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Sources of price discovery in the Australian dollar currency market

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Keywords
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Sources of Price Discovery in the Australian Dollar Currency Market

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Abstract

This paper examines the source of price discovery in the Australian Dollar currency market. The time-varying relationship between changes in quotes posted by cash market dealers and changes in currency futures quotes is estimated. The cash market quotations identify the eleven dealers posting the quotes, as well as geographical location of the dealers (Australia or overseas). Reported results show that price discovery originates in the cash market in any trading period. Amongst currency dealers, the results imply that local desks are price leaders during Australian trading hours. Though some foreign desks do contribute to price discovery during the European and US trading hours, price leadership of local desks is also found to extend to this period. These findings are consistent with the proposition that local desks can provide significant price discovery in the Australian Dollar currency market during Australian daytime.

JEL Classifications: G14

Keywords: Price discovery, futures, foreign exchange, Australian Dollar

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This paper is motivated by several research questions. Firstly, given that the foreign exchange spot market is opaque and order flows are not directly observable, does price determination occur in the futures market? It has been suggested by Dumas (1996) that the futures market is an unlikely source of price discovery, since foreign exchange turnover in the spot market is so overwhelmingly huge compared to that in the futures market. Secondly, are domestic (Australian) desks more informed than foreign desks? Hsieh and Kleidon (1996) provide evidence that the foreign exchange market is not integrated; the trading activity and volatility do not transmit from one location to another (e.g. London to New York), even though the markets are both trading at the same time. Further, Lyon (2001) shows that a trader's net position in one location is not transferred to another.[3] This implies that quotes of trading desks based in different locations may differ in information content, even though they may belong to the same bank. Thirdly, is there a relationship between price leadership and quote contribution? In other words, are frequent quote contributors viewed as price leaders? This paper adds to the literature by providing further insights into the interactions between domestic and foreign trading desks in the AUD currency market, as well as between the AUD futures and spot markets. Additionally, this study contributes to existing research (which is concentrated almost exclusively on the Japanese Yen and Deutsche Mark) by investigating the Australian Dollar currency market.

The remainder of this paper is structured as follows: Section 2 provides a discussion on the literature; Section 3 describes the data; Section 4 presents an overview of quote activity and volatility in spot and futures prices; Section 5 sets out the methodology of

[3] Individual dealers are responsible for managing their own positions, though the books containing customers' limit orders are normally transferred. As Lyons (2001) point out, these unexecuted orders are different from trading positions.

The other studies focus exclusively on either the currency spot or futures market. Ederington and Lee (1993 and 1995) examine the impact of macroeconomic announcements on the transaction prices of the Treasury Bond, Eurodollar and Deutsche Mark futures contracts traded on CBOT and CME. Peiers (1997) investigates the behaviour of price quotations in the Deutsche Mark cash market among the 6 most actively quoting banks following Bundesbank interventions. Dominguez (2003) repeats Peiers' analysis to examine price leadership around Federal Reserve interventions. Sapp (2002) expands the literature by comparing dealers' quoting behaviour across different time periods and economic conditions.

Given that currency traders are situated at various locations, a related research question is whether domestic or foreign dealers are better informed. Hau (2001) has previously shown that foreign traders in the German equities market significantly under-perform domestic traders, implying that domestic traders have an information advantage. Covrig and Melvin (2002) investigate this issue in the Japanese yen market and found that quotes posted by Japanese dealers lead the rest of the market, during periods of trading when the relative level of private information in the spot market is high. ogan and Batten (2005) analyse the USD/AUD market using just one month's data. Using a methodology loosely based on the correlation between the direction of quote variations of individual dealers and returns in the market prices, this study provides evidence that prices by Australia and New Zealand Bank (Singapore desk) are the most informed. DeJong et al. (2001) investigate the Deutsche Mark – Dollar market between 1992 and 1993 to test the hypothesis that German banks provide price leadership. The study found some evidence, in that prices of large German banks, the last the location of the trading desk. For example, the bank code "WBCA" stands for "Westpac Banking Corporation – Australia (Sydney desk)". The strength of the FXFX data lies in its ability to identify potential sources of heterogeneity, given that the data contains the names and locations of the quoting banks.

Two filters were applied to both the FXFX and futures data. First, quotes repeating the values of the immediately preceding quote were excluded if both were entered at the same time. Second, invalid quotes – quotes with values significantly different from surrounding quotes, due to typographical error for example – were also excluded.

4 An Overview of Quote Activity and Volatility in the AUD Spot and Futures Markets

The analysis in this paper begins with an overview of quote activity in the AUD spot and futures markets. Our analysis of quote activities suggest that, on an average daily basis, twice as many quotes are posted in the futures market than in the spot market. This is an interesting finding given the fact that the total foreign exchange turnover in the spot market dominates the futures market.

Figure 1 shows the average number of quotes posted in 5-minute intervals over a 24-hour day for the AUD spot and futures markets. It is clear that there is a correlation between the quote activities in the spot and the futures markets. The number of quotes posted appears to be increasing from about 06:30 GMT as the London market kicks into gear, tops out at about 08:00 as quote activities begin to dip progressively over market is still active. This affirms the importance of London as a foreign exchange location. Fourth, quote activities appear to be correlated between the spot and the futures markets.

