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International Linkages and Macroeconomic News Effects on Interest Rate Volatility - Australia and the US*

by

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ABSTRACT

We examine international linkages between daily time series of US and Australian 3 month Treasury Bills and 10 year Government Bonds from 1987-95, paying particular attention to the effects of macroeconomic announcements in both countries. The 2 country's interest rate data are modelled by a bivariate EGARCH formulation. The results suggest that market participants believed the Reserve Bank of Australia targetted the CPI, while the Federal Reserve targetted economic activity. US macroeconomic activity announcements significantly moved Australian interest rates, particularly at the short end. Australian interest rates moved significantly in response to the previous day's US interest rate shocks. The conditional volatilities of the Australian interest rate changes were also significantly influenced by lagged US interest rate shocks, as well as by surprises in US macroeconomic announcements. Some macroeconomic news announcements raised conditional volatilities, while others reduced them. Overall there was a remarkable and complex array of linkages between the 2 countries.

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I. Introduction

While there is a fair consensus about which macroeconomic variables might be relevant for explaining asset prices, there is less agreement about appropriate econometric models. Unfortunately, macroeconomic variables have not been particularly informative for asset prices in tests with low frequency data. An asset's value typically depends on the future expected values of the fundamentals, such as the relevant macroeconomic variables. Since these expectations are difficult to measure or model, it is unsurprising that macroeconomic variables are not very informative. One important fact is that, in general, the measured volatility of macroeconomic variables is much smaller than that of any asset price. This suggests that asset price analysis requires models that can explain their relatively high volatility. Another important fact is that there are quite obvious international linkages of asset prices and their volatility, sometimes even described as regional contagion. These linkages will contribute to the observed correlations of international business cycles, and so need to be measured and understood. Accordingly, there have been significant research developments in recent years to address these problems.

There is now a large literature looking at models for higher frequency data, focusing on macroeconomic news announcements, endogenous volatility and micro-structural features (see Baillie and Darcorogna,1997, and references therein). The interesting stochastic features of high frequency (and even actual transaction) asset price data have been examined by many different researchers in an attempt to improve the explanation and future predictability of these prices. By examining the micro foundations of virtually continuous asset trading, these models are able to consider how macroeconomic news impacts in the short run on the level of asset prices and on their underlying volatility. The use of the generalised autoregressive conditional heteroscedasticity (GARCH) framework with high frequency data has been able to explain some key features of asset price data (for example, see Bollerslev, 1987, Nelson, 1991) . The levels of asset prices tend to exhibit a high degree of persistence and usually are

non-stationary so that any news impacts may not evaporate even in the relatively long run. Further, the conditional variance of asset prices also tends to be highly persistent, sometimes even non-stationary, and may be disturbed by the arrival of macroeconomic news. In addition, there may be asymmetry in the effects of positive and negative innovations on conditional variances.

Theories to explain all of these interesting reduced form GARCH phenomena have been developed. The asymmetry of the effects of innovations on conditional variances can be readily explained by the existence of biased dynamic hedging providing floor value insurance. The persistence of conditional variance is more difficult to understand.

One explanation relates conditional variance to traded volumes, based on the empirical fact that these two are positively correlated (for example, see Tauchen and Pitts, 1983; Joiron, 1996 etc.). Since asset prices reflect the present value of their expected future income and capital gains, uncertainty about the future will play a crucial role. If all market participants were of one mind and markets were efficient, any news announcement would lead to immediate price re-alignments, and no trading would be necessary. In efficient and perfectly competitive asset markets, one might not expect macroeconomic news to have an effect on the conditional volatility of asset prices. If all participants were equally well informed and comprehending, surprises or news announcements would be equivalent to random events that provide no second moment information. Asset price adjustment would be instantaneous and, apart from minor portfolio re-balancing, there would be no transaction volume effects, nor would the conditional volatility of the asset prices respond instantaneously or over time to the news. If this hypothesis was rejected by tests on actual asset price data, we might be tempted to infer that the asset markets were imperfect in some respect. However the assumption of equally informed and comprehending participants is far too strong, and its failure is more likely to be responsible for the rejection. That is, the presence of asymmetric information along with different beliefs is responsible for the heterogeneity of market response to news.

