# Global price discovery in the Australian dollar market and its determinants

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**Abstract:** Using intraday trading data over the period of January 1999 to December 2013, this paper examines the price discovery of the Australian dollar (AUD) as well as its determinants. We employ a non-parametric Two-scale Realized Variance estimator (TSRV) to estimate the global information distribution of AUD. We find that the European market and particularly the overlapping trading hours of London and New York are the most important markets of price discovery in AUD. We also find that, despite the declining market share of the daily transactions, Asia is rapidly gaining in terms of the information share. In order to examine the determinants of the information shares, we include macroeconomic news as well as order flow measures to market state variables. We find that more favorable market states and more unexpected order flows on macroeconomic announcement days make a significant contribution to the AUD price discovery. Our results also confirm that a higher level of market integration and international consolidation contribute to the price discovery process in the long-run.

**Keywords:** price discovery, foreign exchange market, intraday, information share, macroeconomic news

**JEL classification:** G14, G13

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## 1. Introduction

In recent years, the Australian Dollar (AUD) has started to play an increasingly important role in the global foreign exchange (FX) market. According to the Bank for International Settlements (BIS), the share of AUD in the global foreign exchange (FX) trading has steadily increased. By 2013, AUD has become the 5$^{th}$ most important currency in terms of the turnover. The increase in trading of AUD could be attributed to higher level of internationalization of the Australian economy (Edison, Cashin and Liang, 2003; Debelle, Gyntelberg and Plumb, 2006; Battellino and Plumb, 2011), as well as the growth in Australia's international trade (especially the growth in demand for Australia's natural resources in emerging economies, such as China).

This paper focuses on global price discovery in AUD market and the determinants of the dynamic information shares of AUD trading. More specifically, using the intraday price quotes of AUD against the US Dollar (USD), over the period of 1999 - 2013, we estimate the magnitudes of the information shares of the major global FX markets. We then attempt to identify the determinants of the estimated information shares at different time horizons (i.e. daily and weekly).

The issue of price discovery in financial markets is receiving more attention in recent decades due to rapid globalization and concentration of exchanges. For example, using Helsinki Stock Exchange as an example, Booth *et al*. (2002) examined the role of upstairs and downstairs markets in price discovery. Huang (2002) examined the impact of the market makers and Electronic Crossing Networks (ECNs) on price discovery of NASDAQ stocks. Hasbrouck (2003) analyzed the importance of different trading venues for the price discovery of the US equity indices.[1] Wang and Yang (2011) proposed a structural vector autoregressive (SVAR) model and a non-parametric approach to measure the global information distribution in the FX market and concluded that (i) the information share of the four sequential markets considered in the global FX trading was dominated by Europe and the US and (ii) Asia was losing the information shares in AUD trading. Chai, Lee and Wang (2015) estimated the

[1] Similar studies include Mizrach and Neely (2008) and Fricke and Menkhoff (2011).

information distribution in the over-the-counter (OTC) gold market over the 1996-2012 period, which shared a number of characteristics with the foreign exchange market. They concluded that information on the gold price is concentrated in the London-New York overlapping trading hours.

Some existing studies have considered the determinants of the information share of different markets. Within the context of Euro bond futures market, Fricke and Menkhoff (2011) found that (i) the order flow plays a dominant role in the price discovery process and (ii) the order flow and information share of contracts are positively correlated. Mizrach and Neely (2008) showed that an increase in the spread of the US bond futures contracts increases the price of the incorporated non-common knowledge, which hinders the market's price discovery role relative to the spot market. However, Patel et al. (2014) found that the US options market makes a fairly large (about one third) contribution to price discovery.

While a number of studies have considered the measures as well as the determinants of FX price discovery, some important issues are yet to be fully settled, especially in relation to AUD. This paper aims to fill this gap in the existing literature. While focusing on the information share of AUD, this paper makes some important contributions to the existing literature. First, we use a non-parametric approach to measure the global information distribution of the 24-hour AUD market, which provides an appropriate setting for a sequential-market framework. The widely-used methodology of Hasbrouck's (1995) information share measure relies on the implicit assumption that price differentials among markets are bounded by arbitrage opportunities and hence the prices of the traded assets are cointegrated. Such price differentials can only be observed in each market when these markets are open and studies are typically conducted for short periods, during which trading hours overlap (e.g., Grammig, et al., 2005; Pascual, et al., 2006). For the sequential markets, like the FX market, however, the prices in different markets are not necessarily cointegrated as the fundamental prices may change. In order to mitigate this drawback in Hasbrouck's (1995) information share approach, we utilize a non-parametric Two-scale Realized Variance (TSRV) approach. This approach not only yields a relatively more appropriate measure that can be easily applied to sequential markets but also mitigates the effect of contemporaneous correlations as documented by Hasbrouck. Furthermore, tick-by-tick data used in this study allows us to fully exploit the information and detect information-induced volatility jumps (Erdemlioglu et al., 2012). Using data from January 1996 to December 2003, Wang and Yang (2011) used the same approach to measure the price discovery of four currencies including AUD. However, the share of AUD in the global FX market increased significantly after 2000 (which could be attributed to Australia's closer economic ties with some Asian economies) and hence a re-examination of the case of AUD, using a longer time series that includes the post 2000 period, is highly desirable.[2]

Second, this paper attempts to identify the determinants of the information share of AUD on a daily basis. The conventional macroeconomic models assume that information can be reflected by exchange rates directly. However recent empirical studies on FX microstructure (e.g., Love and Payne, 2008; Evans and Lyons, 2002a, 2002b, 2008) emphasize the role of order flow. In this paper, we argue that order flow is a crucial channel through which heterogeneous information is transmitted into the price. While taking order flows into account, we link the information shares with macroeconomic news. Furthermore, we decompose the order flows into expected and unexpected components and separately examine their impacts.

Third, in this paper, we rely on a much broader set of macroeconomic news from both the U.S. and Australia. In the previous studies, the most commonly used proxies of macroeconomic news are scheduled announcements on Gross Domestic Product (GDP), unemployment, interest rates, durable goods orders, and trade balance. In this paper, we make use of Bloomberg News Service, which includes scheduled as well as unscheduled announcements. Our dataset shows that scheduled announcements account for less than 5 percent of the total macroeconomic news. The existing studies on AUD have mostly ignored unscheduled announcements that account for a very large proportion of macroeconomic

[2] The average daily transactions of AUD in the main markets over the sample period are reported in Appendix A.

news.[3]

The remainder of the paper is structured as follows. Section 2 contains the estimates of the information share of AUD. In Section 3, the determinants of AUD price discovery are discussed. The dataset and empirical strategy are discussed in Section 4. The empirical results are presented and discussed in Section 5. Policy implications along with the conclusion are presented in Section 6.

## 2. Global information share of AUD

### *2.1 Two-scale Realized Variance*

In this paper, the approach used to measure the information flow of AUD is based on the fast expanding literature on realized variance, where change in the efficient price (where demand equals supply) mirrors the price setting behavior of market participants, thereby reflecting the arrival of new information (Wang and Yang, 2011; Chai, et al., 2015). Accordingly, the variance of the efficient price process is a crucial factor in the theory and practice of asset valuation and risk management (Bandi and Russell, 2008). Following Wang and Yang (2011), we divide a trading day into *n* sequential markets. The log return in market *i* on day *t* over sampling interval *s* can be written as follows:

$$r_{i,t,s} = \Delta p_{i,t,s} + \Delta u_{i,t,s} \quad (2.1)$$

where $\Delta p_{i,t,s}$ is the change in the efficient price over the sampling interval, representing a permanent shift in the asset value, and $\Delta u_{i,t,s}$ captures intraday noise.

The information flow in market *i* is then defined as the variation of the efficient price and captured by the variance of $\Delta p_{i,t}$. Thus the information share of market *i* on day *t* can be written as follows:

[3] The unscheduled news includes all the headline news collected from approximately 150 bureaus of Reuters News Service around the world, which relates to macroeconomic fundamentals, market commentary, government intervention or policies, and/or positions taken by multinationals and large financial institutions. For a thorough introduction to the Reuters unscheduled news headlines, please refer to Daniel, Kim, and McKenzie (2014).

$$\mathrm{IS_i} = \frac{\mathrm{var}\left(\Delta \mathrm{p}_{\,i,t}\right)}{\sum_{j=1}^{n} \mathrm{var}\left(\Delta \mathrm{p}_{\,j,t}\right)} \tag{2.2}$$

Since the efficient price and the noise term components in Eq. (2.1) are not observable, the existing studies have proposed alternative approaches to reduce the impact of the noise term on the estimation of the integrated variance (e.g., see Ait-Sahalia, et al., 2005; Zhang, et al., 2005; Bandi and Russell, 2008; Barndorff-Nielsen, et al., 2008). The Two-scale Realized Variance (TSRV) estimator is a consistent estimator of the integrated variance. Barndorff-Nielsen et al. (2008) showed that TSRV estimator can be expressed as a non-parametric estimator, which is based on subsampling as follows:

$$\mathrm{TSRV_{i,t}} = \frac{1}{k}\sum_{j=1}^{k} \mathrm{RV_{i,t,j}} - \frac{[m_i - k + 1]}{m_i k}\mathrm{RV_{i,t}} \tag{2.3}$$

where $\mathrm{RV_{i,t}} = \sum_{s=1}^{m} r_{i,t,s}^{2}$ is the realized variance (RV) for market *i* on day *t*, i.e., the sum of squared log returns over the intervals; and $m_i$ is the total number of sampling intervals for market *i*.

It is worth mentioning that TSRV estimator is in fact a linear combination of the standard RVs at two different frequencies – a highest frequency possible and a low frequency. In our study, we take 1-second and 5-minute sampling intervals as high and low frequencies, respectively. Since the RV consistently estimates the noise variance as sampling frequency approaches infinity, the RV sampled at the high frequency is a good approximation of the noise variance. At the low frequency, some feasible RVs may be computed (e.g., with 1-second return series, we can construct 5-minute RVs based on sub-sampling). The estimation error of the average of these RVs at the low frequency depends on the noise variance. Thus the linear combination of the average of the low-frequency RVs and the high-frequency RV, which serves to correct the impact of the noise term, generates a consistent estimator of the integrated variance (Barndorff-Nielsen et al., 2005). Using a Two-scale estimator as a proxy for information flow, the information share can then be measured as:

$$\mathrm{IS_{i,t}} = \frac{\mathrm{TSRV_{i,t}}}{\sum_{j=1}^{n} \mathrm{TSRV_{i,t,j}}} \tag{2.4}$$

where $\mathrm{TSRV_{i,t}}$ is the two-scale estimator for market *i* on day *t*.

Ait-Sahalia, et al. (2005) argue that the recent studies that rely on high frequency returns and use ad hoc rules for sampling, are sampling substantially more often than would be optimal. Following Andersen, et al. (2005), we aggregate the tick-by-tick data into 5-minute interval data. The 5-minute aggregation is based on a few considerations: first, the sampling frequency should be high enough to make use of the full information in estimating the realized variance; and second, the sampling frequency should be low enough to have sufficient transactions and avoid biasing the auto-correlations towards zero due to a large number of consecutive zero returns (Wang and Yang, 2011).