Using the midpoint of quotes, standard deviation for each 5-minute interval is calculated for both the AUD spot and futures market, as illustrated in Figure 2. Consistent with prior literature (Hsieh and Kleidon, 1996, Hogan and Batten, 2005), a U-shape pattern is observed during the European trading day, with spikes as the Australian, London and US markets open. Additionally, it appears that volatility in the spot market is higher, especially during Australian trading hours.

Figure 2. Standard deviation of midpoint of quotes for the AUD spot and futures markets by 5-min intervals. This plot depicts the standard deviations of midpoint of quotes by 5-minutes intervals for the AUD spot and futures markets. The sample period covers from January 1 2001 to December 31 2004. The European trading period, approximately 6:30am to 6:00pm GMT, is represented by the area between the dotted vertical lines.

Table 1
Descriptive Statistics of Quote Updates for Eleven Selected Dealers in the AUD Currency Market

This table reports descriptive statistics of quotes contribution by the eleven selected AUD spot dealers for the sample period January 1 2001 to December 31 2004. Selection is based on frequency of quote updates and length of sample for each dealer. The "Rank" column ranks the eleven dealers by the total number of posted quotes. The "Bank Code" column lists the Reuters four-alpha codes for each individual dealer. The total number of quote updates provided by each dealer is reported in the "Total Number of Quotes" column. The "Percentage of Total" column presents the total number of quotes by each dealer as a proportion of the total number of quotes posted by all dealers in the dataset. The last two columns, headed "Average Spread" and "Min/Max of Spread", provide summary statistics for the bid-ask spread posted by each dealer in pips, where 1 pip = US$.0001.

Rank	*Bank Code*	*Bank*	*Location*	*Total Number of Quotes*	*Percentage of Total*	*Average Spread (pips)*	*Min/Max of Spread (pips)*
Panel A: Domestic Desks							
1	DEUA	Deutsche Bank	Sydney	372059	10.97%	*5*	*5 / 6*
4	WBCA†	Westpac Bank	Sydney	162044	4.78%	*5*	*5 / 5*
12	RBOZ	Royal Bank of Canada	Sydney	45245	1.33%	*5*	*5 / 5*
14	NATA†*	National Australia Bank	Sydney	35073	1.24%	*5*	*5 / 5*
16	MAQA†	Macquarie Bank	Sydney	19680	1.09%	*5*	*5 / 5*
Panel B: Foreign Desks							
2	HKIB*	HSBC Bank	London	367162	10.82%	*5*	*5 / 6*
3	CIBC*	Canadian Imperial Bank of Commerce	Toronto	306118	9.03%	*5*	*5 / 5*
6	AMRU	ABN AMRO	Amsterdam	143252	4.22%	*3*	*3 / 4*
9	RBSN	Royal Bank of Scotland	New York	122804	3.62%	*4*	*4 / 4*
10	ANZL†*	Australia & New Zealand Bank	London	50899	1.50%	*5*	*5 / 5*
11	WBCL†*	Westpac Bank	London	42541	1.25%	*5*	*5 / 5*

† denotes Australian banks.
* denotes dealers who do not provide quotes for the entire 24-hour period.

Quote activities are less active for the other domestic desks. In comparison, foreign desks appear to be more varied and active in terms of quote contribution, though it is interesting to note that the foreign desks of domestic banks appear to be less active in this regard. Out of the eleven dealers, 6 of them are active throughout the 24-hour day. These dealers contributed 55.23% of all quotes in the data. Sydney is the major

(1969) causality test. Finally, the transmission of volatility, as proxy for information flows, between the spot and futures market is investigated. The examination of the transmission of volatility between markets is a methodology that is frequently adopted in studies examining the source of price discovery between stock index futures and the underlying spot market.

Analysis is separated into two parts. The first part compares only the futures and spot prices, with the latter consisting of quotes by all dealers. This provides an "overall" comparison between the two markets. The second part provides a deeper analysis by also including quotes by selected dealers as shown in Table 1.

5.1 Preparation of Data

Given the disparity in the number of quotes between the spot and futures market, observations have to be adjusted to reflect similar periodicities so as to allow comparisons between them. McInish and Wood (1992) suggest standardising each quote by how long it is alive in the interval.[8] The sampling methodology used in this study is guided by McInish and Wood (1992) in this regard, the process of which is described as follows. In an interval $[T, T']$ where there are N quotes occurring at time t_i, $i = 1, 2, .., N$, the length of time in which a quote is alive, $t_{i+1} - t_i$, is calculated for each natural log of midpoint of quote. Time t_i is measured in seconds. The interval $[T, T']$ is set at 15 minutes to ensure that there is at least 1 quote in each interval for each price series. The total length of time in which all quotes in the interval are alive, $t_{N+1} - t_1$, is calculated for each interval. Time-weight is assigned to each quote as a

[8] Peiers (1997) also standardises quote revisions in similar fashion, albeit in a slightly modified form.

Figure 3. Daily average prices of the AUD futures and spot markets. This plot depicts the daily average mid-prices (sum of bid and ask quotes divided by 2) of the Australian Dollar futures and spot markets for the sample period January 1 2000 to December 31 2004.

