchange rate if that country's currency is one part of the currency pair. The exception is the U.K. where trades have a large impact on all FX markets during Europe hours. In fact, the exchange rate impact of a U.K. trade in Europe, is approximately two times that of a Japan trade in Asia in any one of the markets.

Trading still exists in each location even when their normal business operations in that region have closed. Importantly, with the exception of Australian trades in the AUD market, the exchange rate impact of a trade occurring outside normal business hours is significantly smaller. Overall, across all three currencies pairs, U.S. and U.K. trades have a consistently large impact during their regional business hours.

There are two parts to the variance decomposition results. Tables indicate both the fraction of the 1-period and 20-period variance of the forecast of exchange rate returns explained by each type of trade. In general, this fraction is significantly lower at the shorter horizon than at the longer horizon suggesting that the existence of large transitory effects arising from trades in the short run. Most of the variance decomposition results associated with the 20-period forecast horizon mirror that of the impulse response functions. This is comforting since the two measures attempt to capture similar aspects. In general, the tables provide evidence that the informational content of trades is strongly related to the time of day, and in particular, which financial centers are operating. Interestingly, results suggest that, independent of the ordering chose for the VAR, during North American hours, Canadian trades are more informative than U.S. trades.

In general, we find that both in terms of the exchange rate impact of trades and the explained variability of exchange rate returns, for the CAD, trades in Canada, the U.S. and the U.K. are important. For the AUD, trades in Australia, the U.S. and the U.K. are important. Last, for the NZD, trades in New Zealand, the U.S. and the U.K. are important. In general, traders in the U.S. and U.K. are informative about all three currency pairs during their regular business hours. When the U.S. and U.K markets are closed then trades in other regions are more informative.

In particular, since traders have access to similar news feed around the world in real time, there should be no reason to suspect that trades in one location are associated with a different level of information. One other explanation is that traders in a location that trade when their region is closed for business, may not be as sophisticated as those that have regular business hours. Trades during non-business hours may not be related to fundamentals, and may be associated with liquidity/noise trades.

7. Summary, Conclusion and Future Work

The trading dataset utilized in this paper is unique. Trade information includes the location where each market order is initiated. The availablility of this data may address a number of important questions that have until now been left unanswered. For example, who discovers prices in the CAD market, dealers in New York or those in Toronto? This paper extends the analysis of Payne (2003) and addresses how price discovery depends on where the trade is initiated (e.g., a dealers in the U.K., the U.S., or one of four other FX trading centers). While the FX market operates 24-hours a day in theory, traders and dealers in each region have regular business hours.

It is natural to hypothesize that trades initiated in Australia in the AUD market will be more informative that trades initiated in the U.K. In particular, one could argue that Australia dealers or traders have better information about the fundamentals of the Australia economy, and as a result, more precise information about the direction of the AUD exchange rate. The results of the paper, suggest that this is not always the case, and that during European/Asian overlapping hours, the informativeness of U.K. trades are superior to those of Australians. During overlapping hours where one regions is closing for the day, and another region is just opening. Overall, the results of the paper suggest that location matters, and that trades are heterogenous across regions.

Future work will examine in greater depth the price dynamics associated with trades occuring during overlapping periods. Anodotial 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[16]

CAD/USD	returns	volatility	spreads	gross volume	gross trades	average size
mean	0.0135	0.1761	0.0008	2014.66	981.71	2.04
median	0.0227	0.1605	0.0009	1985.00	974.00	2.02
std	0.3603	0.0776	0.0001	709.16	323.19	0.15
skewness	0.0010	1.8738	-0.4435	0.70	0.86	0.34
kurtosis	2.7086	8.6166	1.5970	4.01	5.18	2.95
qstat2	6.0448	46.0759	577.0815	22.18	29.64	43.22
USD/AUD	returns	volatility	spreads	gross volume	gross trades	average size
mean	0.0141	0.7844	0.0005	7092.93	4137.11	1.71
median	0.0000	0.6840	0.0005	6960.00	4131.00	1.69
std	0.7064	0.4341	0.0000	2520.72	1374.96	0.11
skewness	0.6297	3.2553	0.0045	0.40	0.31	0.60
kurtosis	5.5294	23.9850	1.3782	3.60	4.04	3.44
qstat2	1.2668	96.6039	625.7386	30.90	30.76	104.12
USD/NZD	returns	volatility	spreads	gross volume	gross trades	average size
mean	0.0455	1.7653	0.0007	968.92	631.68	1.52
median	0.0356	1.5669	0.0007	920.50	603.00	1.51
std	0.7572	0.9645	0.0001	376.30	220.87	0.12
skewness	0.1722	1.1670	-0.4408	0.72	0.59	0.52
kurtosis	3.4280	4.2212	8.4931	4.03	4.10	4.04
qstat2	3.8253	87.8480	353.2757	16.73	21.53	3.24