The more heterogeneous are participants' knowledge or beliefs about probability distributions of relevant stochastic variables, the greater will be the observed volumes of trades. Learning about the knowledge and beliefs of others is as crucial as forming one's own beliefs. Therefore an information announcement is liable to generate changes in the level of asset prices as well as a persistent surge in trading volumes, as heterogeneous participants trade through time to improve their understanding of others. The levels change to re-establish equilibrium pricing, while the volume of trading jumps as different agents rebalance their portfolios in response to their own knowledge and beliefs and their perceptions of that of others, and then subsequently in response to the re-balancing by others. This persistence of trading volumes will naturally lead to persistence in measured price volatility. But it is difficult to explain why the persistence in (both volumes and) volatility is so long-lasting, irrespective of the source of the shocks. Though agents may differ in their activity horizons, learning and re-balancing should decay within days at the worst.

There are two types of information asymmetry in financial markets - the first involves private information and the second involves public information. With regard to private information, there is a well-established literature that characterises traders as being either well-informed or uninformed (for example, see Glosten and Milgrom, 1985). If dealers are unable to determine who is informed, adverse selection leads to a necessary widening of bid-ask spreads, with shocks encouraging a flurry of trades which persist for some time to allow the information to percolate through the market. Thus the trading activity process exhibits serial correlation even if the process for the underlying price shocks is independently distributed. The measured cumulative price change over a finite period combines both processes, and so estimation of models with fixed discrete time intervals can be shown to exhibit the GARCH phenomena mentioned above (see Steigerwald, 1998).

Macroeconomic announcements represent the immediate revelation of public information to the market. For these events, the informed-uninformed trader distinction is not

relevant. However, the heterogeneity of beliefs about the implications of the news will matter for trading, and may even be affected by the news. Individuals will have different beliefs about how such news will affect the future fundamentals driving the asset price and how the government or central bank will react.

The news effects on the conditional mean of the interest rate changes can be classified as either equilibrium adjustments or policy anticipation. The former implies a disturbance in the markets by an arrival of new information and a subsequent correction to the new information according to an equilibrium adjustment mechanism for each news variable, while the latter involves market participants' expectations of a possible monetary and/or foreign exchange intervention policy response[1] by the monetary authorities (see Engel and Frankel, 1984; Hardouvelis, 1988; Karfakis and Kim, 1995 etc.). While there is a substantial literature on macroeconomic announcement effects on the conditional means of various asset prices (for example, see Edison, H., 1997; Becker, Finnerty and Kopecky, 1995; Hardouvelis, 1988, etc.), there is little on the effects on the conditional variances. Madura and Tucker (1992) find higher ex-ante (option price implied) volatility of the US exchange rates in response to the US trade balance announcement news. Ederington and Lee (1995) and Johnson and Schneeweis (1994) find higher (historical) US exchange rate volatility on the days of the announcements of US macro-economic variables. Jones, Lamont and Lumsdaine (1998) test but reject the hypothesis that announcements give rise to autocorrelated volatility. Yet it is widely accepted by market participants that these announcements do affect trading activity and thus conditional price volatility, which itself exhibits persistence.

Market-dealers are well-aware that they can make very little profit and therefore few

1 Tests of actual effects of foreign exchange intervention are inconclusive and mixed. For example, Baillie and Osterberg's (1997) GARCH research shows that foreign exchange intervention by the Federal Reserve Bank, the Bundesbank and the Japanese Central Bank had no significant impact on the level and conditional variance of changes in the spot exchange rates, while Dominguez and Frankel (1993) using a portfolio balance model and unconditional variance obtain significant results for intervention by the Federal Reserve Bank, the Bundesbank and the Swiss Central Bank. Others who report significant intervention effects include Bonser-Neal and Tanner (1996), and Hung (1997).

trades in a market where there is very little uncertainty. Equally there is going to be minimal profit in a market with many very uncertain and nervous traders. In between these extremes, market-dealers may increase profits and trades. It is thus possible that some types of news announcements will tend to exacerbate volumes and volatility, while others will reduce it. This suggests that there must be something in the type of macroeconomic news that may lead to either protracted nervousness, or else calming in asset markets.

Some macroeconomic news announcements may increase the heterogeneity of beliefs and thus further disturb a financial market. This might occur for a low volatility macroeconomic variable for which a widespread consensus develops relatively easily about its importance and relevance. In the days approaching the next announcement, the market may settle towards some degree of homogeneity of beliefs. When surprises are announced, the homogeneity evaporates giving rise to excited transaction volumes and thus conditional price volatility. As time goes by, beliefs about the fundamental implications of the previous announcements begin to converge.