Accordingly, the presence of a cointegrating relationship is first examined, before the main analysis, using the methodology specified in Engle and Granger (1987). Two price series are cointegrated if the following two conditions are satisfied: (1) each price series is integrated in the same order, and (2) the linear combination of both non-stationary series is stationary. Therefore, each price series is first examined for stationarity by testing for the presence of a unit root. Many practitioners rely on the augmented Dickey-Fuller (1981) test for this purpose. However, as Perron (1989) notes, failing to account for at least one time structural change in the trend function may bias towards the non-rejection of the null hypothesis[9]. As can be seen in Figure 3, there may possibly exist an exogenous structural break in the prices that may bias the conventional unit root test. Therefore, the unit root test used in this study needs to take

[9] Null: $y_t = \alpha + y_{t-1} + e_t$

Table 2

Unit Root Tests With and Without Consideration for Structural Break

This table presents the results of three unit root tests performed on the time-weighted quote midpoints of the USD/AUD futures, spot (all dealers' quotes included) and eleven selected foreign exchange dealers' series for the sample period January 1 2001 to December 31 2004. Panel A presents the results for the AUD spot and futures markets, while results for the eleven selected AUD foreign exchange dealers are documented in Panel B. The second and third columns shows the t_{δ} of the augmented Dickey-Fuller (1979) test performed on the level series and after first difference, respectively. The null hypothesis (δ=0) is rejected after first difference for both series according to MacKinnon's (1991) critical values (τ=-2.57 at 1%). The structural break test results for Zivot & Andrews's (1992) model C (equation 3.5) and Perron (1997) (equation 3.6) are shown in the next columns. In both tests, the null hypotheses stipulate that the series is integrated without exogenous structural break. *TB* is the date of the one structural break that minimises the test statistic t_{α}. The truncation lag parameter, *k*, is selected according to Perron's (1995) general-to-specific recursive method. The critical values for both Zivot and Andrews (1992) and Perron (1997) tests are -4.82 (10%), -5.08 (5%) and -5.57 (1%) as discussed in the respective studies.

	ADF		**Zivot & Andrews (1992)**			**Perron (1997)**		
	Level t_{δ}	*First Difference* t_{δ}	*TB*	*k*	t_{α}	*TB*	*k*	t_{α}
Panel A:								
Futures	-2.83	-33.92*	Sept 3 2003	2	-3.62	Sept 3 2003	2	-3.60
Spot	-2.70	-36.29*	Sept 3 2003	2	-3.58	Sept 3 2003	2	-3.56
Panel B: AUD Dealers								
DEUA	-2.45	-26.56*	Sept 3 2003	2	-3.32	Sept 3 2003	2	-3.30
WBCA	-2.69	-28.42*	Sept 3 2003	2	-3.28	Sept 3 2003	2	-3.37
NATA	-2.59	-27.85*	Sept 3 2003	2	-3.33	Sept 3 2003	2	-3.30
RBOZ	-2.59	-23.17*	Sept 3 2003	2	-3.65	Sept 3 2003	2	-3.66
MAQA	-2.59	-23.32*	Sept 3 2003	2	-3.21	Sept 3 2003	2	-3.18
HKIB	-2.33	-24.35*	Sept 3 2003	1	-3.25	Sept 3 2003	1	-3.24
CIBC	-2.73	-21.95*	Sept 3 2003	2	-3.64	Sept 3 2003	2	-3.57
AMRU	-2.82	-24.42*	Sept 3 2003	1	-3.34	Sept 3 2003	1	-3.37
RBSN	-2.50	-22.38*	Sept 3 2003	2	-3.37	Sept 3 2003	2	-3.88
ANZL	-2.65	-21.96*	Sept 3 2003	2	-3.26	Sept 3 2003	2	-3.26
WBCL	-2.76	-27.06*	Sept 3 2003	2	-3.33	Sept 3 2003	2	-3.32

* denotes significance at the 0.01 level

5.3 *Cointegration Tests*

If the price series $\{Y_t\}$ and $\{X_t\}$ are integrated in the same order, then the test for non-cointegration is to assess if the estimated residuals $\hat{\xi}_t$ from equation $Y_t = \hat{\varphi}_1 + \hat{\varphi}_2 X_t + \hat{\xi}_t$ are I(1) using the augmented Dickey-Fuller (1979) test:

Price series from the futures, spot and eleven selected foreign exchange dealers are tested for non-cointegration in accordance to Engle and Granger (1987). The futures-cash paired price series F_t and S_t are tested in Panel A, in which regression specification $F_t = \varphi_1 + \varphi_2 S_t + \xi_t$ is first performed. In Panels B and C, regressions specified as $F_t = \varphi_1 + \varphi_2 S_t + \varphi_3 S_t^k + \xi_t$ are run for each foreign exchange dealer k. The estimated residuals $\hat{\xi}_t$ are then tested for stationarity via the equation $\Delta\hat{\xi}_t = \gamma\hat{\xi}_{t-1} + \sum_{i=1}^{p}\alpha_i \Delta\hat{\xi}_{t-i} + \mu_t$ whereby the lag length parameter p is determined by the Schwarz information criterion. The null hypothesis of no cointegration stipulates that the coefficient γ is 0. The test statistic t_γ is presented. MacKinnon's (1991) critical values are used to test the null hypothesis. The null hypothesis is rejected in all cases. Given 2 variables in Panel A, and 3 variables for each foreign exchange dealers in Panels B and C, there can be at most 1 and 2 cointegrating vectors respectively.