### *2.2 Estimated global information shares in AUD*

The trading data of AUD are collected from Thomson Reuters Tick History (TRTH) supplied by the Securities Industry Research Centre of Asia-Pacific (SIRCA). The intraday data for the AUD against the USD spans from 4 January 1999 to 31 December 2013. Trading data include the time a new quote/trade is issued to the nearest millisecond, the prices of bid and ask quotes, and the trade price. We also collect indicative quotes with the identification of the names and locations of quoting banks from TRTH for further analysis.

In general, the trading hours span from 9 am to 4 pm local time. However, it should be noted that due to Daylight Saving Time (DST) practice, the opening and closing times of the local markets shift forward by one hour when DST is implemented. A 24-hour calendar day is divided into four markets according to trading periods: Asian market, which is defined as the period when major financial centers in Asia-Pacific operate (i.e. Sydney, Japan, Hong Kong SAR, and Singapore) are open; European market, which covers most of the trading hours in Zurich, Frankfurt, Amsterdam, Paris, and London; the overlapping hours of London afternoon trading and New York early morning trading (also known as the “NYLON” market); and the one covers trading hours in the U.S. excluding the “NYLON” period, which is called the North American market. Table 1 shows the local trading times relative to Greenwich Mean Time (GMT) after adjusting for the DST.

Table 1: Local trading time relative to GMT

| Time Zone | Asia | Europe | London/New York (NYLON) | North America |
|---|---|---|---|---|
| DST | 23:00 GMT to 7:00 GMT (+1 day) | 7:00 GMT to 13:00 GMT | 13:00 GMT to 15:00 GMT | 15:00 GMT to 23:00 GMT |
| Non-DST | 22:00 GMT to 6:00 GMT (+1 day) | 6:00 GMT to 12:00 GMT | 12:00 GMT to 14:00 GMT | 14:00 GMT to 22:00 GMT |

Note: The market hours are inclusive, e.g., Asia starts at 23:00:00 GMT on day *t - 1* and ends at 6:59:59 GMT on day *t* during Daylight Saving Time (DST) and starts at 22:00:00 GMT on day *t - 1* and ends at 5:59:59 GMT on day *t* during non-DST periods respectively.

We drop outlier observations by applying the following filtering rules as suggested by Barndorff-Nielsen et al. (2009): the ones with a bid, ask or trade price equal to zero; the ones for which the quoted bid-ask spread (i.e. the bid-ask spread divided by midpoint of the bid and ask prices) is either in excess of 25% or negative; the ones for which the mid-quote (i.e. the average of the bid and ask prices) deviated by more than 10 times the mean absolute deviations from a rolling centered median of 50 observations (25 observations before and 25 after); and the ones with prices that are either above the "ask" plus the bid-ask or below the "bid" minus the bid-ask spread. The summary statistics of open-to-close returns are reported in Table 2 panel A. As showed in Table 2 panel A, AUD/USD exchange rate has the highest volatility in the Asian market and the lowest volatility in "NYLON" market. The returns in the four markets have the same direction of skewness, i.e. all the returns are left-skewed. The Ljung-Box statistics show that the returns have strong autocorrelations at 12 lags in the Asian and North American markets, while no autocorrelation in "NYLON" market. Returns in the European market are positively correlated with returns in the Asian and North American markets and negatively correlated with returns in "NYLON" market.

Intraday returns at high frequency (i.e., 1-second) and low frequency (i.e., 5-minute) intervals are computed in order to calculate the TSRV as discussed in Section 2.1. As a first step, we construct the mid-quotes as the average of bid and ask quotes at the end of each sampling interval or the bid and ask quotes immediately before the end of an interval.[4] The intraday return $r_{i,t}$ is then calculated as 100 times the log ratio of the mid-quotes at times *t* and *t-1*, that is:

$$r_{i,t} = 100 * \ln\left(p_{i,t}/p_{i,t-1}\right) \tag{2.5}$$

Table 2 Panel B reports the summary statistics of the information shares measured by the ratio of TSRV in market *i* to the daily TSRV on a specific day. In the four markets, Europe has the largest average information share, followed by North America, Asia, and "NYLON". Besides, the information share in Asia has not only the largest standard deviation but also the strongest autocorrelation at lag 12.

Table 2: Summary statistics of open-to-close returns and information shares

| | Asia | Europe | London/New York | North America |
|---|---|---|---|---|
| **Panel A** | | | | |
| n | 3841 | 3841 | 3841 | 3841 |
| Mean | 0.001 | 0.006 | -0.006 | 0.008 |
| Std. Dev. | 0.457 | 0.457 | 0.319 | 0.424 |

[4] An alternative approach is to use the linear interpolation of the midpoint of the bid and ask quotes immediately before and after the end of the interval. One drawback of the linear interpolation is that when the sampling interval goes to zero, the return and the realized variance reduce to zero (Hanson and Lunde, 2006).

| | | | | |
|---|---|---|---|---|
| Skewness | -0.349 | -0.329 | -1.310 | -0.078 |
| Kurtosis | 9.252 | 6.173 | 14.667 | 17.597 |
| $Q_{LB}(12)$ | 50.16* | 20.82 | 31.38* | 57.64* |
| Correlation | | | | |
| Europe | 0.043* | | | |
| NYLON | -0.028 | -0.046* | | |
| North America | 0.049* | 0.036* | -0.007 | |
| **Panel B** | | | | |
| n | 3841 | 3841 | 3841 | 3841 |
| Mean | 0.2685 | 0.3315 | 0.1407 | 0.2593 |
| Std. Dev. | 0.1359 | 0.1109 | 0.0740 | 0.1193 |
| Skewness | 1.1842 | 0.3336 | 1.2706 | 1.4164 |
| Kurtosis | 1.8573 | 0.6047 | 2.9674 | 3.3534 |
| $Q_{LB}(12)$ | 446.23* | 315.92* | 211.53* | 113.25* |
| Correlation | | | | |
| Europe | -0.4473* | | | |
| NYLON | -0.4147* | -0.0122 | | |
| North America | -0.4665* | -0.4128* | -0.1362* | |

Note: The definitions of the four sequential markets, namely, "Asia", "Europe", "NYLON" (London/New York), and "North America", are as given in Table 1. Open-to-close returns are defined as $100 * \ln(midquote_{close}/midquote_{open})$. Information shares are calculated as in Section 2.1. $Q_{LB}(12)$ is the Ljung-Box statistics for 12 lags. The asterisk * indicates significance at the 5% level.

Table 3 reports the yearly average information share of the four markets. It is interesting to note that if the 24 hours are divided into three 8-hour time zones, then the European market, which includes the Europe and "NYLON" market, dominates price discovery in AUD trading. The combined information share of Europe and "NYLON" ranges from 40.0% to 54.0%, of which "NYLON" market (i.e. the two-hour overlapping trading hours) accounts for a significant portion of price discovery in most years. Furthermore, although we find a high and dominating share of the European market (see Appendix A), the information share of Asia has been increasing steadily since 2003, even with its declining market share of the daily transactions as shown in Appendix A. Finally, Table 3 shows that a market's large share may not be associated with a high information share. For example, Europe accounted for 51.2% of the global AUD trading in 2013, but only a 31.2% share of information flow.

Table 3: Sub-period information share

| | *N* | Asia | Europe | London/ NYC | North America |
|---|---|---|---|---|---|
| 1999 | 256 | 0.296 | 0.300 | 0.111 | 0.292 |
| 2000 | 256 | 0.316 | 0.277 | 0.122 | 0.286 |
| 2001 | 257 | 0.259 | 0.349 | 0.130 | 0.261 |
| 2002 | 250 | 0.268 | 0.343 | 0.125 | 0.264 |

| | | | | | |
|---|---|---|---|---|---|
| 2003 | 253 | 0.210 | 0.355 | 0.163 | 0.271 |
| Average[1999-2003] | | 0.270 | 0.325 | 0.130 | 0.275 |
| 2004 | 256 | 0.207 | 0.369 | 0.173 | 0.251 |
| 2005 | 258 | 0.238 | 0.358 | 0.159 | 0.245 |
| 2006 | 259 | 0.240 | 0.360 | 0.162 | 0.238 |
| 2007 | 257 | 0.286 | 0.349 | 0.129 | 0.235 |
| 2008 | 258 | 0.261 | 0.328 | 0.139 | 0.273 |
| Average[2004-2008] | | 0.247 | 0.353 | 0.152 | 0.248 |
| 2009 | 257 | 0.249 | 0.323 | 0.153 | 0.275 |
| 2010 | 258 | 0.275 | 0.317 | 0.144 | 0.264 |
| 2011 | 260 | 0.282 | 0.323 | 0.143 | 0.252 |
| 2012 | 258 | 0.303 | 0.315 | 0.135 | 0.246 |
| 2013 | 256 | 0.336 | 0.306 | 0.121 | 0.238 |
| Average[2009-2013] | | 0.289 | 0.317 | 0.139 | 0.255 |
| Average[1999-2013] | | 0.268 | 0.332 | 0.141 | 0.259 |

Note: This table reports the annual average estimates of the information shares calculated at 5-minute sampling intervals using the Two-scale Realized Variance (TSRV) approach. *N* is the number of observations in each year.

We have to bear in mind that the total trading hours vary in the four markets. A market may have a high information share simply because of its long trading hours. As suggested by Wang and Yang (2011), an alternative comparison of information flow is based on the per-hour information shares as reported in Table 4. The results shown in Table 4 highlight the dominant role of the "NYLON" market in AUD trading. Europe has the second-highest information shares on a per-hour basis. Asia is ranked three in the price discovery of AUD trading since 2006, closely followed by the U.S. These results contradict Wang and Yang (2011), who argued that the US market contributes more to the price discovery of the Australian dollar as a result of its leading role in AUD future contracts traded on the Chicago Mercantile Exchange.[5] This could perhaps be explained by the sampling period. Wang and Yang (2011) used a sample that covers the January 1996 to December 2003 time period, which covers only a small proportion of the dataset used in our study. Besides, the evidence of current increasing information share in the Asian market is consistent with the perception of rising importance of the emerging markets in Asia, such as Shanghai, Jakarta, and Kuala Lumpur (Rime and Schrimpf, 2013) as well as increasing financial market integration in the Asia-Pacific (Devereux, et al., 2011). Furthermore, we do find a downward trend for the information share of the Asian market before 2003, which is consistent with Wang and Yang (20011).

[5] However, Chen and Gau (2010) and Evans (2002) argue that the spot rates provide more price discovery compared to CME futures rates because of the large trading volume and high liquidity of the FX spot market.