By contrast, some other types of macro news announcement may tend to almost immediately settle a market. For these macroeconomic variables, some individual participants in asset markets may have a poor understanding or conviction about the importance and relevance of these variables, while others may have relatively better knowledge or conviction. Leading up to these announcements, nervous trading occurs based on the diversity of knowledge or conviction about the possible value that will be contained the announcement. After the announcements, the bigger the surprise, the less likely are the ill-informed to trade, and the more likely is a price adjustment reflecting the knowledge or conviction of the other group. Thus the surprise in such announcements has a calming effect by sidelining those less able or unwilling to take a different position. A good example of an important participant who might act with knowledge and conviction is the central bank. After a large macroeconomic surprise, the central bank may adjust its policy instrument to affect the

conditional mean of, say, the short term interest rate, but it may also decide to demonstrate an extra degree of firmness in its stance by acting to reduce the volatility of that rate, ie by "leaning into the wind". If market participants believe that is a credible stance, they will be less willing to trade.

These asset volatility shocks appear now to move rapidly across international boundaries, and sometimes within particular regions. This has been made possible by the decline in barriers to international capital movements in the last twenty years, which brought in its wake stronger linkages in real economic activity across countries. As a first stage in this paper, we try only to understand the links across countries for short and long-term interest rates, and to see how surprise local and foreign macroeconomic announcements affect the stochastic processes for the interest rates. We work with two different sized countries with no capital controls, USA and Australia, to establish their interconnections. By choosing a very small and a very large country, some causation and exogeneity properties become more obvious.

Accordingly we construct a bivariate daily (exponential) GARCH model for 3 month and 10 year interest rates from Australia and the USA and we test how macroeconomic news in the two countries impacts on the conditional level and volatility of the change of each of their interest rates. We aim to focus on these effects, and thus in this paper avoid further complications concerning exchange rates and policy reaction functions.

This paper is organized as follows: Section II presents the nature of the data used in the study, section III discusses the econometric methodology, section IV includes the analysis of the empirical findings, and lastly, section V offers some conclusion.

II. Data Description

II.I Data Time-lines

Figure 1 shows the time-line of debt market trading in Australia and in the US. The US market opened after the Australian market closed in a calendar day, and so there was no overlap of trading between the two markets. The changes of daily interest rates in both markets to be modelled were measured as the change of closing rates from one day to the next, Δi_t and Δi_t^* for Australian and the US rates. This created overlaps in time horizons over which the daily changes were measured, and so joint modelling of the changes was appropriate (see Figure 1).

Scheduled announcements of Australian and the US macroeconomic variables were investigated for their effects on the daily volatility of Australian and the US interest rate changes. The Australian macro-economic announcements were made at 11:30 am Australian EST (GMT+10) while the Australian debt market was trading, whereas US announcements were at 8:30 am US EST (GMT-5) which was before the US debt market opening. The times of announcements fell between the market close on the day of announcement and the previous day's close in both markets, and so the modelling of announcement news can be through the examination of daily changes on announcement days.

The interest rates examined in this study were the daily closing of short- and long-term Australian rates measured as the 3-month federal treasury bill rate and 10-year Commonwealth bond yield, respectively; and the corresponding US interest rates, the 3-month US treasury bill and 10-year US treasury bond rates. The sample period for this analysis was 25 March 1987 to 13 April 1995 which amounts to 2005 total usable observations. The choice of the starting point of the sample reflected the restrictions imposed by the unavailability of daily observations of the Australian 10-year rate prior to 25 March 1987. The Australian daily interest rates were provided by the Reserve Bank of Australia and the US rates were obtained from the US Federal Reserve statistical data repository. Five macro-economic announcements for each country were considered: current account deficit (trade balance deficit for the US), CPI inflation rate, GDP growth rate, unemployment rate

and retail sales growth rate (see Table 1). All announcements were made monthly except for the GDP announcements for both countries and the CPI announcements for Australia which were quarterly. Market participants responded to the surprise element of each announcement, measured by the difference between the actual figures announced and the market participants' expectations proxied by the median survey expectations produced by Money Market Services in both countries. The surprise measures reflected the extent to which announcements contained new information. Those that contained significant new information might have had a discernible effect on the active trading of market participants. These monthly and quarterly news variables were transformed into daily variables by assigning zero for days without the particular news announcement and the magnitude of the news on announcement days.