	γ	t_γ		*Maximum Possible Number of Cointegrating Vectors*
Panel A:				
Overall (Spot and Futures)	-0.004	-7.20	**	1
Panel B: Domestic Desks				
Deutsche Bank	-0.005	-6.47	**	2
Westpac Bank	-0.005	-5.65	**	2
National Australia Bank	-0.015	-6.25	**	2
Royal Bank of Canada	-0.006	-5.17	**	2
Macquarie Bank	-0.012	-5.35	**	2
Panel C: Foreign Desks				
HSBC Bank	-0.003	-6.23	**	2
Canadian Imperial Bank of Commerce	-0.005	-6.73	**	2
ABN AMRO	-0.003	-4.76	**	2
Royal Bank of Scotland	-0.010	-4.10	**	2
Australia & New Zealand Bank (London)	-0.006	-5.44	**	2
Westpac Bank (London)	-0.004	-4.93	**	2

** denotes rejection of the null hypothesis at the 0.01 level

Table 4 reports the trace statistics and maximum eigenvalues (Max-Eigen) from the Johansen cointegration tests. Panel A presents the cointegration test results for the AUD futures-cash price pair, while Panels B and C report results for the combination of futures, cash and dealer's price series. Panel A shows that there is 1 cointegrating equation in the combination of AUD futures and spot price series, and 2 cointegrating equations for each dealer, given 3 price series (futures, spot and dealers' price series).

		$r \leq 2$	5.34	5.34
ANZ Bank (London)	3	$r = 0$	4167.89*	4109.41*
		$r \leq 1$	58.48*	48.81*
		$r \leq 2$	9.67	9.67
Westpac Bank (London)	6	$r = 0$	2523.80*	2482.09*
		$r \leq 1$	41.71*	31.23*
		$r \leq 2$	10.48	10.48

* Denotes rejection at the 0.01 level

Having established that the price series are cointegrated with up to 2 cointegrating vectors, the next section discusses the error correction specifications.

5.4 Error Correction Models

Given that the trading of currencies is relatively uninhibited, we expect prices in currency futures or spot markets to be very close in the long run, not withstanding cost-of-carry or microstructural considerations. Given the hypothesis that the currency spot market is the main contributor to price discovery, each error correction model is estimated using two price differentials which include spot prices in each error correction term: $\lambda_1 = S_t - F_t$ and $\lambda_2 = S_t - S_t^d$. That is, the first cointegrating equation represents price differentials between spot and futures prices, and the second cointegrating equation represents price differentials between spot prices and prices of individual currency dealers. Therefore, in the cointegrating vector (γ^{spot}, γ^{future} and γ^{dealer}), a condition is set in the Johansen estimation whereby γ^{spot} is normalised, i.e. set to one.[10] Given the long-run price equilibrium between these three price series, the normalised values of γ^{spot} and γ^{future} are expected to be one and negative one respectively. The same is expected in regards to the normalised values of

[10] In Harris et al. (1995), Eun and Sabherwal (2003) and Lok and Kalev (2005), the cointegrating vector is normalised with respect to the home market where price discovery is expected to take place. Likewise, γ^{spot} is set to one in this study on the expectation that price discovery originates from the spot market.

The second branch of the analysis studies currency dealers' contributions to price discovery. The error correction models for each currency dealer d are specified as follows:

$$\Delta F_t = \alpha_1 + \lambda_1^{future}(S_t - \gamma^{future} F_t)_{-1} + \lambda_2^{future}(S_t - \gamma^{dealer} S_t^d)_{-1} + \sum_{i=1}^{i} \beta_i \Delta S_{t-i} + \sum_{j=1}^{j} \delta_j \Delta F_{t-j} + \sum_{k=1}^{k} \phi_k S_{t-k}^d + \varepsilon_t \quad (5)$$

$$\Delta S_t = \alpha_2 + \lambda_1^{spot}(S_t - \gamma^{future} F_t)_{-1} + \lambda_2^{spot}(S_t - \gamma^{dealer} S_t^d)_{-1} + \sum_{i=1}^{i} \beta_i \Delta S_{t-i} + \sum_{j=1}^{j} \delta_j \Delta F_{t-j} + \sum_{k=1}^{k} \phi_k S_{t-k}^d + \varepsilon_t \quad (6)$$

$$\Delta S_t^d = \alpha_3 + \lambda_1^{dealer}(S_t - \gamma^{future} F_t)_{-1} + \lambda_2^{dealer}(S_t - \gamma^{dealer} S_t^d)_{-1} + \sum_{i=1}^{i} \beta_i \Delta S_{t-i} + \sum_{j=1}^{j} \delta_j \Delta F_{t-j} + \sum_{k=1}^{k} \phi_k S_{t-k}^d + \varepsilon_t \quad (7)$$

where $\alpha_1 \neq \alpha_2 \neq \alpha_3 \neq 0$, $i = j = k$ and

ΔS_t^d = returns of time-weighted midpoint of AUD currency dealer d in interval t.

$\lambda_1(futures, spot, dealer) =$ first error correction coefficient which measures the magnitude of price adjustment in interval t given price differentials between spot and futures price series in interval t - 1.

$\lambda_2(futures, spot, dealer) =$ second error correction coefficient which measures the magnitude of price adjustment in interval t given price differentials between spot and dealers' price series in interval t - 1.

For a cleaner experiment, when comparing futures quotes, spot quotes and quotes by selected dealer d, the quotes by dealer d are excluded when constructing the series of differentials between the two price series in the prior interval. This represents ostensible evidence that both markets provide price discovery in the AUD currency market. Therefore, the next step of the analysis considers which price series exerts a greater influence on the determination of prices. The error correction coefficients can be used to assess the relative strength of the price series in this regard.