Table 4: Sub-period information share on a per-hour basis

| | *N* | Asia | Europe | London/ NYC | North America |
|---|---|---|---|---|---|
| 1999 | 256 | 0.037 | 0.037 | 0.060 | 0.040 |
| 2000 | 256 | 0.039 | 0.041 | 0.055 | 0.036 |
| 2001 | 257 | 0.032 | 0.043 | 0.070 | 0.033 |
| 2002 | 250 | 0.033 | 0.042 | 0.069 | 0.033 |
| 2003 | 253 | 0.026 | 0.054 | 0.071 | 0.034 |
| Average$^{1999\text{-}2003}$ | | 0.034 | 0.043 | 0.065 | 0.036 |
| 2004 | 256 | 0.026 | 0.058 | 0.074 | 0.031 |
| 2005 | 258 | 0.030 | 0.053 | 0.072 | 0.031 |
| 2006 | 259 | 0.030 | 0.054 | 0.072 | 0.030 |
| 2007 | 257 | 0.036 | 0.043 | 0.070 | 0.029 |
| 2008 | 258 | 0.033 | 0.046 | 0.066 | 0.034 |
| Average$^{2004\text{-}2008}$ | | 0.031 | 0.051 | 0.071 | 0.031 |
| 2009 | 257 | 0.031 | 0.051 | 0.065 | 0.034 |
| 2010 | 258 | 0.034 | 0.048 | 0.063 | 0.033 |
| 2011 | 260 | 0.035 | 0.048 | 0.065 | 0.032 |
| 2012 | 258 | 0.038 | 0.045 | 0.063 | 0.031 |
| 2013 | 256 | 0.042 | 0.040 | 0.061 | 0.030 |
| Average$^{2009\text{-}2013}$ | | 0.036 | 0.046 | 0.063 | 0.032 |
| Average$^{1999\text{-}2013}$ | | 0.034 | 0.047 | 0.066 | 0.032 |

Note: This table reports the annual average estimates of the information shares on a per hour basis using the Two-scale Realized Variance (TSRV) approach at 5-minute sampling intervals. *N* is the number of observations in each year.

## 3. Determinants of price discovery: Hypotheses formulation

Following the estimation of the information shares of AUD in different markets, based on the exiting literature, we now turn to the determinants of price discovery.

### *3.1 Market state-related variables*

The existing studies show that information shares vary considerably across financial markets and these shares are also subject to instability arising from different market states. The market states variables include ask-bid spread, trading volume, and volatility (see Brandt, et al., 2007; Mizrach and Neely, 2008), as well as the return. Analysis of the market state variables can help one to identify the unconditional information shares. Mizrach and Neely (2008), who were the first ones to systemically explore the role of market state variables, showed that ask-bid spread, traded contracts, and volatility can explain the price discovery shifts between the US Treasury spot and future markets. Fricke and Menkhoff (2011) also used market state variables to examine the level of competition in price discovery among Euro bond futures with different maturities. In this paper we use three market state variables,

(i) spread, (ii) volume, and (iii) volatility. Moreover, we also consider the correlation between the information shares of the market and the size of the returns (i.e., the information share of the market is high on high market return days and vice versa).

Based on Mizrach and Neely (2008), we expect that a high spread increases the price of incorporating the private information, which in turn impedes the price discovery process. However, Patel et al. (2014) found that high options price discovery shares are associated with wide options bid-ask spreads, which is consistent with the theory of adverse selection risks from informed traders (Kyle, 1985). In contrast, a higher share of trading volume indicates more information processing – or at least, facilitates informed trading – and thus increases the information share. Besides, higher returns may help attract more trading activity, especially the speculative trading, and thereby facilitating the information flow. Finally, the impact of volatility is ambiguous: volatility may be seen as an indicator of the noise in the market and hence volatility decreases the information share. However, volatility can also be seen as a sign of heterogeneously distributed information processing, which is expected to have a positive relationship with market information share (Fricke and Menkhoff, 2011). In overall terms, the evidence suggests that market state variables are important but their expected effect on market information shares is less obvious ex ante (e.g., see Fricke and Menkhoff, 2011). Based on this discussion, the following hypothesis can be formulated.

*Hypothesis 1: Market related variables, including ask-bid spread, trading volume, volatility and return, have significant impact on the information share of AUD.*

*3.2 Macroeconomic news announcements*

Among all the factors that influence price discovery, the impact of macroeconomic news announcements has received special attention. Moshirian et al. (2012) argued that public information is crucial for the efficient functioning of the capital market. The earliest studies of announcement effects on the foreign exchange market constrained their consideration to the level changes of exchange rate. However since 1990s, researchers have paid more attention to volatility. Engle et al. (1990) introduced the concepts of the heat waves and meteor showers effects to explore the links between intraday volatility pattern and macroeconomic news announcements in the foreign exchange market.[6] Andersen and Bollerslev (1998) conjectured that the intraday volatility patterns alter daily trading patterns and the real US announcements are helpful in explaining volatility movements in Deutsche Mark (DEM)/USD spot rate. Upper and Werner (2007) showed that more information is

[6]*Heat waves* refer to the idea that most important news that affects volatility and price discovery occurs during a particular market's trading hours and there is little price discovery when that market is closed. In contrast, *meteor showers* pertain to the idea that information flow spills over from market to market. For example, from the Asian to European to North American markets (Engle, *et al.*, 1990).

incorporated in the German bonds futures market and the contribution of the spot market to the common efficient price varies in the range 19-33%. Mizrach and Neely (2008) found that macroeconomic news announcements decrease the importance of the German bond spot prices compared to the futures market. Andersen et al. (2007) detected strong but short-lived news-effects on the 5-year bond futures contract in an international context. In the FX microstructure study, it is widely accepted that information arrival typically does increase volatility (Melvin and Yin, 2000) and news might create order flows that transmit private information to the FX market (Dominguez and Panthaki, 2006). For example, Evans (2002) decomposed macro news into common knowledge and non-common knowledge shocks and found that non-common knowledge shocks are of greater importance in price discovery.

In this paper, we use a wider set of macroeconomic news types compared to the previous studies and examine whether this set of macroeconomic news affects the price discovery process. Specifically, most Australian macroeconomic announcements arrive during the Asian trading hours (i.e. from 23:00 GMT on day t-1 to 1:00GMT on day t), while most of the US macroeconomic announcements occur during the "NYLON" and North American market trading hours (i.e., from 12:00 GMT to 19:00 GMT on the same day). In order to investigate whether macroeconomics news announced during the trading hours affect the specific market's price discovery process, we compare the average information shares of the markets on announcement days versus non-announcement days. As shown in Table 5, during the Australian macroeconomic news announcement days, the information share of Asia increases significantly, whereas those of the European and North American markets decline. In contrast, during the US related macroeconomic news announcements days, the information share shifts from Asia to "NYLON" and North America. Accordingly, the market becomes relatively more efficient in reflecting information when more publicly available information is released during their trading hours. The gain in information share when public information is released is consistent with the findings of Jiang, et al. (2014).

Table 5: Information shares on days with and without macroeconomic news

| Category | Average Information Share | | | |
|---|---|---|---|---|
| | Asia | Europe | NYLON | North America |
| Days with US news (1) | 0.265 | 0.211 | 0.224 | 0.307 |
| | (0.120) | (0.086) | (0.110) | (0.137) |
| Days with Australian news (2) | 0.313 | 0.204 | 0.170 | 0.274 |
| | (0.135) | (0.083) | (0.101) | (0.123) |
| Days without news (3) | 0.272 | 0.201 | 0.183 | 0.270 |
| | (0.121) | (0.098) | (0.084) | (0.120) |
| (1) - (3) | -0.007 | 0.010* | 0.041*** | 0.038*** |
| | [0.145] | [0.000] | [0.000] | [0.000] |
| (2) - (3) | 0.042*** | -0.004 | -0.013* | 0.004 |
| | [0.000] | [0.135] | [0.050] | [0.097] |

Note: This table compares the average information shares for each market on the days with macroeconomic news and those without. N are the number of days in each category. The values in the parentheses and the brackets are standard deviations and p-values respectively. The asterisks ***, **, and * indicate significance at the 1%, 5%, and 10% level, respectively.

There is no doubt that macroeconomic news is among the most significant elements of the price discovery process in financial markets and hence its impact on information shares in the FX markets needs to be thoroughly examined. Macroeconomic news can also be considered as a control variable that affects the information share of AUD. Thus we have

*Hypothesis 2: The release of macroeconomic news has a positive impact on the information share of AUD.*

### *3.3 Order flows*

Order flow is a measure of the signed trades and thus indicates the buying pressure (assuming that buys are coded positive). It is well documented that order flow is positively related to contemporaneous returns in many markets.[7] This is often interpreted as an indication of order flow being the medium for incorporating information into prices. In microstructure studies, it is accepted that private information is embedded in the transactions and order flows. For example, Evans and Lyons (1999) argued that order flow is a crucial determinant of the price in microstructure models that aim to explain exchange rate fluctuations. Using a microstructure model, Killeen, Lyons and Moore (2006) showed that shocks to order flow induce more volatility under flexible exchange rates. Evans and Lyons (2008), using a microstructure model, showed that up to two thirds of the level changes and volatilities in exchange rate movements are associated with order flows.

It has been argued that order flow may contain elements that are not related to information. For example, in practice, the momentum trading strategy may generate a large amount of order flows that are unrelated to information. Pasquariello and Vega (2007) suggested a new approach that allows one to extract the truly informative part of order flow. They highlighted a linkage between unexpected order flow and information processing in the bond market. In addition, Chai, Lee, and Wang (2015) examined the information distribution in the global gold market and used the unexpected order flow as a proxy for private information. Furthermore, Green (2004) emphasized the processing of public news via an indirect channel, i.e. via order flow. The order flow can impact price discovery and its information effect varies across the days with and without news. Based on this discussion,

[7] The Pearson correlations among the market state variables and order flow measures in our study also suggest that order flow is positively related to contemporaneous returns in all of the four markets. The results are not presented here due to space constraints, but available upon request.

hypothesis 3 can be specified as follows:

*Hypothesis 3: The Order flow has a significant and positive impact on information shares, and its impact depends on the news announcement.*

*3.4 Long-run determinants of the information shares*

The existing literature on market risks suggests that aggregate volatility is subject to shocks at different frequencies (Engle and Lee, 1999; Adrian and Rosenberg, 2008) and two-component volatility models outperform one-component specifications in explaining the equity market volatility. Following this line of reasoning, we also examine the determinants of the information shares over a longer horizon. We conjecture that, in the long run, the development of financial markets and market integration also affect price discovery. In this study, we use price efficiency and volume of futures contracts as indicators of the development of financial markets, and the number of quoting banks and percentage of quotes posted by foreign banks as indicators of market integration. Our fourth hypothesis is as follows:

*Hypothesis 4: The market-wide determinants, including pricing efficiency, number of quoting banks, percentage of quotes posted by foreign banks and the volume of futures contracts affect the information share of AUD in the long-run.*

## 4. Estimation strategy and the data

Consistent with the hypotheses formulated, our empirical specifications include market state-related variables, the announcement of macroeconomic news, order flow and the long-run determinants of AUD. We use a simple Ordinary Least Squares (OLS) approach to estimate the coefficients and the Newey-West heteroscedasticity autocorrelation consistent (HAC) standard errors to correct for the problems of heteroskedasticity and autocorrelation. Following Fricke and Menkhoff (2011), Hypothesis 1 will be tested by the following specification:

$$\ln\left(\frac{IS_{i.t}}{1-IS_{i.t}}\right) = \alpha + \beta_1 \ln(Spr_{i.t}) + \beta_2 \ln(Vol_{i.t}) + \beta_3 \ln(Ret_{i.t}) + \beta_4 \ln(Volatility_{i.t}) + \sum_{j=Mon}^{Thu} \beta_j WD^j + \epsilon_{i,t} \quad (4.1)$$

where $IS_{i.t}$represents the information share of market *i* on day t. $Spr_{i,t}$, $Vol_{i,t}$, $Ret_{i.t}$, and $Volatility_{i.t}$ are the daily shares of time-weighted average quoted spread, trading volume, open-to-close return, and standard deviation of log returns over 5-minute intervals. The dummy variables $WD^j$ ($j = Monday, Tuesday, Wednesday, and\ Thursday$ captures the day-of-the-week effect, which is 1 if the day is Monday, Tuesday, Wednesday, or Thursday and zero otherwise. All the daily shares are calculated as the market-specific data divided by the sum of four markets. We also use a logarithmic transformation of the information shares and market state variables to overcome any distributional problems related to limited depend variables (See Mizrach and Neely, 2008).