II.II Summary Statistics of Daily Interest Rate Changes

Upper panels of Figure 2 and 3 show histograms while Table 2 presents the summary statistics of the daily changes of the 3-month and 10-year Australian and the US interest rates. As is evident from the first section of the Table, the distributions of the daily changes were non-normal. Both the skewness[2] and excess kurtosis reported were significantly higher than those of the comparable normal distributions. The excess kurtosis which was considerably higher in the 3-month rate changes suggests that the changes of short-term rates were more volatile and sensitive to shocks than long-term ones. Looking more closely at the data, the skewness and kurtosis of the daily changes in 3-month rates (particularly in Australia) were associated mainly with negative outliers in October 1987 and some positive outliers in late 1988[3].

[2] Newey and Steigerwald (1997) show that quasi-ML estimates, used in most GARCH applications, are not consistent when applied to data exhibiting significant skewness. To achieve consistency, the conditional variance needs to appear in the conditional mean specification though not in the same way as for a GARCH-M model. We were unable to obtain to obtain convergence with this correction in our EGARCH model.

[3] The negative outliers in October 1987 may be explained by swift and large reactions to the stock market crash by the central banks to initiate or maintain easy monetary policy. The positive outliers for the Australian 3-month rate may also be explained by a changing monetary policy stance in June 1988, when the RBA was aiming to discourage rapidly expanding domestic demand by raising

The level and changes of short-term interest rates would certainly have reflected the current and changing domestic monetary policy stance since the monetary authorities in both countries carried out monetary policy by targetting official short-term interest rates. On the other hand, long-term interest rates are likely to be determined more by longer-term economic fundamentals. Therefore, demand and supply forces for short-term debt instruments are expected to be subject to more speculation regarding changes in both short-term economic conditions and monetary policy regime shifts, leading to a higher probability of observing sharper movements of short-term interest rates compared to long-term ones, and thus higher kurtosis. However the relative sizes of the skewness and kurtosis statistics for the two countries does suggest that monetary policy was more erratic in Australia than in the USA. We will test to see whether conditioning for macroeconomic surprises and international linkages in the EGARCH framework removes this apparently erratic behaviour.

The second section of Table 2 reports the test results of linear and non-linear serial correlation of the changes. These are Ljung-Box Q tests on the changes and the square of the changes. Except for the US 10-year rate, all showed significant linear serial correlation at any meaningful significance level. Furthermore, all exhibited highly significant non-linear serial dependence suggesting the presence of time-varying volatility in the daily changes.

The third section reports the joint *iid* statistics between the Australian and the US interest rate changes. It is a bivariate version of Ljung-Box portmanteau test (Hosking, 1980) of joint white noise residuals, and the test statistic is defined as below:

$$Q = T^2 \sum_{i=1}^{P} \frac{Tr(\hat{C}_i \hat{C}_0^{-1} \hat{C}_i \hat{C}_0^{-1})}{(P-i)},$$

overnight cash rates. The 3-month treasury rate in both countries are very closely linked to the corresponding monetary policy instrument, but are determined by market forces. This implies that they are influenced not only by the monetary policy stance of the respective central banks but also by the market's expectation of future policy directions, and thus are inherently more volatile.

where $\hat{C}_i = \frac{1}{T} \sum_{t=i+1}^{T} (\hat{\varepsilon}_t \hat{\varepsilon}_{t-i})$, $\varepsilon_t = \begin{bmatrix} \varepsilon_{1t} \\ \varepsilon_{2t} \end{bmatrix}$,

T = no. of observations

P = no. of lags

$Q \sim \chi^2$ with $d.f. = 4 \times P$.

From the test statistics, joint linear and non-linear independence of the Australian and US daily interest rate changes were strongly rejected for both the 3-month and the 10-year rate changes. This implies that both the first and second moments of the Australian interest rate changes moved closely with those of the corresponding US rate changes and that this bivariate nature of the distributions needs to be addressed in the modelling of the daily interest rate changes.

The fourth section of Table 2 reports the results of the Engel and Ng (1993)'s sign bias tests which are designed to detect asymmetries of error variance. In general, both positive and negative sign biases were present in the daily changes of both Australian and US interest rates. This indicates the presence of strong asymmetric effects of positive and negative innovations on the future volatility of changes as proxied by the square of changes.