Comparing the error correction coefficients λ_1^{future} and λ_1^{spot} provides better insight into the adjustment process. First, the coefficient λ_1^{spot}, representing the magnitude of price adjustment in the spot market, is smaller in absolute value than the magnitude of price adjustment in futures prices, λ_1^{future}. This suggests that reactions in the spot market to price differential as defined by the cointegrating equation are generally smaller than reactions in the futures market.

Interpretation of the results is intuitive: looking at Panel A of Table 5, if the spot price is 1 percent higher than the futures price in the prior interval, error correction takes place in the current interval, so that the spot price decreases by 0.009%, while the futures price increases by 0.025%.

Given that the magnitude of price adjustment is greater in the futures market than in the spot market, it can be concluded that the spot prices are dominant, while futures prices are considered satellite[11]. This is consistent with the hypothesis that the currency spot market is the main contributor to price discovery.

[11] The dominant and satellite market argument developed in Garbade and Silber (1979) is useful here. Generally, a market is considered dominant if exerts a greater influence on price discovery. Conversely, a market that contributes less to price discovery is satellite.

Table 5
Estimation Results: Australian Trading Period

This table reports the test results of the error correction models for the Australian trading period (21:00 to 07:00 GMT). The sample period covers January 1 2001 to December 31 2004. Panel A reports the estimation results for equations (3) and (4), while Panels B and C present the test results for equations (5) to (7). Only results of the cointegrating vectors, λ_1 and λ_2 are reported. λ_1 measures the magnitude of price adjustment in the respective series, given the price deviation between the spot and futures markets in the previous period. λ_2 measures the magnitude of price adjustment in the respective series, given the deviation between the prices of spot market and individual dealers in the previous period. For comparison, the absolute values of the coefficients are summed with each coefficient expressed as a percentage of the total. The *t*-statistics are reported in parentheses. *N* denotes the number of 15-minute intervals.

			Price Differentials Between Futures and Spot			**Price Differentials Between Spot and Dealer**		
	Lags	N	λ_1^{future}	λ_1^{dealer}	λ_1^{spot}	λ_2^{future}	λ_2^{dealer}	λ_2^{spot}
Panel A:								
Overall (Spot and Futures)	7	27907	0.018	—	-0.009	—	—	—
			(3.46)		(-2.39)			
			67.44%	—	32.56%			
Panel B: Domestic Desks								
Deutsche Bank	4	14793	0.026	-0.014	-0.015	-0.436	0.189	-0.908
			(3.16)	(-1.73)	(-1.90)	(-2.47)	(1.08)	(-5.20)
			46.88%	25.32%	27.80%	28.44%	12.32%	59.23%
Westpac Bank	4	15045	0.023	-0.013	-0.016	-0.251	0.179	-0.652
			(3.21)	(-1.86)	(-2.26)	(-1.68)	(1.19)	(-4.34)
			43.74%	25.37%	30.89%	23.23%	16.52%	60.25%
Royal Bank of Canada	2	3542	0.010	-0.002	-0.005	-0.260	0.358	-0.431
			(0.78)	(-0.17)	(-0.35)	(-0.81)	(1.10)	(-1.33)
			59.86%	13.40%	26.74%	24.82%	34.10%	41.09%

Given the correlation between spot and dealers'prices, it follows that the second error correction coefficient, λ_2, provides better insights into the price discovery process for currency dealers. Given the high concentration of actively quoting currency desks in the AD spot market, certain desks may be pe rceived as price leaders by the markets and hence are able to exert a significant price discovery influence. Therefore, the magnitude of error correction adjustment is expected to be smaller for those dealers, compared to the spot and futures markets. The results reported in Table 3-6 provide support for this theory, given that the magnitude of error correction adjustments, λ_2^{dealer}, for the three most actively quoting domestic desks (Deutsche Bank, Westpac Bank and Royal Bank of Canada), are smaller than λ_2^{spot}. In particular, the coefficients for Deutsche Bank and Westpac Bank are almost identical, while the coefficient for Royal Bank of Canada is almost twice as large.

Additionally, the error correction coefficients are not statistically significant, implying that the prices of these dealers do not significantly depend on spot prices in general. There is no evidence to make the same conclusion for the other three desks (two domestic and one foreign).