Data on market related variables are collected from Thomson Reuters Tick History (TRTH) provided by the Securities Industry Research Centre of Asia-Pacific (SIRCA). The summary statistics of the market state variables for the four markets (i.e. Asia, Europe, London/New York, and North America) are provided in Appendix B. The Ljung-Box Q statistics show that the volatility has strong autocorrelations for Asian, European, and North American market, while it shows no autocorrelation for "NYLON" market. The Augmented Dicky-Fuller (ADF) tests suggest that the daily shares of all the market state variables are stationary, i.e. all the series expressed as daily shares are I(0) processes and hence simple regression can be used for hypothesis testing.

In order to test hypothesis 2 regarding the impact of macroeconomics news release on market information share, we regress the information shares on the news dummy variables as well as the control variables as specified in Eq. (4.2):

$$\ln\left(\frac{IS_{i.t}}{1-IS_{i.t}}\right) = \alpha + \beta_1 \ln(Spr_{i.t}) + \beta_2 \ln\left(Vol_{i,t}\right) + \beta_3 \ln(Ret_{i.t}) + \beta_4 \ln(Volatility_{i.t})$$

$$+ \sum_{j=A}^{U} \beta_j NewsDum_{i,t}^{j} + \epsilon_{i,t} \tag{4.2}$$

where the dummy variable $NewsDum_{i,t}^{j},\ j = A, U$ ("$A$" for Australia and "$U$" for the US), takes the value of one if there were news arrivals related to Australia or the U.S. during market *i*'s trading hours and zero otherwise.

The US and Australian macroeconomic news announcements used in this paper are sourced from the Bloomberg News service. The news dataset includes the date and time of news release, news ticker, and realizations of the relevant macroeconomic fundamentals of the US and Australia.[8] As indicated earlier, we use a much wider set of macro news types compared to the previous studies, namely, scheduled announcement as well as the unscheduled announcements. Unscheduled announcements include all the headline news collected from approximately 150 bureaus of Reuters News Service around the world, which relates to macroeconomic fundamentals, market commentary, government intervention or

[8] The volatility and volume responses of AUD are mostly driven by the Australian and the US announcements, whereas the scheduled news from the Eurozone and Japan were not found to be important (Kim, et al., 2014).

policies, and/or positions taken by multinationals and large financial institutions.[9]

In order to test hypothesis 3, regarding the implications of order flow, we first regress the information shares of the four markets on their relative order flows. Moreover, in order to distinguish the net trading effect on days with and without news, we add the news dummy variable $NewsDum^j$ $(j = A, U)$[10] and interaction term of news dummies and order flow measures, the resulting empirical model is as follows:

$$\ln\left(\frac{IS_{i.t}}{1-IS_{i.t}}\right) = \alpha + \beta_1 \ln(Spr_{i.t}) + \beta_2 \ln(Vol_{i,t}) + \beta_3 \ln(Ret_{i.t}) + \beta_4 \ln(Volatility_{i.t}) + \beta_5 \ln(OF_{i,t}) + \sum_{j=A}^{U} \beta_{6j} NewsDum_{i,t}^{j} + \sum_{j=A}^{U} \beta_{7j} [ln(OF_{i,t}) \cdot NewsDum_{i,t}^{j}] + \epsilon_{i,t} \quad (4.3)$$

where $OF_{i,t}$ represents the daily shares of order flow in market *i* on day *t*, $NewsDum^j$ $(j = A, U)$ is the news dummy variable as defined earlier.

Furthermore, in order to extract the informative element from the order flow, following Chai *et al.* (2014), we to run a regression of the current order flow on the lagged returns and order flows, where unexpected order flow can be defined as the residuals, that is:

$$OF_{i,t} = \alpha + B_1(L)OF_{i,t} + B_2(L)Ret_{i,t} + v(OF_{i,t}) \quad (4.4)$$

where $OF_{i,t}$ and $Ret_{i,t}$ refer to the order flow and log-return aggregated within 5-minute intervals in market *i* respectively. $B_1(L)$ and $B_2(L)$ are polynomials in the lag operator.

The Bayesian Information Criterion (BIC) suggests using a lag length of 8 for the Asian and North American market, 6 for the European market, and 5 for the “NYLON” market. The residuals $v(OF_{i,t})$ reveal the amount of unexpected order flow (*UOF*) in 5-minute intervals and are then summed up per market. It gives us a measure for informed order flow, possibly nurtured by customer order flow (Menkveld *et al.*, 2012). The expected order flow (*EOF*) stands for the predicted value $\widehat{OF}_{i,t}$ from equation (4.4).

In the next stage, we estimate the impact of the expected and unexpected order flow by using the following specification, where *UOF* is used as a proxy for private information:

$$\ln\left(\frac{IS_{i.t}}{1-IS_{i.t}}\right) = \alpha + \beta_1 \ln(Spr_{i.t}) + \beta_2 \ln(Vol_{i,t}) + \beta_3 \ln(Ret_{i.t}) + \beta_4 \ln(Volatili_{i.t}) + \beta_5 \ln(EOF_{i,t}) +$$

9 For a through introduction to the Reuters unscheduled news headlines, please see Daniel, Kim, and McKenzie (2014).

10 The news dummies $NewsDum^j$ $(j = A, U)$ represent announcement days (when$NewsDum^j = 1$) and non-announcement days (when$NewsDum^j = 0$).

$$\beta_6 \ln(UOF_{i,t}) + \sum_{j=A}^{U} \beta_{7j} NewsDum_{i,t}^{j} + \sum_{j=A}^{U} \beta_{8j} [\ln(UOF_{i,t}) \cdot NewsDum_{i,t}^{j}] + \epsilon_{i,t} \quad (4.5)$$

In order to decompose the information share into the long-run and short-run components and test hypothesis 4, following Adrian and Rosenberg (2008), we model the monthly moving average information shares of the four markets as their long-run components. This approach parsimoniously captures the shocks at different horizons. Specifically, we model the dynamics of long-run component of the information shares using the following specification.

$$\ln\left(\frac{IS_{i,t}}{1-IS_{i,t}}\right) = \alpha + \beta_1 \ln(Eff_{i,t}) + \beta_2 \ln(Num_{i,t}) + \beta_3 \ln(Pct_{i,t}) + \beta_4 \ln(VolF_{i,t}) + \epsilon_{i,t} \quad (4.6)$$

where $IS_{i,t}$ is the moving average information share of market $i$ in month $t$. $Eff_{i,t}$ is the monthly average pricing efficiency as calculated in Table 6. $Num_{i,t}$, $FQuot_{i,t}$, and $VolF_{i,m}$, respectively are the total number of quoting banks, percentage of quotes posted by foreign banks identified based on their locations, and the average volume of AUD futures contracts trading on Chicago Mercantile Exchange (CME)'s Globex electronic trading system which is sourced from the Institute for Financial Markets. In addition, we collect indicative quotes with the identification of the names and locations of quoting banks from TRTH, from which we can calculate the total number of quoting banks and percentage of quotes posted by foreign banks identified based on their locations for each of the four markets $Pct_{i,t}$.

Pricing efficiency is the ratio of the TS estimator to the realized variance ($TSRV_{i,t}/RV_{i,t}$) as the TSRV separates microstructure noise variance from the RV. TSRV ratio close to one implies that less noise is observed in market $i$ (Wang and Yang, 2011). Table 6 reports the estimated yearly pricing efficiency by using log returns over 5-minute intervals $\mathrm{RV_{5m}}$ and Two-scale estimator $\mathrm{TSRV}$ for the four markets. As $\mathrm{TSRV}$ is a proxy for the information flow (i.e. the variance of the efficient price change) and $\mathrm{RV_{5m}}$ contains both the information and noise components, the ratio $\mathrm{TSRV/RV_{5m}}$ provides a measure of market-specific pricing efficiency. Table 6 shows that for all markets, the ratio $\mathrm{TSRV/RV_{5m}}$ is less than one, implying that $\mathrm{RV_{5m}}$ contains considerable noise, ranging from 15% to 30%. Using this measure of the pricing efficiency, it can be argued that Europe has the highest efficiency for AUD trading, followed by "NYLON". It is interesting to note that the pricing efficiency in North America has increased since 2005, which is consistent with Chaboudet et al. (2014) who find that with the rise of algorithmic trading, which speeds up price discovery, the pricing efficiency in the US/North American market has been constantly improving since 2005.

Table 6: Sub-period pricing efficiency

| | *N* | Asia | Europe | London/NYC | North America |
|---|---|---|---|---|---|
| 1999 | 256 | 0.697 | 0.778 | 0.807 | 0.727 |
| 2000 | 256 | 0.722 | 0.806 | 0.811 | 0.737 |

| | | | | | |
|---|---|---|---|---|---|
| 2001 | 257 | 0.727 | 0.779 | 0.827 | 0.750 |
| 2002 | 250 | 0.766 | 0.786 | 0.820 | 0.777 |
| 2003 | 253 | 0.775 | 0.802 | 0.818 | 0.763 |
| Average$^{1999\text{-}2003}$ | | 0.737 | 0.791 | 0.816 | 0.751 |
| 2004 | 256 | 0.777 | 0.820 | 0.841 | 0.797 |
| 2005 | 258 | 0.777 | 0.803 | 0.817 | 0.786 |
| 2006 | 259 | 0.792 | 0.821 | 0.828 | 0.802 |
| 2007 | 257 | 0.807 | 0.819 | 0.847 | 0.803 |
| 2008 | 258 | 0.807 | 0.805 | 0.817 | 0.820 |
| Average$^{2004\text{-}2008}$ | | 0.792 | 0.813 | 0.830 | 0.802 |
| 2009 | 257 | 0.804 | 0.818 | 0.833 | 0.831 |
| 2010 | 258 | 0.792 | 0.806 | 0.842 | 0.809 |
| 2011 | 260 | 0.804 | 0.819 | 0.860 | 0.819 |
| 2012 | 258 | 0.801 | 0.819 | 0.829 | 0.796 |
| 2013 | 256 | 0.786 | 0.807 | 0.841 | 0.787 |
| Average$^{2009\text{-}2013}$ | | 0.797 | 0.814 | 0.841 | 0.808 |
| Average$^{1999\text{-}2013}$ | | 0.793 | 0.810 | 0.832 | 0.797 |

Note: This table reports the annual average estimates of the pricing efficiency calculated at 5-minute sampling intervals. *N* is the number of observations in each year.