Table 2: Summary Statistics of Trading Volume Across Locations[17]

CAD/USD	Australia	Canada	Japan	New Zealand	U.K.	U.S.
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	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
qstat2	15.77	14.57	12.73	3.94	59.88	14.16
USD/AUD						
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	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
qstat2	21.87	17.97	90.84	71.80	20.40	8.17
USD/NZD						
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	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
qstat2	6.26	40.21	9.44	68.25	9.00	26.35

[16] 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. Volatility is realized volatility calculated as the sum of the intraday 5-minute squared returns. Spreads are the difference between offer and bid quotes. 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 for autocorrelation. The last statistic is distributed $\chi(5)$ with asymptotic 5% and 1% critical values of 11.07 and 15.09.

[17] 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 for autocorrelation.

Tables 3: Volatility Spillovers in the CAD Market[18]

CAD	Asia	Asia/Europe	Europe	Europe/America	America
Asia	122.89	27.17	9.12	8.39	0.69
	(0.00)	(0.00)	(0.02)	(0.03)	(0.87)
Asia/Europe	4.87	2.64	37.48	2.26	6.95
	(0.18)	(0.45)	(0.00)	(0.52)	(0.07)
Europe	1.31	3.52	5.46	34.70	6.48
	(0.72)	(0.32)	(0.14)	(0.00)	(0.09)
Europe/America	6.30	0.71	8.34	12.39	74.57
	(0.09)	(0.87)	(0.04)	(0.00)	(0.00)
America	2.99	13.23	0.63	33.01	6.49
	(0.39)	(0.00)	(0.89)	(0.00)	(0.09)
Adjusted R^2	0.26	0.14	0.21	0.30	0.31

Tables 4: Volatility Spillovers in the AUD Market

AUD	Asia	Asia/Europe	Europe	Europe/America	America
Asia	9.70	27.74	6.92	11.73	20.53
	(0.02)	(0.00)	(0.07)	(0.01)	(0.00)
Asia/Europe	6.96	0.48	19.20	4.76	2.23
	(0.07)	(0.92)	(0.00)	(0.19)	(0.52)
Europe	7.84	14.63	9.14	24.73	1.09
	(0.05)	(0.00)	(0.02)	(0.00)	(0.78)
Europe/America	9.15	16.74	20.89	11.15	22.09
	(0.03)	(0.00)	(0.00)	(0.01)	(0.00)
America	17.06	2.54	1.12	22.20	14.25
	(0.00)	(0.46)	(0.77)	(0.00)	(0.00)
Adjusted R^2	0.25	0.24	0.31	0.37	0.24

[18] Tables 3-4 presents results from SUR regressions with realized volatility across regional time zones. Wald test statistics and their associated p-values under the null that each block of coefficients, representing lagged terms in each region, are jointly zero. Dependent variables are in columns and independent variables are in rows. Wald test statistics have a null of either no intraregional or interregional volatility persistence. For each equation, R^2 statistics are also reported at the bottom of each table.

Table 9: Specification of VAR, Granger Causality tests[19]

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

[19] Table 9 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 all the coefficients on trades in each location are zero.

Table 10: Summary of VAR results for trades in the CAD market[20]

CAD/USD	Location of Trades:	Australia		Canada		Japan	
		Low	High	Low	High	Low	High
Accumulated Returns	Asia Hours	0.439	0.483			0.355	0.400
Impulse Response Function	Asia / Europe Hours	0.275	0.359			0.321	0.413
	Europe Hours	0.152	0.242	-0.001	0.059	-0.168	-0.125
	Europe / N. America Hours	-0.048	-0.015	0.589	0.761	-0.016	0.019
	N. America Hours	0.050	0.081	0.658	0.737	-0.004	0.030
Variance Decomposition	Asia Hours	0.019	0.020			0.009	0.010
1-Step Ahead Forecast	Asia / Europe Hours	0.003	0.005			0.007	0.009
	Europe Hours	0.001	0.002	0.001	0.002	0.001	0.001
	Europe / N. America Hours	0.000	0.000	0.075	0.080	0.000	0.000
	N. America Hours	0.000	0.000	0.058	0.063	0.000	0.000
Variance Decomposition	Asia Hours	0.099	0.120			0.065	0.082
20-Step Ahead Forecast	Asia / Europe Hours	0.071	0.118			0.098	0.159
	Europe Hours	0.021	0.053	0.000	0.003	0.014	0.026
	Europe / N. America Hours	0.000	0.003	0.334	0.594	0.000	0.000
	N. America Hours	0.003	0.007	0.487	0.642	0.000	0.001