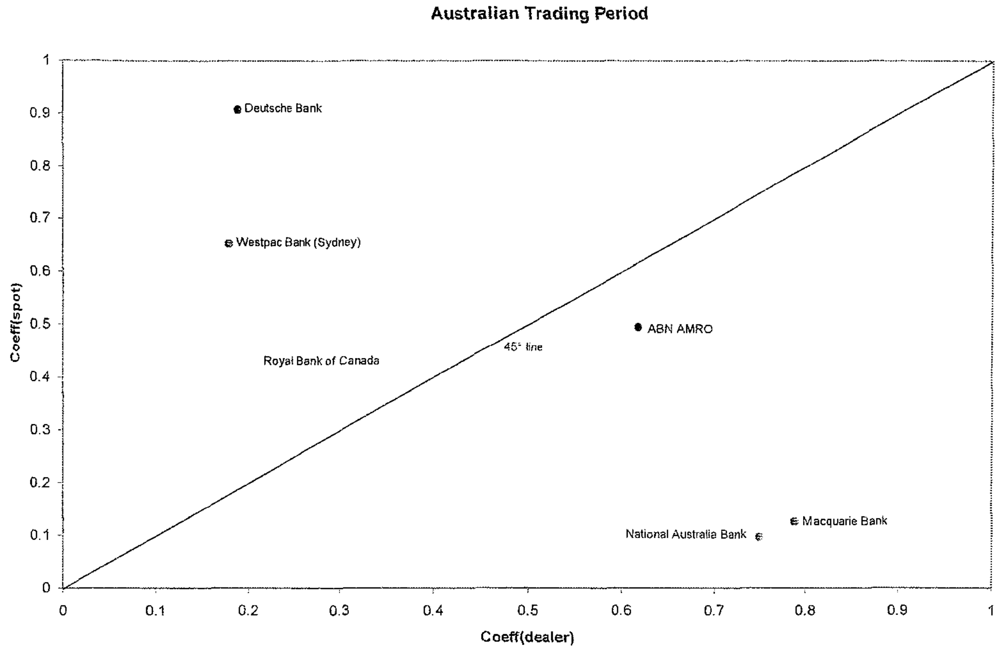
Table 6 (con't)

	Lags	N	Price Differentials Between Futures and Spot λ_1^{future}	λ_1^{dealer}	λ_1^{spot}	Price Differentials Between Spot and Dealer λ_2^{future}	λ_2^{dealer}	λ_2^{spot}
Panel C: Foreign Desks								
HSBC Bank	7	32570	0.006	-0.002	-0.003	-0.028	0.100	-0.174
			(2.47)	(-1.05)	(-1.09)	(-0.25)	(1.39)	(-1.04)
			54.15%	22.58%	23.26%	9.27%	33.11%	57.62%
Canadian Imperial Bank	4	28689	0.010	-0.003	-0.004	-0.107	0.583	-0.203
			(3.04)	(-1.08)	(-1.24)	(-1.36)	(7.59)	(-2.64)
			57.17%	19.86%	22.97%	11.98%	65.26%	22.77%
ABN AMRO	4	15272	0.009	-0.005	-0.005	-0.384	0.143	-0.408
			(1.71)	(-1.04)	(-0.95)	(-2.22)	(1.25)	(-3.20)
			46.38%	28.20%	25.42%	41.07%	15.29%	43.64%
Royal Bank of Scotland	3	20779	-0.019	-0.034	-0.034	-0.669	0.361	-0.826
			(-1.22)	(-2.20)	(-2.20)	(-1.44)	(0.77)	(-1.78)
			21.76%	39.29%	38.95%	36.07%	19.44%	44.49%
ANZ Bank (London)	3	20577	0.011	-0.004	-0.003	-0.103	0.727	-0.170
			(2.49)	(-0.94)	(-0.72)	(-1.62)	(11.36)	(-2.71)
			60.08%	22.86%	17.05%	10.33%	72.67%	17.00%
Westpac Bank (London)	4	22189	0.011	-0.006	-0.006	-0.257	0.548	-0.275
			(2.85)	(-1.51)	(-1.60)	(-4.05)	(8.29)	(-4.40)
			47.52%	26.19%	26.28%	23.81%	50.73%	25.46%

price adjustments as defined by λ_1^{spot}, given that the λ_1^{dealer} and λ_1^{spot} coefficients are virtually identical (different by less than 5 percent) for all dealers (the only exception being Macquarie Bank). Looking at the error correction coefficient for dealers, λ_2^{dealer}, in the second cointegrating equation, shows that the magnitude of price adjustment is smaller than λ_2^{spot} for 2 out of 3 domestic desks, and 3 out of 6 foreign desks respectively. Amongst the domestic desks, evidence provided for the European + US trading period highlights the importance of both Deutsche Bank and Westpac Bank in their respective price discovery roles. This further affirms their position as price leaders given the same findings for the Australian trading period. It is important to note that they are the only currency dealers which have been shown to be dominant in terms of price discovery in both trading periods. In this regard, Deutsche Bank appears to be stronger than Westpac Bank.

Panel C (of Table 7) shows that the magnitudes of the λ_2^{dealer} coefficient are lower than the respective λ_2^{spot} coefficient in absolute value for the following three foreign desks, namely, HSBC Bank (London desk), ABN AMRO (Amsterdam desk) and Royal Bank of Scotland (New York desk), for the European + US trading period. It is important to note that there is no reported evidence to suggest the same for two Australian banks (Westpac Bank and ANZ Bank) where both trading desks are based in London for this trading period. In particular, prices of Westpac Bank's Sydney desk appear to be dominant, whereas this is not so for its London desk. This confirms the notion that the trading position for each foreign exchange desk is unique. Interestingly, prices of ABN AMRO (Amsterdam desk) — the only foreign desk which provides quotes in both trading periods — are shown to be influential in terms of price discovery for the European + US trading period, but not so for the Australian