## 5. Estimation results

The empirical results are reported and discussed in this section. As discussed in section 3, market related variables (i.e., the announcement of macroeconomic news and order flows) , macroeconomic news announcement and order flow are the determinants of information share of AUD in the short-run, while price efficiency, number of quoting banks, percentage of quotes posted by foreign quoting banks, and the volume of AUD futures contracts trading are the long-run determinants of the dynamic price discovery of AUD. The results of robustness testing are also presented in this section.

### *5.1 Market-related variables*

The estimation results regarding the market related determinants are presented in Table 7. These results confirm that market state variables explain a significant proportion of the fluctuations in the information shares for AUD market. In overall terms, the market-related variables perform better in explaining the shifts in the information shares of the Asian and North American markets compared to the European market. A positive change in the trading volume from the 25th to the 75th percentile increases the information content of the Asian market by 7.3%.[11] Interestingly, in general, increases in spreads do not indicate less

[11] The calculation results are based on the results of Tables 7, assuming market-related variables take their mean

information processing. The reason could be that, in the case of all the markets, larger spreads are generally associated with more information shares, which is consistent with the findings of Glosten and Milgrom (1985) who reported that the presence of informed traders leads to larger bid-ask spreads. However, it is worth noting that after controlling for volatility (i.e., the standard deviation of mid-quote returns over 5-minute intervals), the sign of the variable spread changes from positive to negative as shown in columns labeled 2 in Table 7. This could be attributed to the fact that the spread consists of three components; namely the asymmetric information component (AIC), order processing component (OPC), and inventory holding component (IHC) (Lin, et al., 1995; Stoll, 1989). While the asymmetric information component, proxied by volatility in our regression, is positively related with the information share, the order processing component and inventory holding components are negatively related with the information share. In addition, the estimation results confirm that higher returns have a positive effect on price discovery in the foreign exchange market.

We also considered the day-of-the-week effect by having the weekday dummies in the regressions. We find that the information share of Asia tends to be higher on Mondays and that of the US/North America is higher on Thursdays and Fridays as shown in columns labelled 3 in Table 7. A possible explanation of these results is that the accumulated information during the weekend is incorporated into the exchange rate quickly when the Asian market opens on Mondays, which increases the information share of Asia. While for the US market, the higher information share on Thursdays and Fridays is consistent with the findings of Harvey and Huang (1991) who confirm that in the foreign exchange futures market, returns on Thursdays and Fridays are more volatile as many news releases related to the US take place on these days.

In overall terms, there is strong evidence supporting the view that market state variables are important determinants of the information share of AUD is different markets. More favorable market states, i.e. more volume, narrower spread, and higher return, tentatively increase the information share of a certain market. However, it is not possible to make a general statement concerning the direction of the relationship (i.e., the expected coefficient signs). For example, in some cases, an increase in spread (volatility) may decrease the information share, while in other cases relatively high spread (volatility) may accelerate the price discovery process, thereby increasing the information share. For example, higher spread in the North American market increases the information share but its effect is consistently negative in the European market.

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values. The $25^{th}$ and $75^{th}$ percentile of the trading volume of AUD are 13.5% and 22.5%, respectively.

Table 7: Responses of information shares to market state variables

| Variable | Asia | | | Europe | | | NYLON | | | North America | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Intercept* | 0.038 | 0.529*** | 0.429*** | 0.050* | 1.226*** | 1.281*** | 0.340*** | 1.222*** | 1.231*** | 0.184*** | 1.434*** | 1.406*** |
| | (00027) | (0.040) | (0.046) | (0.027) | (0.041) | (0.045) | (0.042) | (0.059) | (0.061) | (0.023) | (0.031) | (0.032) |
| *Spread* | 0.012 | -.122*** | -.165*** | -0.011 | -.298*** | -.256*** | 0.119*** | -.140*** | -.123*** | 0.127*** | 0.531*** | 0.187*** |
| | (0.021) | (0.033) | (0.035) | (0.021) | (0.037) | (0.039) | (0.028) | (0.045) | (0.046) | (0.018) | (0.020) | (0.0300 |
| *Volume* | 0.106*** | 0.251*** | 0.254*** | 0.213*** | 0.419*** | 0.432*** | 0.281*** | 0.444*** | 0.453*** | 0.226*** | 0.007*** | 0.524*** |
| | (0.013) | (0.020) | (0.021) | (0.015) | (0.024) | (0.025) | (0.018) | (0.027) | (0.028) | (0.014) | (0.002) | (0.021) |
| *Return* | 0.006*** | 0.014*** | 0.013*** | 0.002* | 0.004** | 0.004** | 0.003*** | 0.010*** | 0.010*** | 0.003*** | 0.028*** | 0.007*** |
| | (0.002) | (0.002) | (0.002) | (0.001) | (0.002) | (0.002) | (0.001) | (0.002) | (0.002) | (0.001) | (0.001) | (0.002) |
| *Volatility* | | 0.684*** | 0.679*** | | 0.581*** | 0.556*** | | 0.427*** | 0.408*** | | 0.517*** | 0.503*** |
| | | (0.019) | (0.021) | | (0.024) | (0.025) | | (0.028) | (0.029) | | (0.025) | (0.026) |
| *Monday* | | | 0.054*** | | | -.058*** | | | -0.038** | | | -0.009 |
| | | | (0.019) | | | (0.016) | | | (0.019) | | | (0.018) |
| *Tue*eday | | | -0.042** | | | -0.008 | | | -0.005 | | | -.067*** |
| | | | (0.017) | | | (0.015) | | | (0.019) | | | (0.018) |
| *Wednesday* | | | -.071*** | | | -0.032** | | | 0.001 | | | -.047*** |
| | | | (0.017) | | | (0.015) | | | (0.018) | | | (0.018) |
| *Thursday* | | | -.070*** | | | -.041*** | | | 0.007 | | | 0.044** |
| | | | (0.017) | | | (0.015) | | | (0.018) | | | (0.018) |
| $n$ | 3825 | 3825 | 3825 | 3824 | 3824 | 3824 | 3804 | 3804 | 3804 | 3816 | 3816 | 3816 |
| $Adj\ R^2$ | 0.7902 | 0.8102 | 0.8097 | 0.7142 | 0.7253 | 0.7258 | 0.7001 | 0.7114 | 0.7110 | 0.7025 | 0.7357 | 0.7365 |

Note: The values in the parentheses are the Newey-West standard errors. The asterisks ***, **, and * indicate significance at 1%, 5%, and 10% level, respectivel

*5.2 Macroeconomic news announcement*

Colum 1 of Table 8 highlights the importance of the US news on information shares, which is consistent with Andersen et al. (2007) and Ehrmann and Fratzscher (2005). The relevance of US news stems from the economic importance of the US economy as well as the fact that the price quotes used in our study are expressed as the values of the AUD in terms of the USD. In contrast, the coefficient of the Australian news dummy does not show any clear pattern in the European and "NYLON" markets. However, we observe a significant impact of the Australian announcements on the information share in the Asian market, which suggests that Australian macroeconomic news have a significant impact on trading of on AUD in the Asian market. A possible explanation for the high information share when there are macroeconomic news announcements may be that relatively more informed traders react quickly around the time of macroeconomic news releases (Evans and Lyons, 2008). Unfortunately, the signs of the estimated coefficients do not show a consistent pattern across the four markets.

Table 8: Responses of information shares to macroeconomic news announcements and order flows

| Variable | Asia | | Europe | | NYLON | | North America | |
|---|---|---|---|---|---|---|---|---|
| | Column 1 | Column 2 | Column 1 | Column 2 | Column 1 | Column 2 | Column 1 | Column 2 |
| $Intercept$ | 0.481*** | 0.490*** | 1.230*** | 1.244*** | 1.246*** | 1.283*** | 1.417*** | 1.417*** |
| | (0.040) | (0.041) | (0.042) | (0.042) | (0.061) | (0.061) | (0.031) | (0.032) |
| $OF$ | | 0.019*** | | 0.017*** | | 0.042*** | | 0.019*** |
| | | (0.007) | | (0.006) | | (0.008) | | (0.005) |
| $Spread$ | -0.134*** | -0.122*** | -0.312*** | -0.300*** | -0.158*** | -0.138*** | 0.157*** | 0.163*** |
| | (0.033) | (0.033) | (0.037) | (0.037) | (0.045) | (0.045) | (0.029) | (0.029) |
| $Volume$ | 0.276*** | 0.254*** | 0.430*** | 0.414*** | 0.479*** | 0.450*** | 0.550*** | 0.527*** |
| | (0.019) | (0.020) | (0.024) | (0.025) | (0.027) | (0.027) | (0.020) | (0.020) |
| $Return$ | 0.016*** | 0.014*** | 0.005*** | 0.004*** | 0.012*** | 0.010*** | 0.008*** | 0.007*** |
| | (0.002) | (0.002) | (0.002) | (0.002) | (0.002) | (0.002) | (0.002) | (0.002) |
| $Volatility$ | 0.684*** | 0.680*** | 0.595*** | 0.589*** | 0.438*** | 0.434*** | 0.518*** | 0.513*** |
| | (0.019) | (0.019) | (0.024) | (0.024 | (0.028) | (0.028) | (0.025) | (0.025) |
| $NewsDum^A$ | 0.056*** | 0.064*** | 0.063 | 0.068*** | -0.091 | 0.01 | 0.020* | 0.024 |
| | (0.011) | (0.016) | (0.023) | (0.029) | (0.097) | (0.167) | (0.012) | (0.043) |
| $NewsDum^U$ | 0.069 | 0.017 | -0.015 | -0.015 | 0.038*** | 0.059*** | 0.043* | 0.048** |
| | (0.050) | (0.056) | (0.010) | (0.012) | (0.012) | (0.020) | (0.025) | (0.019) |
| $OF$ | | 0.010* | | -0.007 | | 0.072 | | -0.011 |
| $* NewsDum^A$ | | (0.006) | | (0.018) | | (0.088) | | (0.021) |
| $OF$ | | 0.039 | | 0.001 | | -0.013 | | 0.017* |
| $* NewsDum^U$ | | (0.029) | | (0.008) | | (0.010) | | (0.009) |
| $n$ | 3825 | 3825 | 3824 | 3824 | 3804 | 3804 | 3816 | 3816 |

| $Adjusted\ R^2$ | 0.8088 | 0.8102 | 0.7240 | 0.7252 | 0.7077 | 0.7114 | 0.7339 | 0.7358 |
|---|---|---|---|---|---|---|---|---|

Note: The values in the parentheses are the Newey-West standard errors. The asterisks ***, **, and * indicate significance at 1%, 5%, and 10% level, respectively.