CAD/USD	Location of Trades:	New Zealand		United Kingdom		United States	
		Low	High	Low	High	Low	High
Accumulated Returns	Asia Hours	0.069	0.074	0.138	0.151	0.166	0.208
Impulse Response Function	Asia / Europe Hours	-0.095	-0.051	0.678	0.745	0.032	0.120
	Europe Hours			0.774	0.844	0.395	0.519
	Europe / N. America Hours			0.104	0.348	0.516	0.720
	N. America Hours			0.013	0.092	0.411	0.570
Variance Decomposition	Asia Hours	0.000	0.000	0.001	0.001	0.003	0.004
1-Step Ahead Forecast	Asia / Europe Hours	0.001	0.001	0.057	0.060	0.005	0.007
	Europe Hours			0.075	0.079	0.018	0.021
	Europe / N. America Hours			0.030	0.033	0.062	0.068
	N. America Hours			0.004	0.004	0.054	0.060
Variance Decomposition	Asia Hours	0.002	0.003	0.010	0.012	0.014	0.022
20-Step Ahead Forecast	Asia / Europe Hours	0.002	0.008	0.430	0.520	0.001	0.013
	Europe Hours			0.538	0.656	0.143	0.241
	Europe / N. America Hours			0.013	0.117	0.268	0.520
	N. America Hours			0.000	0.009	0.202	0.360

Table 11: Summary of VAR results for trades in the AUD market

USD/AUD	Location of Trades:	Australia		Canada		Japan	
		Low	High	Low	High	Low	High
Accumulated Returns	Asia Hours	1.240	1.285			0.300	0.511
Impulse Response Function	Asia / Europe Hours	0.701	0.902			0.275	0.470
	Europe Hours	0.511	0.769	0.111	0.230	0.013	0.109
	Europe / N. America Hours	0.359	0.619	-0.007	0.218	0.037	0.076
	N. America Hours	0.682	0.869	0.505	0.663	-0.062	-0.018
Variance Decomposition	Asia Hours	0.102	0.103			0.019	0.020
1-Step Ahead Forecast	Asia / Europe Hours	0.078	0.080			0.017	0.017
	Europe Hours	0.041	0.043	0.004	0.004	0.003	0.003
	Europe / N. America Hours	0.041	0.042	0.020	0.020	0.000	0.000
	N. America Hours	0.036	0.039	0.010	0.011	0.000	0.000
Variance Decomposition	Asia Hours	0.459	0.520			0.028	0.079
20-Step Ahead Forecast	Asia / Europe Hours	0.222	0.351			0.036	0.095
	Europe Hours	0.127	0.263	0.006	0.025	0.000	0.005
	Europe / N. America Hours	0.073	0.191	0.001	0.024	0.001	0.003
	N. America Hours	0.108	0.173	0.059	0.101	0.000	0.001

USD/AUD	Location of Trades:	New Zealand		United Kingdom		United States	
		Low	High	Low	High	Low	High
Accumulated Returns	Asia Hours	0.196	0.287	0.159	0.254	0.388	0.479
Impulse Response Function	Asia / Europe Hours	-0.107	0.013	0.961	1.100	0.165	0.273
	Europe Hours			1.110	1.192	0.178	0.249
	Europe / N. America Hours			0.774	0.985	0.684	0.926
	N. America Hours			0.440	0.570	1.026	1.186
Variance Decomposition	Asia Hours	0.003	0.003	0.003	0.004	0.005	0.005
1-Step Ahead Forecast	Asia / Europe Hours	0.007	0.007	0.114	0.115	0.002	0.002
	Europe Hours			0.135	0.137	0.005	0.005
	Europe / N. America Hours			0.112	0.114	0.096	0.098
	N. America Hours			0.009	0.010	0.076	0.079
Variance Decomposition	Asia Hours	0.011	0.025	0.008	0.019	0.045	0.070
20-Step Ahead Forecast	Asia / Europe Hours	0.000	0.005	0.402	0.538	0.012	0.032
	Europe Hours			0.549	0.689	0.014	0.030
	Europe / N. America Hours			0.315	0.521	0.253	0.445
	N. America Hours			0.045	0.075	0.245	0.328

[20] Tables 10-15 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 1- and 20-step-ahead forecast horizon.