Finally, the last section in Table 2 reports Augmented Dickey-Fuller and Phillips and Perron unit root tests. The lags in the testing equations are determined by choosing the number of lags that render white noise errors. The presence of a unit root in the interest rate changes was strongly rejected in all cases.

III. Econometric Modelling of Daily Interest Rate Changes

We aim to model the statistical properties of the daily changes in general and investigate the impact of macroeconomic news arrivals in particular. The daily interest rate changes have been shown to have been leptokurtic, serially correlated both linearly and non-linearly, with innovations having asymmetric effects on the future volatility of the changes. Modelling of the daily interest rate changes, therefore, must address these observed statistical properties.

The time-varying volatility and the leptokurtosis of the distributions of the changes may be accommodated by a suitably specified GARCH model with a non-normal conditional density for the residuals. The asymmetric effects of unexpected changes can be handled by applying Nelson (1991)'s Exponential-GARCH approach that explicitly models the effects of positive and negative innovations separately. EGARCH models also has the advantage of not having to impose positivity restrictions on the coefficients in the conditional variance equation. Indeed, negative coefficients for exogenous variables included will have a special meaning in this paper. The significant linear and non-linear correlation between the daily changes of Australian and US interest rates can be jointly modelled by bivariate EGARCH models of the daily changes of both the Australian and the US interest rates. To simplify the analysis, the conditional correlations are assumed to be constant through time along the line of Bollerslev (1990), which helps economise on the number of parameters to be estimated.

Brenner, Harjes and Kroner (1996) stress the importance of unexpected information shocks in interest rate volatility modelling. We utilise the information shock created by announcements of unexpected movements of macro-economic variables to better explain daily interest rate volatility movements. The announcement news effects were constructed as daily news variables in each macroeconomic variable and were used as exogenous variables to help explain movements of conditional means and variances on the days of announcements. The Australian and US news variables were defined as the percentage differential of the announced figures for the current account deficit, inflation rate, GDP growth rate, unemployment rate and retail sales growth rate from their Money Market Services median market survey expectations. The bivariate model to be estimated is as below:

Conditional Mean Equations:

$$\Delta i_t^A = \alpha_c^A + \alpha_{Mon}^A D_{Mon,t} + \alpha_{HOL}^A D_{HOL,t}^A + \sum_{i=CAD}^{RET} \alpha_i^A \cdot ANEWS_{jt} + \sum_{j=TB}^{RET} \alpha_j^A \cdot USNEWS_{jt}$$

$$+ \alpha_{US} \varepsilon_{t-l}^{US} + \varepsilon_t^A + \sum_{l=1}^{R} \alpha_{\varepsilon,l}^A \varepsilon_{t-l}^A$$

$$\Delta i_t^{US} = \alpha_c^{US} + \alpha_{Mon}^{US} D_{Mon,t} + \alpha_{HOL}^{US} D_{HOL,t}^{US} + \sum_{j=TB}^{RET} \alpha_j USNEWS_{jt} + \varepsilon_t^{US} + \sum_{l=1}^{R} \alpha_{\varepsilon,l}^{US} \varepsilon_{t-l}^{US}$$

where, $\varepsilon_t = \begin{bmatrix} \varepsilon_t^A \\ \varepsilon_t^{US} \end{bmatrix} \sim (\mathbf{0}, \mathbf{H_t})$, $\quad \mathbf{H_t} = \begin{bmatrix} h_t^A & h_t^{A,US} \\ h_t^{A,US} & h_t^{US} \end{bmatrix}$

Conditional Variance Equations:

$$\ln h_t^A = \beta_t^A + \beta_{Mon}^A D_{Mon,t} + \beta_{Hol}^A D_{Hol,t}^A + \sum_{i=CAD}^{RET} \beta_i^A (ANEWS_{i,t})^2 + \sum_{j=TD}^{RET} \beta_j^{US} (USNEWS_{j,t})^2$$

$$+ \left(\beta_{\varepsilon 1}^A \frac{\varepsilon_{t-1}^A}{\sqrt{h_{t-1}^A}} + \beta_{\varepsilon 2}^A \left(\frac{\left|\varepsilon_{t-1}^A\right|}{\sqrt{h_{t-1}^A}} - \sqrt{\frac{2}{\pi}} \right) + \beta_h^A \ln h_{t-1}^A \right)$$