### *5.3 Order flow*

The results presented in columns 2 of Table 8 show that the relative order flows in all four markets are positive and statistically significant. Table 9 reports the responses of the information shares to expected and unexpected order flows. The impact of the expected order is shown in columns labelled 1 and the response of unexpected order flow is shown in columns labeled 2. Comparing the results of Table 9, columns 2 show a remarkable increase in the explanatory power (as shown by the values of adjusted $R^2$). The Wald test results suggest that the unexpected order flow plays a more important role in explain the information shares.[12] The previously observed positive impact of the order flow on information share vanishes with the inclusion of the unexpected order flow and macro-news dummy interactions, which confirms the elements of order flow that are unrelated to information shares. It is interesting to note that the unexpected order flow and the interactions of order flow with the news dummies significantly improve our understanding of information shares in the Asian and North American market. Again, this finding confirms the results of Pasquariello and Vega (2007), who argued that the importance of order flow depends on the existence of information signals. Overall, we can argue that order flow, particularly the unexpected order flow, is a crucial determinant of the information shares, which supports the view that order flow is a medium for incorporating heterogeneous information.

Table 9: Responses of information shares to expected and unexpected order flow

| Variable | Asia | | Europe | | NYLON | | North America | |
|---|---|---|---|---|---|---|---|---|
| | Column 1 | Column 2 | Column 1 | Column 2 | Column 1 | Column 2 | Column 1 | Column 2 |
| $Intercept$ | 0.508*** | 0.494*** | 1.243*** | 1.242*** | 1.286*** | 1.300*** | 1.430*** | 1.426 |
| | (0.040) | (0.041) | (0.042) | (0.043) | (0.062) | (0.064) | (0.031) | (0.032) |
| $EOF$ | 0.014*** | 0.005 | 0.005 | 0.004 | 0.004 | 0.007 | 0.010** | 0.011* |
| | (0.005) | (0.007) | (0.004) | (0.007) | (0.005) | (0.008) | (0.004) | (0.006) |
| $UOF$ | | 0.015** | | 0.008* | | 0.037*** | | 0.013** |
| | | (0.006) | | (0.005) | | (0.007) | | (0.005) |
| $Spread$ | -0.119*** | -0.120*** | -0.304*** | -0.303*** | -0.136*** | -0.135*** | 0.159*** | 0.160*** |
| | (0.033) | (0.033) | (0.037) | (0.037) | (0.045) | (0.045) | (0.029) | (0.029) |
| $Volume$ | 0.252*** | 0.253*** | 0.427*** | 0.427*** | 0.461*** | 0.460*** | 0.533*** | 0.533*** |

[12] The results of Wald tests are not presented here due to space constraint, but available upon request.

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | (0.019) | (0.020) | (0.025) | (0.025) | (0.028) | (0.028) | (0.020) | (0.020) |
| $Return$ | 0.014*** | 0.014*** | 0.004*** | 0.004*** | 0.010*** | 0.010*** | 0.007*** | 0.007*** |
| | (0.002) | (0.002) | (0.002) | (0.002) | (0.002) | (0.002) | (0.002) | (0.002) |
| $Volatility$ | 0.680*** | 0.680*** | 0.588*** | 0.588*** | 0.432*** | 0.431*** | 0.514*** | 0.513*** |
| | (0.019) | (0.019) | (0.0.025) | (0.025) | (0.028) | (0.028) | (0.025) | (0.025) |
| $NewsDum^A$ | 0.056*** | 0.079*** | 0.062* | -0.050 | -0.090 | 0.132 | 0.020* | 0.028** |
| | (0.011) | (0.018) | (0.043) | (0.034) | (0.097) | (0.193) | (0.012) | (0.011) |
| $NewsDum^U$ | 0.070* | -0.061 | -0.016 | -0.014 | 0.039* | 0.069** | 0.039 | 0.046*** |
| | (0.040) | (0.070) | (0.010) | (0.014) | (0.022) | (0.029) | (0.025) | (0.015) |
| $UOF$ | | 0.008*** | | 0.005 | | 0.025 | | 0.004 |
| $* NewsDum^A$ | | (0.001) | | (0.019) | | (0.085) | | (0.022) |
| $UOF$ | | 0.033 | | 0.002 | | 0.011* | | 0.009** |
| $* NewsDum^U$ | | (0.029) | | (0.008) | | (0.006) | | (0.005) |
| $n$ | 3819 | 3819 | 3818 | 3818 | 3798 | 3798 | 3809 | 3809 |
| $Adjusted\ R^2$ | 0.8109 | 0.8310 | 0.7250 | 0.7353 | 0.7121 | 0.7120 | 0.7352 | 0.7854 |

Note: The values in the parentheses are the Newey-West standard errors. The asterisks ***, **, and * indicate significance at 1%, 5%, and 10% level, respectively.

### *5.4 Long-run determinants*

The long-run estimation results are reported in Table 10. First of all, the pricing efficiency, which can be seen as an indicator of market development, has a positive and significant impact on price discovery. Second, with more quoting banks, particularly the foreign quoting banks in Asia, the information share of Asia increases substantially, which could be attributed to the fact that most of the top dealing banks in the FX market are headquartered outside of Asia. With an increased degree of market integration (i.e. with more dealing banks, particularly the foreign banks, quoting in the Asian market), Asia is playing an increasingly important role in the price discovery of global FX trading.[13] Finally, considering the importance of the futures contracts in facilitating the price discovery process, we include the volume of AUD futures contracts in our regressions. The empirical results presented in Table 10 confirm that trading volume of futures contracts, also affects the information shares of all four markets and the effect is the highest in the North American market, which is dominated by the US. In overall terms, a higher degree of market development and integration is highly desirable.

[13] An alternative is to use the Chinn-Ito index (KAOPEN) to measure the financial openness and market integration, which measures a country's degree of capital account openness on a yearly basis. The index, which was initially introduced by Chinn and Ito (2006), is based on a binary dummy variable that codifies the tabulation restrictions on cross-border financial transactions reported in the IMF Annual Report on Exchange Arrangements and Exchange Restrictions (AREAER). See, Chinn and Ito (2006, 2008) for details.

Table 10: Responses of information shares to long-run determinants variables

| Variable | Asia | Europe | NYLON | North America |
|---|---|---|---|---|
| *Intercept* | -1.8559*** | -1.2400*** | -1.4828*** | -1.4506*** |
| | (0.0793) | (0.0745) | (0.0595) | (0.0634) |
| *Efficiency* | 0.4835*** | 0.6792*** | 0.4942*** | 0.5665*** |
| | (0.0840) | (0.0838) | (0.0617) | (0.0758) |
| *Number of Banks* | 0.0138*** | 0.0187*** | 0.0074*** | 0.0065** |
| | (0.0028) | (0.0067) | (0.0030) | (0.0026) |
| *Percentage of Quotes* | 0.0383*** | -0.0006 | 0.0089 | 0.0102 |
| | (0.0178) | (0.0019) | (0.0242) | (0.0182) |
| *Volume of Futures* | 0.0280** | 0.0224*** | 0.0456*** | 0.0814*** |
| | (0.0161) | (0.0048) | (0.0071) | (0.0050) |
| $n$ | 3814 | 3839 | 3840 | 3840 |
| *Adjusted* $R^2$ | 0.2964 | 0.3110 | 0.4551 | 0.4102 |

Note: The values in the parentheses are the Newey-West standard errors. The asterisks ***, **, and * indicate significance at 1%, 5%, and 10% level, respectively.

### *5.5 Robustness test*

In order to examine the robustness of our empirical results and to mitigate the potential endogeneity (particularly in the spread), the model was also re-estimated using Two-stage Least Squares (2SLS). Specifically, in the first stage, we use several instrumental variables (i.e. volatility, return, and trading volume) for spread. In the second stage, we regress the information shares on the fitted value of the first stage regression. The results presented in Table 11 mostly reconfirm our earlier findings concerning the impact of market state variables, order flow, and macroeconomic news announcements on information shares in different markets. Of course, some of the explanatory variables are insignificant in 2SLS estimation.

Table 11: Robust Regression (2SLS)

| | Asia | | Europe | | NYLON | | US | |
|---|---|---|---|---|---|---|---|---|
| Variable | 1st Stage | 2nd Stage | 1st Stage | 2nd Stage | 1st Stage | 2nd Stage | 1st Stage | 2nd Stage |
| *Intercept* | -1.146*** | 8.303*** | -1.253*** | 8.974*** | -1.247*** | 11.455*** | -0.974*** | 3.916*** |
| | (0.011) | (0.612) | (0.007) | (0.530) | (0.016) | (0.776) | (0.014) | (0.140) |
| *EOF* | -0.006* | 0.042 | -0.010*** | 0.070 | -0.012*** | 0.110* | -0.008** | 0.028** |
| | (0.004) | (0.026) | (0.003) | (0.053) | (0.003) | (0.028) | (0.003) | (0.012) |
| *UOF* | -0.011*** | 0.092*** | -0.008*** | 0.057*** | -0.006** | 0.073*** | -0.006* | 0.035*** |
| | (0.003) | (0.025) | (0.003) | (0.020) | (0.003) | (0.025) | (0.003) | (0.012) |
| $\widehat{Spread}$ | | 1.141*** | | 1.952*** | | 1.833*** | | 1.752*** |
| | | (0.064) | | (0.087) | | (0.071) | | (0.082) |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| *Volume* | -0.087*** | 0.717*** | -0.174*** | 1.414*** | -0.075*** | 0.864*** | -0.275*** | 1.223*** |
| | (0.010) | (0.080) | (0.011) | (0.103) | (0.010) | (0.099) | (0.012) | (0.056) |
| *Return* | -0.001 | 0.012 | 0.000 | -0.001 | -0.000 | 0.006 | -0.001 | 0.006 |
| | (0.001) | (0.009) | (0.001) | (0.005) | (0.001) | (0.006) | (0.001) | (0.004) |
| *Volatility* | 0.109*** | 0.309** | 0.113*** | 0.201* | 0.081*** | 0.311*** | 0.203*** | 0.276*** |
| | (0.004) | (0.123) | (0.005) | (0.115) | (0.004) | (0.120) | (0.006) | (0.080) |
| $NewsDum^A$ | | 0.067** | | -0.055 | | 0.369 | | 0.176 |
| | | (0.027) | | (0.117) | | (0.676) | | (0.104) |
| $NewsDum^U$ | | -0.355 | | 0.109** | | 0.235** | | 0.210*** |
| | | (0.260) | | (0.050) | | (0.102) | | (0.050) |
| $UOF$ | | 0.031* | | 0.004 | | 0.042 | | -0.040 |
| $*\ NewsDum^A$ | | (0.021) | | (0.065) | | (0.298) | | (0.052) |
| $UOF$ | | -0.088 | | 0.003 | | 0.010 | | 0.022** |
| $*\ NewsDum^U$ | | (0.110) | | (0.026) | | (0.032) | | (0.012) |
| $n$ | 3818 | 3818 | 3817 | 3817 | 3797 | 3797 | 3808 | 3808 |
| Adjusted $R^2$ | 0.1553 | 0.2574 | 0.1386 | 0.2149 | 0.1002 | 0.1959 | 0.2758 | 0.3870 |

Note: This table reports coefficient estimates using the 2SLS regression, which takes the following form:

$$\ln\left(\frac{IS_{i.t}}{1-IS_{i.t}}\right)=\alpha+\beta\ln\left(\widehat{Spr}_{i.t}\right)+\sum_j \gamma_j Control_{j,it}+\epsilon_{i,t}$$

where $\widehat{Spr}_{i.t}$ is the predicted value from the first stage of 2SLS regression. $Control_{j,it}$ represent the control variables. The values in the parentheses are the Newey-West standard errors. The asterisks ***, **, and * indicate significance at the 1%, 5%, and 10% level, respectively.