Table 12: Summary of VAR results for trades in the NZD market

USD/NZD	Location of Trades:	Australia		Canada		Japan	
		Low	High	Low	High	Low	High
Accumulated Returns	Asia Hours	1.450	1.649			0.237	0.337
Impulse Response Function	Asia / Europe Hours	1.093	1.334			0.345	0.443
	Europe Hours	0.103	0.282	0.370	0.461	0.729	0.980
	Europe / N. America Hours	0.130	0.257	0.500	0.682	-0.285	-0.261
	N. America Hours	1.118	1.219	0.472	0.568	0.051	0.075
Variance Decomposition	Asia Hours	0.013	0.014			0.001	0.001
1-Step Ahead Forecast	Asia / Europe Hours	0.013	0.015			0.002	0.002
	Europe Hours	0.004	0.004	0.002	0.002	0.013	0.014
	Europe / N. America Hours	0.004	0.004	0.002	0.003	0.000	0.000
	N. America Hours	0.005	0.006	0.002	0.002	0.000	0.000
Variance Decomposition	Asia Hours	0.032	0.041			0.001	0.002
20-Step Ahead Forecast	Asia / Europe Hours	0.061	0.091			0.006	0.010
	Europe Hours	0.001	0.004	0.007	0.011	0.028	0.050
	Europe / N. America Hours	0.001	0.004	0.014	0.025	0.004	0.005
	N. America Hours	0.017	0.021	0.003	0.005	0.000	0.000

USD/NZD	Location of Trades:	New Zealand		United Kingdom		United States	
		Low	High	Low	High	Low	High
Accumulated Returns	Asia Hours	2.230	2.338	0.382	0.429	0.283	0.349
Impulse Response Function	Asia / Europe Hours	1.463	1.750	2.005	2.199	0.241	0.313
	Europe Hours			2.695	2.753	-0.018	0.050
	Europe / N. America Hours			2.169	2.379	1.711	1.968
	N. America Hours			0.918	1.050	2.318	2.389
Variance Decomposition	Asia Hours	0.027	0.028	0.000	0.000	0.000	0.000
1-Step Ahead Forecast	Asia / Europe Hours	0.026	0.029	0.042	0.044	0.000	0.000
	Europe Hours			0.069	0.070	0.002	0.002
	Europe / N. America Hours			0.056	0.059	0.034	0.036
	N. America Hours			0.003	0.003	0.017	0.017
Variance Decomposition	Asia Hours	0.075	0.083	0.002	0.003	0.001	0.002
20-Step Ahead Forecast	Asia / Europe Hours	0.111	0.157	0.204	0.247	0.003	0.005
	Europe Hours			0.376	0.393	0.000	0.000
	Europe / N. America Hours			0.260	0.312	0.162	0.212
	N. America Hours			0.012	0.015	0.075	0.079

Table 13: Summary of VAR results for volumes in the CAD market

CAD/USD	Location of Trade Volume:	Australia		Canada		Japan	
		Low	High	Low	High	Low	High
Accumulated Returns	Asia Hours	0.383	0.427			0.329	0.371
Impulse Response Function	Asia / Europe Hours	0.226	0.293			0.267	0.333
	Europe Hours	0.170	0.248	-0.030	0.044	-0.169	-0.115
	Europe / N. America Hours	-0.025	0.009	0.649	0.786	-0.051	-0.022
	N. America Hours	0.020	0.038	0.659	0.713	0.033	0.055
Variance Decomposition	Asia Hours	0.013	0.015			0.007	0.008
1-Step Ahead Forecast	Asia / Europe Hours	0.003	0.004			0.005	0.006
	Europe Hours	0.001	0.001	0.001	0.001	0.001	0.001
	Europe / N. America Hours	0.000	0.000	0.065	0.070	0.000	0.000
	N. America Hours	0.000	0.000	0.048	0.051	0.000	0.000
Variance Decomposition	Asia Hours	0.077	0.096			0.057	0.072
20-Step Ahead Forecast	Asia / Europe Hours	0.056	0.092			0.078	0.121
	Europe Hours	0.029	0.060	0.000	0.002	0.013	0.028
	Europe / N. America Hours	0.000	0.001	0.407	0.630	0.001	0.003
	N. America Hours	0.001	0.002	0.514	0.636	0.001	0.004