$$+ \left(\beta_{\varepsilon 1}^{A,US} \frac{\varepsilon_{t-1}^{US}}{\sqrt{h_{t-1}^{US}}} + \beta_{\varepsilon 2}^{A,US} \left(\frac{\left|\varepsilon_{t-1}^{US}\right|}{\sqrt{h_{t-1}^{US}}} - \sqrt{\frac{2}{\pi}} \right) + \beta_h^{US} \ln h_{t-1}^{US} \right)$$

$$ln\, h_t^{US} = \beta_t^{US} + \sum_{i=MON}^{THU} \beta_i^{US} D_{it} + \sum_{j=CAD}^{RET} \beta_i^{US} (USNEWS_{j,t})^2 +$$

$$\beta_{\varepsilon 1}^{US} \frac{\varepsilon_{t-1}^{US}}{\sqrt{h_{t-1}^{US}}} + \beta_{\varepsilon 2}^{US} \left(\frac{\left|\varepsilon_{t-1}^{US}\right|}{\sqrt{h_{t-1}^{US}}} - \sqrt{\frac{2}{\pi}} \right) + \beta_h^{US}\, ln\, h_{t-1}^{US}$$

$$h_t^{A,US} = \rho \sqrt{h_t^A \times h_t^{US}}$$

where:

D_{Mon} = Monday dummy which takes the value of one for Mondays and zero otherwise.

D_{Hol} = Holiday dummy which takes the value of one for the day immediately after public holidays.

$ANEWS_{it}$ = Five Australian news variables transformed into daily variables by assigning the value of zero for days without the particular news announcement and the magnitude of the news (deviation of actual announcement from the MMS expectations) for announcement days.

$USNEWS_{it}$ = Five US news variables constructed as per the Australian news variables.

R = Number of moving average terms included in the mean equation to eliminate linear serial correlation.

h_t = Conditional variance of daily interest rate changes.

Superscripts A and US denote Australia and US, respectively.

In essence, the conditional mean and variance of the daily Australian interest rate changes may depend on those of the corresponding US rate changes, while the reverse dependence is assumed away. The spill-over effects of US macro-economic announcement news have been reported in Becker, Finnerty and Kopecky (1995) where some US news announcements affect German, British and Japanese interest rates. Kitchen (1996) reports a rise in US and foreign interest rates in response to US federal deficit announcements.

The effects of individual announcement news can be ascertained by examining the sign and the magnitude of the estimated news coefficients in the conditional mean and variance equations[4]. The news effects on the conditional variance will depend on micro-structural forces at work before and after each information release, as discussed in the introduction. The empirically established link between trading volume and volatility suggests a rise in price volatility is associated with increased trading activities. We infer from this that higher (or lower) price volatility in response to a news announcement arises from increased (or decreased) volume of trade following the announcement, while the persistence of this volatility is a reflection of the gradual unwinding of trading positions.

In addition, daily and holiday dummy variables are included to test for day of the week and holiday effects on the conditional means and variances of the interest rate changes. These may account for the possibility of significant differences in the volume of information relevant for trading on particular days leading to consistently different patterns in the conditional mean and variance movements. The daily dummies ($D_{i,t}$) take the value of one for the relevant day of the week and the holiday dummy ($D_{HOL,t}$) on days following the closure of the markets due to public holidays, and zero for other days.

Lastly, for the joint distribution of the two error processes, a conditional bivariate standardized t distribution with variance-covariance matrix $\mathbf{H}_t$ and d degrees of freedom is used instead of the customary bivariate normal, thus accounting for possible leptokurtosis in the joint conditional densities (see Bollerslev, 1987; Hamilton, 1994). The virtue of using this

4 We use the square of the news measures in the conditional variance equations to remain dimensionally conformable; using actual or absolute values made no difference to our conclusions.

distribution is that the unconditional leptokurtosis observed in most high frequency asset price data sets can show up as conditional leptokurtosis, and yet have the important property that it converges asymptotically to the Normal distribution, which appears to be appropriate with low frequency data. The t conditional density is as below (k=2 for the bivariate case):

$$f(\varepsilon_t) = (2\pi)^{-\frac{k}{2}} \left(\frac{d-2}{d}\right)^{-\frac{1}{2}} |\mathbf{H}_t|^{-\frac{1}{2}} \left(\frac{d}{2}\right)^{-\frac{k}{2}} \Gamma\left(\frac{d+k}{2}\right) \Gamma^{-1}\left(\frac{d}{2}\right) \left(1 + \frac{\varepsilon'_t \mathbf{H}_t^{-1} \varepsilon_t}{d-2}\right)^{-\frac{d+k}{2}} .$$