Panel A: Australian Trading Period



Panel B: European + US Trading Period

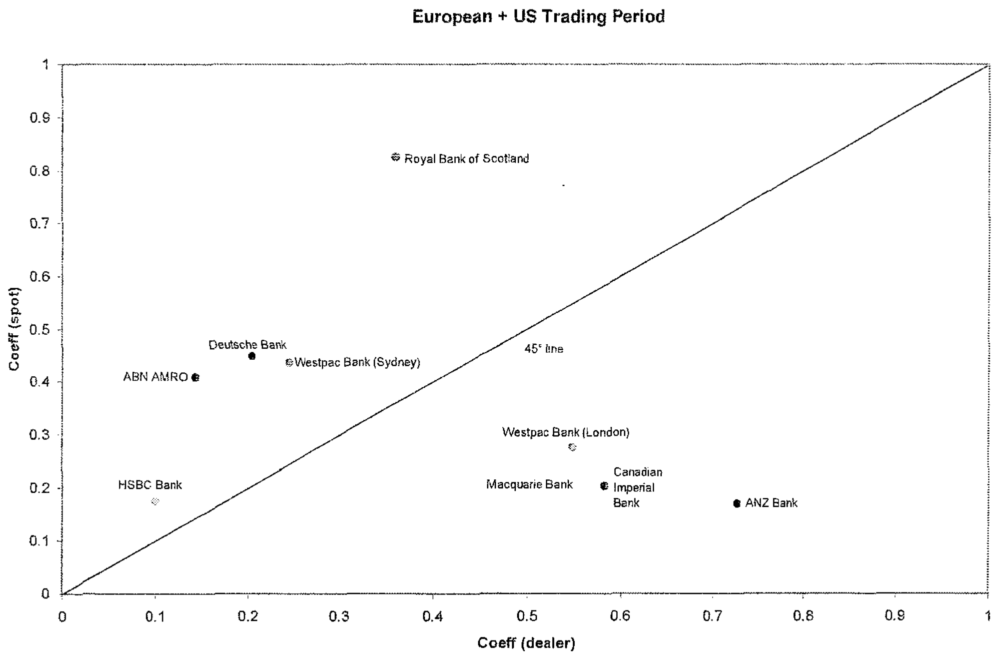


Figure 4. Scatter plot (by trading period) of $|\lambda_2^{spot}|$ against λ_2^{dealer}. This plot depicts the comparison of error correction coefficients $|\lambda_2^{spot}|$ (y-axis) and λ_2^{dealer} (x-axis) for selected currency dealers in the USD/AUD market by trading period. Price discovery is evident if the node deviates away from the 45° line. Dealer's prices are more dominant than spot prices in terms of price discovery if the respective node lies above the 45° line, and vice versa.

prices do on current spot prices. The dominance of spot prices over futures prices is further confirmed by these results.

Panel B (of Table 7) reports the results of the Granger test for domestic desks. The first observation to be made is that prices of all desks exhibit one-direction Granger-causality relationship with futures prices in the Australian trading period, while the causality relationships become bidirectional for most desks in the European + US trading period. Similarly, the results also provide evidence of one-way causality between prices of some desks and spot prices in the Australian trading period, which also becomes bidirectional in the European + US trading period. See, for example, Deutsche Bank and Westpac Bank, whose prices dominate over spot prices in terms of causality in the Australian trading period, though spot prices appear to strengthen against their prices in the European + US trading period.

There is a rational explanation for these phenomena. To begin, it is important to note that Australian and US trading hours are mutually exclusive. It follows that major news releases and announcements which affect either the Australian dollar or the US dollar take place during their respective trading hours. During Australian trading hours, domestic desks are expected to be better informed than their foreign counterparts (due to superior efficiency and access to information) about domestic market elements which affect the pricing of the Australian dollar component in the USD/AUD equilibrium exchange rate. For example, information about movements in the Australian interest rate is more readily discerned by domestic desks. Because of this information advantage, domestic desks are able to set better prices, which are consequently perceived to be informed. As an example, recall that in Table 5, ABN

Table 7
Granger-Causality Test Results:Overall Spot-Futures Analysis and Domestic Desks

This table presents the Granger-causality results for the AUD currency domestic desks as well as for the overall spot and futures markets. F_t and S_t represent the futures and spot price series, respectively. The 4-character alpha codes are the respective dealer's RIC code from Reuter's database. The sample period covers January 1 2001 to December 31 2004. Results are separated by trading periods. "Australian" columns report results for the Australian trading period (21:00 to 07:00 GMT), while "European + US" columns present results for the European + US trading period (06:30 to 21:00 GMT).

		Australian				**European +US**			
	Null Hypothesis	*Lags*	*Obs*	*F-statistic*		*Lags*	*Obs*	*F-statistic*	
Panel A:									
Overall (Spot and Futures)	F_t does not Granger Cause S_t	7	27907	3.16	**	10	54192	4.08	**
	S_t does not Granger Cause F_t			21.49	**			152.19	**

Table 8
Granger-Causality Test Results:Foreign Desks

This table presents the Granger-causality results for AUD currency foreign desks. F_t and S_t represent the futures and spot price series, respectively. The 4-character alpha codes are the respective dealer's RIC code from Reuter's database. The sample period covers January 1 2001 to December 31 2004. Results are separated by trading periods. "Australian" columns report results for the Australian trading period (21:00 to 07:00 GMT), while "European + US" columns present results for the European + US trading period (06:30 to 21:00 GMT).