CAD/USD	Location of Trade Volume:	New Zealand		United Kingdom		United States	
		Low	High	Low	High	Low	High
Accumulated Returns	Asia Hours	0.089	0.104	0.112	0.125	0.138	0.171
Impulse Response Function	Asia / Europe Hours	-0.066	-0.027	0.602	0.657	0.011	0.093
	Europe Hours			0.689	0.767	0.393	0.494
	Europe / N. America Hours			0.081	0.271	0.530	0.708
	N. America Hours			0.042	0.099	0.363	0.496
Variance Decomposition	Asia Hours	0.000	0.000	0.001	0.001	0.002	0.003
1-Step Ahead Forecast	Asia / Europe Hours	0.001	0.001	0.039	0.041	0.002	0.003
	Europe Hours			0.055	0.059	0.011	0.014
	Europe / N. America Hours			0.018	0.020	0.044	0.049
	N. America Hours			0.002	0.003	0.036	0.041
Variance Decomposition	Asia Hours	0.004	0.006	0.007	0.008	0.010	0.015
20-Step Ahead Forecast	Asia / Europe Hours	0.001	0.005	0.398	0.467	0.000	0.009
	Europe Hours			0.469	0.579	0.153	0.238
	Europe / N. America Hours			0.007	0.071	0.282	0.495
	N. America Hours			0.002	0.012	0.164	0.291

Table 14: Summary of VAR results for volumes in the AUD market

USD/AUD	Location of Trade Volume:	Australia		Canada		Japan	
		Low	High	Low	High	Low	High
Accumulated Returns	Asia Hours	1.124	1.167			0.214	0.379
Impulse Response Function	Asia / Europe Hours	0.802	0.924			0.363	0.509
	Europe Hours	0.535	0.705	0.113	0.192	0.074	0.138
	Europe / N. America Hours	0.279	0.487	0.059	0.227	-0.005	0.018
	N. America Hours	0.695	0.830	0.480	0.609	-0.066	-0.032
Variance Decomposition	Asia Hours	0.082	0.083			0.015	0.016
1-Step Ahead Forecast	Asia / Europe Hours	0.062	0.063			0.014	0.014
	Europe Hours	0.031	0.032	0.003	0.003	0.003	0.003
	Europe / N. America Hours	0.033	0.035	0.016	0.017	0.000	0.000
	N. America Hours	0.027	0.028	0.007	0.008	0.000	0.000
Variance Decomposition	Asia Hours	0.398	0.441			0.015	0.045
20-Step Ahead Forecast	Asia / Europe Hours	0.308	0.407			0.066	0.123
	Europe Hours	0.147	0.246	0.006	0.019	0.003	0.010
	Europe / N. America Hours	0.046	0.127	0.003	0.028	0.000	0.000
	N. America Hours	0.116	0.165	0.055	0.089	0.000	0.001

USD/AUD	Location of Trade Volume:	New Zealand		United Kingdom		United States	
		Low	High	Low	High	Low	High
Accumulated Returns	Asia Hours	0.206	0.275	0.243	0.311	0.410	0.482
Impulse Response Function	Asia / Europe Hours	-0.119	-0.031	0.716	0.865	0.095	0.183
	Europe Hours			0.961	1.046	0.260	0.304
	Europe / N. America Hours			0.694	0.871	0.739	0.897
	N. America Hours			0.412	0.517	0.866	1.024
Variance Decomposition	Asia Hours	0.002	0.002	0.003	0.003	0.003	0.003
1-Step Ahead Forecast	Asia / Europe Hours	0.005	0.005	0.095	0.096	0.001	0.001
	Europe Hours			0.108	0.109	0.004	0.004
	Europe / N. America Hours			0.092	0.094	0.073	0.075
	N. America Hours			0.007	0.007	0.056	0.058
Variance Decomposition	Asia Hours	0.013	0.024	0.019	0.031	0.052	0.074
20-Step Ahead Forecast	Asia / Europe Hours	0.001	0.007	0.250	0.354	0.004	0.015
	Europe Hours			0.455	0.560	0.033	0.047
	Europe / N. America Hours			0.274	0.432	0.302	0.461
	N. America Hours			0.041	0.064	0.183	0.253