Finally, we categorize the macroeconomic news announcements into scheduled and unscheduled news and re-estimate the model. The estimated results, as shown in Table 12, suggest that the unscheduled news has a stronger positive impact on information shares and hence unscheduled news can play a relatively more important role in announcement-effect analysis.

Table 12: Responses of information shares to scheduled macro news

| Variable | Asia | | Europe | | NYLON | | North America | |
|---|---|---|---|---|---|---|---|---|
| *Intercept* | 0.513*** | 0.822*** | 1.225*** | 1.406*** | 1.221*** | 1.325*** | 1.432*** | 1.551*** |
| | (0.040) | (0.041) | (0.042) | (0.041) | (0.016) | (0.054) | (0.031) | (0.030) |
| *EOF* | | 0.006 | | 0.006 | | -0.006 | | -0.002 |
| | | (0.004) | | (0.004) | | (0.005) | | (0.004) |
| *UOF* | | 0.006 | | 0.006 | | 0.013*** | | 0.004 |
| | | (0.004) | | (0.004) | | (0.005) | | (0.004) |
| *Spread* | -0.124*** | 0.098*** | -0.304*** | -0.015*** | -0.137*** | 0.132*** | 0.152*** | 0.309*** |
| | (0.033) | (0.034) | (0.037) | (0.038) | (0.045) | (0.045) | (0.028) | (0.028) |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| $Volume$ | 0.248*** | 0.366*** | 0.418*** | 0.509*** | 0.443*** | 0.550*** | 0.530*** | 0.531*** |
| | (0.020) | (0.016) | (0.024) | (0.019) | (0.027) | (0.021) | (0.020) | (0.016) |
| $Return$ | 0.014 | 0.010*** | 0.004** | 0.003* | 0.010*** | 0.008*** | 0.007*** | 0.005*** |
| | (0.002) | (0.003) | (0.002) | (0.001) | (0.002) | (0.002) | (0.002) | (0.002) |
| $Volatility$ | 0.681*** | 0.581*** | 0.584*** | 0.473*** | 0.426*** | 0.267*** | 0.518*** | 0.441*** |
| | (0.019) | (0.018) | (0.024) | (0.023) | (0.028) | (0.026) | (0.025) | (0.024) |
| $Scheduled\ News$ | 0.039* | 0.025 | 0.013 | 0.004 | 0.041 | -0.002 | 0.072** | 0.017 |
| | (0.021) | (0.020) | (0.008) | (0.012) | (0.043) | (0.038) | (0.038) | (0.363) |
| $EOF * Sch\_News$ | | 0.004 | | 0.010 | | -0.003 | | -0.077 |
| | | (0.012) | | (0.008) | | (0.021) | | (0.197) |
| $UOF * Sch\_News$ | | 0.012 | | 0.004 | | 0.004 | | 0.017** |
| | | (0.014) | | (0.022) | | (0.022) | | (0.010) |
| $n$ | 3825 | 3819 | 3824 | 3818 | 3804 | 3798 | 3809 | 3807 |
| $Adjusted\ R^2$ | 0.8091 | 0.8254 | 0.7248 | 0.7505 | 0.7107 | 0.7391 | 0.7258 | 0.7558 |

Note: This table reports the estimation results of market state variables, macroeconomic news, and order flows on daily information shares of different markets. The dummy variable *Sch News* take the value of one if the scheduled news announcement is related to the US or Australia and occurs during market *i*'s trading hours (including employment, Gross Domestic Product (GDP), trade balance, and durable goods orders for the US and the equivalent variables for Australia) and zero otherwise. The values in the parentheses are the Newey-West standard errors. The asterisks ***, **, and * indicate significance at the 1%, 5%, and 10% level, respectively.

## 6. Conclusions and policy implications

With rapid growth in some developing economies, such as China and India, the demand for Australia's natural resources has increased substantially. As a result, the role of the Australian dollar (AUD) in the global financial markets has become more important. Using trading data from 1999 to 2013, this paper aims to estimate the information share of AUD in the Asian, European, and North American markets. Specifically, we employ a non-parametric Two-scale Realized Variance (TSRV) methodology to estimate the global information distribution for AUD quotes in terms of the US dollar. We find that the European market and particularly the overlapping trading hours of London and New York play an important role in price discovery of AUD, but Asia is rapidly gaining information share even with its declining market share of daily transactions.

After estimating the information shares, we focused on their determinants in each market. We consider macroeconomic news, order flow measures and market state variables. The empirical analysis presented in this paper shows that more favorable market states and more unexpected order flows on macroeconomic announcement days make a positive contribution to price discovery of AUD in all markets. Our results also confirm that a higher degree of market integration and international consolidation contribute to price discovery in the long-run, which is consistent with the findings of Sassen (1999).

The distinguishing feature of this paper is that we consider the impact of a broader set of news announcements on information shares, which includes both scheduled and unscheduled news announcements. We also contribute to the literature on price discovery by narrowing the gap between microstructure and macroeconomic studies on the development of global financial centers. Specifically, we make an attempt to explore the relationship between the price discovery, market integration, and the development of financial markets by estimating the long-run determinants of price discovery. Sassen (1999) claimed that the two most important factors in transforming a city into a global financial center are international consolidation of financial activities (i.e. concentration of financial institutions and transactions at one location) and financial market liberalization (financial services openness and free capital flows). We measure the rise and fall of global financial centers from the perspective of price discovery (i.e., we make an attempt to identify the key factors determining the information distribution in the long run). We also show that decomposition of the order flow into an expectation-related and an innovation term can significantly improve the understanding of the trader behavior to different types of information arrival.

Our study on price discovery in AUD has some important policy implications, especially for financial centers in Asia. In order to be better competing with the leading financial centers of North America and Europe, there is a need for the financial centers in Asia to be more open to international investors and adopt international standards. The analysis presented in this paper suggests that as far as the markets for AUD are concerned, both scheduled and unscheduled news matter and hence a better understanding of the market responses to news announcements will be valuable to dealers and liquidity traders in considering the timing of their trades as well as to the Reserve Bank of Australia in considering the timing of its market transactions.

The research presented in this paper can also be extended in several directions. For example, how to measure the information shares in the sequential markets is one question that is yet to be fully answered. Furthermore, additional research is required to consider the generalizability of our results. This will involve considering price discovery of AUD in terms of other major currencies. Last but not least, the issue of how to identify volatility jumps associated with macroeconomic news announcements deserves further study.

# Appendix A: Average daily transactions of AUD

This table reports the average daily transactions for AUD from April 2007 to April 2013 in the top-10 foreign exchange markets. It is based on a series of triennial central bank surveys conducted by the Bank for International Settlements (BIS, 2007, 2010, and 2013). Transactions include spot, outright forward, and swap transactions against USD and are measured in billion USD.

| AUD | 2007 | | 2010 | | 2013 | |
|---|---|---|---|---|---|---|
| | Value | Precent | Value | Precent | Value | Precent |
| Australia | 76.70 | 33.41 | 75.50 | 23.09 | 80.50 | 17.30 |
| Denmark | 0.46 | 0.20 | 1.40 | 0.43 | 2.31 | 0.50 |
| France | 5.89 | 2.57 | 6.25 | 1.91 | 9.00 | 1.93 |
| Germany | 1.25 | 0.54 | 2.11 | 0.65 | 3.08 | 0.66 |
| Hong Kong | 14.00 | 6.10 | 24.64 | 7.54 | 20.81 | 4.47 |
| Japan | 10.60 | 4.62 | 8.16 | 2.50 | 18.11 | 3.89 |
| Singapore | 15.70 | 6.84 | 27.57 | 8.43 | 37.19 | 7.99 |
| Switzerland | 6.12 | 2.67 | 10.08 | 3.08 | 8.12 | 1.75 |
| United Kingdom | 55.90 | 24.35 | 102.00 | 31.19 | 181.80 | 39.08 |
| United States | 30.90 | 13.46 | 56.06 | 17.14 | 82.39 | 17.71 |
| Asia in Top 10 | 117.00 | 50.96 | 135.87 | 41.55 | 156.61 | 33.67 |
| Europe in Top 10 | 69.60 | 30.31 | 121.84 | 37.26 | 204.31 | 43.92 |
| America in Top 10 | 30.90 | 13.46 | 56.06 | 17.14 | 82.39 | 17.71 |
| Top 10 | 217.50 | 94.73 | 313.77 | 95.95 | 443.31 | 95.29 |
| Global Total | 229.60 | 100.00 | 327.00 | 100.00 | 465.20 | 100.00 |

## Appendix B: Summary statistics of market related variables

The definitions of the four sequential markets, namely, Asia, Europe, "NYLON" (London/New York), and North America, are as given in Table 3. Market state variables are defined as in Section 5.1. $Q_{LB}(12)$ is the Ljung-Box statistics for 12 lags. The asterisk * indicates significance at 5% level.

| *Variable* | Asia | Europe | NYLON | North America |
|---|---|---|---|---|
| *Return* | | | | |
| Mean | 0.0020 | 0.0078 | -0.0067 | 0.0076 |
| Std. Dev. | 0.4543 | 0.4524 | 0.3192 | 0.4255 |
| Skewness | -0.1900 | -0.1230 | -1.3077 | -0.0749 |
| Kurtosis | 8.0828 | 4.4468 | 14.684 | 17.564 |
| $Q_{LB}(12)$ | 50.162* | 20.823 | 31.385* | 57.644* |
| *Volatility* | | | | |
| Mean | 0.2326 | 0.2485 | 0.1092 | 0.2401 |
| Std. Dev. | 0.6887 | 0.4920 | 0.2447 | 0.5173 |
| Skewness | 32.238 | 23.620 | 15.810 | 8.9657 |
| Kurtosis | 483.585 | 928.900 | 369.794 | 107.746 |
| $Q_{LB}(12)$ | 50.162* | 20.823 | 31.385* | 57.644* |
| *Volume* | | | | |
| Mean | 2032.427 | 3197.217 | 1501.991 | 1662.861 |
| Std. Dev. | 1718.741 | 2610.793 | 1305.225 | 1559.119 |
| Skewness | 1.4368 | 1.3251 | 1.3406 | 2.1011 |
| Kurtosis | 3.0132 | 2.2263 | 2.1284 | 7.6782 |
| $Q_{LB}(12)$ | 50.162* | 20.823 | 31.385* | 57.644* |
| *Spread* | | | | |
| Mean | 3.0193 | 2.7880 | 2.7871 | 3.8538 |
| Std. Dev. | 1.5244 | 1.1901 | 1.2263 | 2.1143 |
| Skewness | 2.5456 | 1.6253 | 1.2367 | 1.6142 |
| Kurtosis | 21.593 | 5.5241 | 1.8771 | 4.3544 |
| $Q_{LB}(12)$ | 50.162* | 20.823 | 31.385* | 57.644* |
| *Order Flow* | | | | |
| Mean | 22.272 | 10.3867 | -0.7730 | 6.3212 |
| Std. Dev. | 158.808 | 206.0221 | 128.547 | 139.158 |
| Skewness | -0.1340 | -0.3135 | -0.3717 | -0.7010 |
| Kurtosis | 3.7240 | 2.8042 | 4.4580 | 7.5839 |
| $Q_{LB}(12)$ | 50.162* | 20.823 | 31.385* | 57.644* |

## References

Aït-Sahalia, Y., Mykland, P. A., & Zhang, L. (2005a). Ultra high frequency volatility estimation with dependent microstructure noise. National Bureau of Economic Research Working Paper. No. w11380.