		Australian				**European +US**			
	Null Hypothesis	*Lags*	*Obs*	*F-statistic*		*Lags*	*Obs*	*F-statistic*	
ABN AMRO	$AMRU_t$ does not Granger Cause F_t	1	2224	0.28		4	15272	0.75	
	F_t does not Granger Cause $AMRU_t$			0.01				8.44	**
	S_t does not Granger Cause $AMRU_t$			12.20	**			2.88	*
	$AMRU_t$ does not Granger Cause S_t			3.20				5.84	**
HSBC Bank	$HSBC_t$ does not Granger Cause F_t			—		11	32570	18.63	**
	F_t does not Granger Cause $HSBC_t$			—				3.81	**
	S_t does not Granger Cause $HSBC_t$			—				6.42	**
	$HSBC_t$ does not Granger Cause S_t			—				12.81	**
Canadian Imperial Bank	$CIBC_t$ does not Granger Cause F_t			—		4	28689	60.56	**
	F_t does not Granger Cause $CIBC_t$			—				24.57	**
	S_t does not Granger Cause $CIBC_t$			—				105.96	**
	$CIBC_t$ does not Granger Cause S_t			—				6.37	**

While the results of the Granger-causality tests shown previously provide evidence, through the observation of the F-statistics, that lagged prices of some desks exert more influence on current futures prices than lagged futures prices on current prices of trading desks, there is one additional point that can be readily observed: these test results, which highlight the short-run time-varying interactions between the price series, provide solid support for results reported in the long-run analysis, as presented previously. Compare the results in Tables 7 and 8 with Figure 4; for example, Panel A of Figure 4 shows that the error correction coefficient $\left|\lambda_2^{spot}\right|$ is higher than λ_2^{dealer} for three domestic desks during the Australian trading hours, namely, Deutsche Bank, Westpac Bank and Royal Bank of Canada. This implies that prices of these dealers are more dominant than spot prices, given the relatively larger magnitude of price adjustments in spot prices. Panel B of Table 7 provides support of these findings by reporting results which show that the prices of these dealers Granger-caused spot prices. Therefore, the dominance of these dealers as price leaders in this trading period is conclusively supported by the short and long-run evidence. Likewise, prices of trading desks not shown to be dominant in the long-run are also shown not to Granger-cause spot prices (see for example Macquarie Bank and National Australia Bank). This finding is also consistent for results for foreign desks during the European + US hours. Though there is bidirectional causality between dealers' and spot prices, the respective F-statistics testing the null hypothesis that dealers' prices do not Granger-cause spot prices is larger for the respective long-run price leaders.

6.3 Transmission of Volatility

The final analysis examines the transmission of volatility between the spot and futures markets as a proxy for information flow. This analysis is frequently adopted in studies

Table 9

Transmission of Volatility between AUD Spot and Futures Markets

This table presents the Granger-causality results examining the transmission of volatility between the AUD spot and futures market. F_t and S_t represent the futures and spot price series, respectively. The sample period covers January 1 2001 to December 31 2004. Results are separated by trading periods. "Australian" columns report results for the Australian trading period (21:00 to 07:00 GMT), while "European + US" columns present results for the European + US trading period (06:30 to 21:00 GMT).

	Australian				European + US			
Null Hypothesis	*Lags*	*Obs*	*F-statistic*		*Lags*	*Obs*	*F-statistic*	
V_t^s does not Granger Cause V_t^f	3	82616	145.88	**	3	153990	420.59	**
V_t^f does not Granger Cause V_t^s			139.61	**			124.57	**
V_t^s does not Granger Cause V_t^f	6	82616	66.04	**	6	153990	175.61	**
V_t^f does not Granger Cause V_t^s			43.69	**			42.44	**
V_t^s does not Granger Cause V_t^f	12	82616	18.98	**	12	153990	62.14	**
V_t^f does not Granger Cause V_t^s			10.90	**			12.02	**

** denotes significance at the 0.01 level

Further, an examination of the F-statistics reveals that, generally, lagged spot volatilities are more influential on current futures volatilities than lagged futures volatilities are on spot volatilities. Additionally, the causality relationship appears to strengthen during European + US trading hours. This finding somewhat contradicts Crain and Lee (1995), who provide significant evidence of one-way transfer of volatility from the futures to spot, on news announcement and non-announcement days for the Eurodollar and Deutsche Mark currency markets.

Overall, the results examining the transmission of volatility between the spot and futures markets provide a complementary perspective to findings presented previously.

Westpac Bank and Royal Bank of Canada dominate both futures and spot prices. Foreign desks do not contribute to price discovery during Australian trading hours given that most of them do not provide quotes in this period. In the European and US trading period, strong evidence is documented that suggests that prices of two domestic desks (Deutsche Bank and Westpac Bank) continue to dominate futures and spot prices. These findings confirm their status as price leaders. Amongst the foreign desks, results show that prices of HSBC Bank, ABN AMRO and Royal Bank of Scotland are influential in terms of price discovery during the European and US trading hours.

Given that the AUD futures contracts are traded on two futures exchanges — one in the US and the other in Sydney — inclusion of futures prices from the Sydney Futures Exchange (SFE) in future research would provide a better location-based analysis.[14] In particular, it may be possible to examine price interactions between spot and futures markets in instances where dealers are active in both markets. In this context, Appendix B of this dissertation highlights Deutsche Bank's quote activities in the AUD futures contract traded on the SFE.

The inclusion of foreign exchange transaction information using transaction data (identifiable by dealer and location of desk) will provide the opportunity for future researchers to investigate, for example, whether price leaders in the currency market are also those with the largest turnover. This may not be far away, as more data is becoming available, given currency dealers' increased participation in electronic broking services.

[14] The AUD futures contract on the CME is selected for the purpose of analysis in this essay given its superior liquidity over its counterpart on the SFE.

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