Table 15: Summary of VAR results for volumes in the NZD market

USD/NZD	Location of Trade Volume:	Australia		Canada		Japan	
		Low	High	Low	High	Low	High
Accumulated Returns	Asia Hours	1.237	1.438			0.180	0.276
Impulse Response Function	Asia / Europe Hours	1.200	1.395			0.310	0.355
	Europe Hours	-0.002	0.157	0.387	0.450	0.704	0.900
	Europe / N. America Hours	0.075	0.189	0.484	0.607	-0.278	-0.251
	N. America Hours	0.771	0.867	0.442	0.532	0.030	0.072
Variance Decomposition	Asia Hours	0.009	0.010			0.000	0.001
1-Step Ahead Forecast	Asia / Europe Hours	0.012	0.014			0.002	0.002
	Europe Hours	0.003	0.003	0.002	0.002	0.012	0.013
	Europe / N. America Hours	0.002	0.003	0.002	0.002	0.000	0.000
	N. America Hours	0.002	0.003	0.001	0.001	0.000	0.000
Variance Decomposition	Asia Hours	0.023	0.031			0.000	0.001
20-Step Ahead Forecast	Asia / Europe Hours	0.077	0.104			0.005	0.007
	Europe Hours	0.000	0.001	0.008	0.011	0.028	0.044
	Europe / N. America Hours	0.000	0.002	0.014	0.022	0.004	0.005
	N. America Hours	0.008	0.011	0.003	0.004	0.000	0.000

USD/NZD	Location of Trade Volume:	New Zealand		United Kingdom		United States	
		Low	High	Low	High	Low	High
Accumulated Returns	Asia Hours	2.140	2.228	0.385	0.431	0.316	0.405
Impulse Response Function	Asia / Europe Hours	1.236	1.490	1.792	1.957	0.152	0.202
	Europe Hours			2.370	2.428	-0.061	-0.019
	Europe / N. America Hours			1.849	2.028	1.550	1.745
	N. America Hours			0.701	0.825	2.078	2.128
Variance Decomposition	Asia Hours	0.020	0.021	0.000	0.000	0.000	0.000
1-Step Ahead Forecast	Asia / Europe Hours	0.021	0.024	0.030	0.032	0.000	0.000
	Europe Hours			0.053	0.054	0.003	0.003
	Europe / N. America Hours			0.041	0.043	0.025	0.027
	N. America Hours			0.001	0.002	0.012	0.012
Variance Decomposition	Asia Hours	0.070	0.076	0.002	0.003	0.001	0.002
20-Step Ahead Forecast	Asia / Europe Hours	0.083	0.118	0.169	0.204	0.001	0.002
	Europe Hours			0.308	0.323	0.000	0.000
	Europe / N. America Hours			0.203	0.243	0.142	0.179
	N. America Hours			0.007	0.010	0.061	0.064

Figure 1-3: Number of Trades by Country where Trade is Initiated, CAD, AUD, NZD

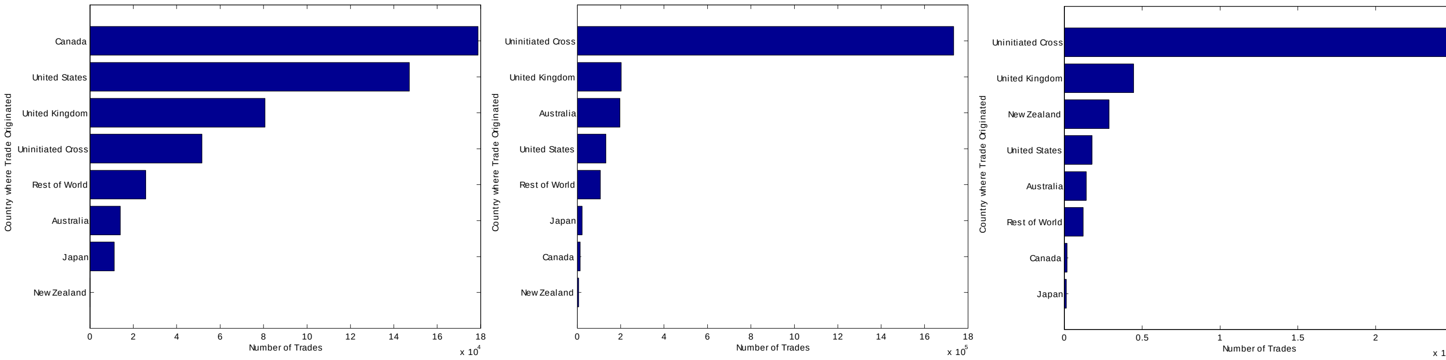

Figure 4 & 5: Hourly Statistics for CAD across 24-hour Clock (No DST & DST)