Aït-Sahalia, Y., Mykland, P. A., & Zhang, L. (2005b). How often to sample a continuous-time process in the presence of market microstructure noise. Review of Financial studies, 18(2), 351-416.

Andersen, T. G., & Bollerslev, T. (1998). Deutsche mark–dollar volatility: intraday activity patterns, macroeconomic announcements, and longer run dependencies. The Journal of Finance, 53(1), 219-265.

Andersen, T. G., Bollerslev, T., & Diebold, F. X. (2007). Roughing it up: Including jump components in the measurement, modeling, and forecasting of return volatility. The Review of Economics and Statistics, 89(4), 701-720.

Andersen, T. G., Bollerslev, T., Diebold, F. X., & Vega, C. (2007). Real-time price discovery in global stock, bond and foreign exchange markets. Journal of International Economics, 73(2), 251-277.

Bandi, F. M., & Russell, J. R. (2008). Microstructure noise, realized variance, and optimal sampling. The Review of Economic Studies, 75(2), 339-369.

Bank for International Settlements. (2007), Foreign Exchange and Derivatives Market Activity in 2013. Triennial Central Bank Survey.

Barndorff-Nielsen, O. E., & Shephard, N. (2004). Power and bipower variation with stochastic volatility and jumps. Journal of Financial Econometrics, 2(1), 1-37.

Barndorff-Nielsen, O. E., & Shephard, N. (2006). Econometrics of testing for jumps in financial economics using bipower variation. Journal of Financial Econometrics, 4(1), 1-30.

Barndorff-Nielsen, O. E., Hansen, P. R., Lunde, A., & Shephard, N. (2008). Designing realized kernels to measure the ex post variation of equity prices in the presence of noise. Econometrica, 1481-1536.

Barndorff-Nielsen, O. E., Hansen, P. R., Lunde, A., & Shephard, N. (2009). Realized kernels in practice: Trades and quotes. The Econometrics Journal,12(3), C1-C32.

Bollerslev, T., & Domowitz, I. (1993). Trading patterns and prices in the interbank foreign exchange market. The Journal of Finance, 48(4), 1421-1443.

Booth, G. G., Lin, J. C., Martikainen, T., & Tse, Y. (2002). Trading and pricing in upstairs and downstairs stock markets. Review of Financial Studies, 15(4), 1111-1135.

Brandt, M. W., Kavajecz, K. A., & Underwood, S. E. (2007). Price discovery in the treasury futures market. Journal of Futures Markets, 27(11), 1021-1051

Dacorogna, M. M., Müller, U. A., Pictet, O. V., & De Vries, C. G. (2001). Extremal forex returns in extremely large data sets. Extremes, 4(2), 105-127.

Das, S. R. (2002). The surprise element: jumps in interest rates. Journal of Econometrics, 106(1), 27-65.

Dominguez, K. M., & Panthaki, F. (2006). What defines 'news' in foreign exchange markets? Journal of International Money and Finance, 25(1), 168-198.

Chai E., A.D. Lee, & J.X. Wang, (2015). Global Information Distribution in the Gold OTC Markets, International Review of Financial Analysis. 41, 206-217

Ehlers, T., & Packer, F. (2013). FX and derivatives markets in emerging economies and the internationalisation of their currencies. BIS Quarterly Review, December.

Ehrmann, M., & Fratzscher, M. (2005). Exchange rates and fundamentals: new evidence from real-time data. Journal of International Money and Finance, 24(2), 317-341.

Eraker, B., Johannes, M., & Polson, N. (2003). The impact of jumps in volatility and returns. The Journal of Finance, 58(3), 1269-1300.

Euromoney, May 2014, Euromoney Foreign Exchange Survey in 2014.

Evans, M. D., (2002), FX trading and exchange rate dynamics. Journal of Finance, 57(6), 2405–2447.

Evans, M. D., & Lyons, R. K. (2002a). Informational integration and FX trading. Journal of International Money and Finance, 21(6), 807-831.

Evans, M. D., & Lyons, R. K. (2002b). Time-varying liquidity in foreign exchange. Journal of Monetary Economics, 49(5), 1025-1051.

Evans, M. D., & Lyons, R. K. (2008). How is macro news transmitted to exchange rates? Journal of Financial Economics, 88(1), 26-50.

Fricke, C., & Menkhoff, L. (2011). Does the "Bund" dominate price discovery in Euro bond futures? Examining information shares. Journal of Banking & Finance, 35(5), 1057-1072.

Frijns, B., Gilbert, A., & Tourani-Rad, A. (2010). The dynamics of price discovery for cross-listed shares: evidence from Australia and New Zealand. Journal of Banking & Finance, 34(3), 498-508.

Glosten, L. R., & Milgrom, P. R. (1985). Bid, ask and transaction prices in a specialist market with heterogeneously informed traders. Journal of financial economics, 14(1), 71-100.

Grammig, J., Melvin, M., & Schlag, C. (2005). Internationally cross-listed stock prices during overlapping trading hours: price discovery and exchange rate effects. Journal of Empirical Finance, 12(1), 139-164.

Green, T. C. (2004). Economic news and the impact of trading on bond prices. The Journal of Finance, 59(3), 1201-1234.

Hansen, P. R., & Lunde, A. (2006). Realized variance and market microstructure noise. Journal of Business & Economic Statistics, 24(2), 127-161.

Hasbrouck, J. (1995). One security, many markets: Determining the contributions to price discovery. Journal of Finance, 1175-1199.

Hasbrouck, J. (2003). Intraday price formation in US equity index markets. The Journal of Finance, 58(6), 2375-2400.

Hendershott, T., & Jones, C. M. (2005). Trade-through prohibitions and market quality. Journal of Financial Markets, 8(1), 1-23.

Huang, R. D. (2002). The quality of ECN and Nasdaq market maker quotes. The Journal of Finance, 57(3), 1285-1319.

Huang, X., & Tauchen, G. (2005). The relative contribution of jumps to total price variance. Journal of financial econometrics, 3(4), 456-499.

Ito, T., Engle, R. F., & Lin, W. L. (1992). Where does the meteor shower come from? The role of stochastic policy coordination. Journal of International Economics, 32(3), 221-240.

Jiang, G., Lo, I., & Valente, G. (2014). High-frequency trading around macroeconomic news announcements: Evidence from the US treasury market. Bank of Canada Working Paper.

Killeen, W. P., Lyons, R. K., & Moore, M. J. (2006). Fixed versus flexible: Lessons from EMS order flow. Journal of International Money and Finance,25(4), 551-579.

King, M. R., Osler, C., & Rime, D. (2011). Foreign Exchange Market Structure, Players, and Evolution. Handbook of Exchange Rates, Norges Bank Research Department Working Paper.

Liu, J., Longstaff, F. A., & Pan, J. (2003). Dynamic asset allocation with event risk. The Journal of Finance, 58(1), 231-259.

Love, R., & Payne, R. (2008). Macroeconomic news, order flows, and exchange rates. Journal of Financial and Quantitative Analysis, 43(02), 467-488.

Melvin, M., & Taylor, M. P. (2009). The crisis in the foreign exchange market. Journal of International Money and Finance, 28(8), 1317-1330.

Melvin, M., & Yin, X. (2000). Public information arrival, exchange rate volatility, and quote frequency. The Economic Journal, 110(465), 644-661.

Menkveld, A. J., Sarkar, A., & Wel, M. V. D. (2012). Customer order flow, intermediaries, and discovery of the equilibrium risk-free rate. Journal of Financial and Quantitative Analysis, 47(04), 821-849.

Mizrach, B., & Neely, C. J. (2008). Information shares in the US Treasury market. Journal of Banking & Finance, 32(7), 1221-1233.

Moshirian, F., Nguyen, H.G., & Pham, P.K. (2012). Overnight public information, order placement, and price discovery during pre-opening period. Journal of Banking & Finance, 36(10), 2837-2851.

Pascual, R., Pascual-Fuster, B., & Climent, F. (2006). Cross-listing, price discovery and the informativeness of the trading process. Journal of Financial Markets, 9(2), 144-161.

Pasquariello, P., & Vega, C. (2007). Informed and strategic order flow in the bond markets. Review of Financial Studies, 20(6), 1975-2019.

Patel, V., Putniņš, T. J., & Michayluk, D. (2014). Price discovery in stock and options markets. Available at SSRN 2506712.

Phylaktis, K., & Chen, L. (2010). Asymmetric information, price discovery and macroeconomic announcements in FX market: do top trading banks know more?. International Journal of Finance & Economics, 15(3), 228-246.

Rime, D., & Schrimpf, A. (2013). The anatomy of the global FX market through the lens of the 2013 Triennial Survey. BIS Quarterly Review, December.

Tauchen, G., & Zhou, H. (2011). Realized jumps on financial markets and predicting credit spreads. Journal of Econometrics, 160(1), 102-118.

Upper, C., & Werner, T. (2002). Tail wags dog? Time-varying information shares in the Bund market. Deutsche Bundesbank, Economic Research Centre Working Paper, (24/02).

Wang, J., & Yang, M. (2011). Housewives of Tokyo versus the gnomes of Zurich: Measuring price discovery in sequential markets. Journal of Financial Markets, 14(1), 82-108.

Yin, X. (2005). A comparison of centralized and fragmented markets with costly search. The Journal of Finance, 60(3), 1567-1590.

Zhang, L., Mykland, P. A., & Aït-Sahalia, Y. (2005). A tale of two time scales: Determining Integrated. Volatility With Noisy High-Frequency Data, Journal of the American Statistical Association, 100(472).