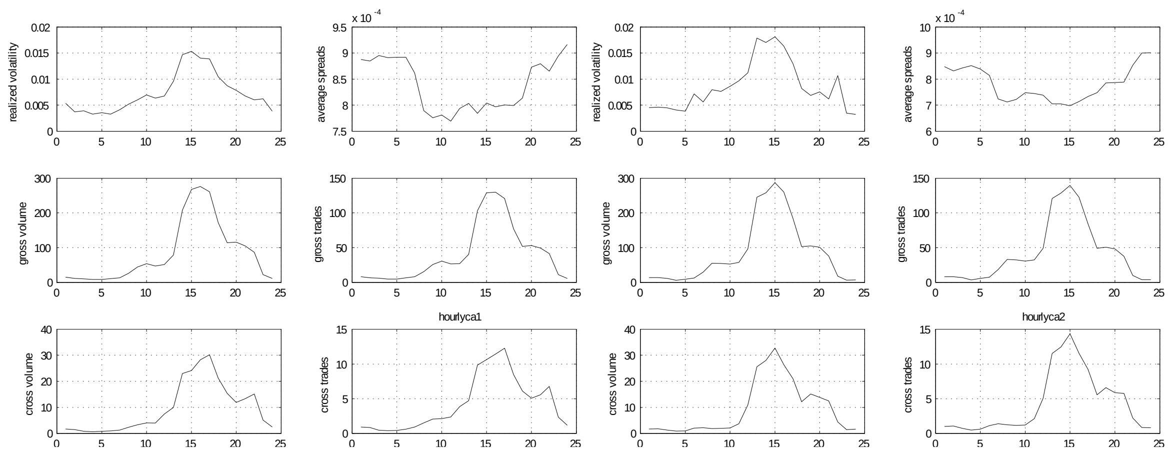

Figure 6 & 7: Hourly Statistics for AUD across 24-hour Clock (No DST & DST)

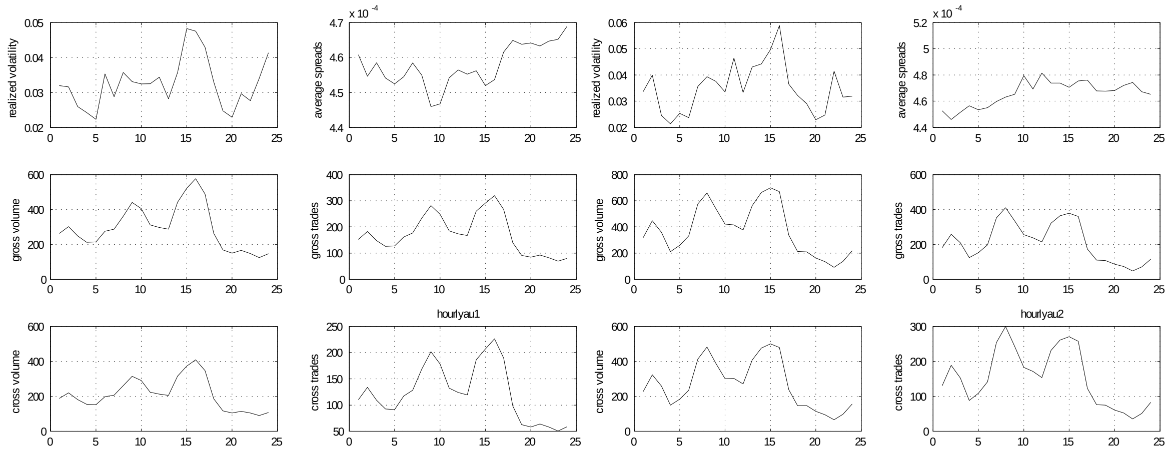

Figure 8 & 9: Hourly Statistics for NZD across 24-hour Clock (No DST & DST)