IV. Empirical Results

The maximum likelihood estimates of the bivariate EGARCH models for both the 3-month and 10-year interest rates are reported in Table 3a. The effects of Australian and US macroeconomic announcement news on the Australian and US interest rate changes are investigated by examining the sign and magnitude of the coefficients of the news variables included in the conditional mean and variance equations. The usefulness of the bivariate model and the nature of the interest rate linkage between the two countries are discussed in turn.

IV.I News Effects

Australian Interest Rates

There is evidence of significant news effects of Australian CPI announcements on the 3-month rate changes. Unexpectedly high announcements of CPI changes raised the interest rate on the days of announcement. Interestingly, the short-term rate, which was more directly affected by monetary policy, was not significantly changed by any economic activity surprise variable. Thus it would appear that market participants believed on average that the Reserve Bank of Australia was targetting CPI inflation.

The conditional variance of the short-term rate was significantly raised in response to Australian CPI, current account deficit (CAD), and unemployment news. For the last two variables, we argue that the surprise component in their announcements added to volatility by expanding the heterogeneity of beliefs, even though the average belief and hence the interest rate level remained unchanged. With the unexpected CPI inflation raising both the conditional mean and variance of the short-rate, we might infer that the market was sure on average that the Reserve Bank would respond, but were unsure about the intensity or commitment of the response.

The 10-year rate changes show significant positive news effects for Australian CPI, CAD, and GDP announcements. The higher response to unexpected CPI inflation suggests the operation of an inflation expectations component that raised the nominal yield. An unexpectedly higher CAD would lead to portfolio readjustment by generating a net excess supply of domestic debt, thus raising its yield. An unexpectedly high GDP growth rate would have presaged future inflationary pressures which needed to be acknowledged in higher long-term interest rates.

Significant news effects are also detected in the conditional variance of the 10-year rate. Unexpected Australian CPI, CAD and unemployment rate announcements raised the conditional variance on the days of announcement. On the other hand, news on retail sales growth rate lowered it which implies the release of this information may have reduced uncertainty or discouraged ill-informed traders, leading to a lower volume of trade and volatility for the day. Thus retail sale growth announcements calmed the market, perhaps because they gave some early indication of future economic activity, stifling a developing heterogeneity of beliefs.

Comparing the Australian news effects on short- and long-term interest rates, it is noticeable that all of the news coefficients are larger in magnitudes for the long-term rate. This is particularly true of the CPI and unemployment rate news. This may be because the problems associated with inflation and unemployment are long-term in nature, and so unexpected announcements of these variables represented surprises in long-term fundamentals requiring a larger change in longer term interest rates.

Only the Australian short-term interest rate responded directly to any US announcement news. A significant positive news effect on the mean is found only for US GDP news. Market participants might have anticipated that an unexpected rise in the US GDP would have a positive impact on Australian economic activity, which would then feed through to the Australian short-term rate. The weak significance of Australian GDP news on the Australian short-rate may reflect this multicollinearity.

Significant US news effects are to be found in the conditional variance equations. US trade deficit, GDP and unemployment rate news raised the conditional volatility of the Australian 3-month rate, while the retail sales news had the opposite effect. The conditional volatility of the 10-year rate was also increased by US GDP and retail sales news. The retail sales news apparently had a market calming effect on the short-term debt markets while the reverse is observed in the long-term market, suggesting that market participants enhanced their consensus on the short-term bond market, while on the longer-term one became more uncertain. An explanation might be that Australian participants are confident about the Federal Reserve's response to US retail sales news, but the divergent beliefs about the possible future inflation effects are amplified by this news.

US Interest Rates

We also investigate how US announcement news effects affected US interest rate changes. An unexpectedly high unemployment rate announcement lowered both the 3-month and 10-year interest rates, while a higher than expected retail sales announcement had a positive effect on the days of announcement. The negative impact of unemployment news on the short-term interest rate may indicate an anticipation of expansionary monetary policy response to unexpected unemployment. The unexpectedly high unemployment will also imply reduced inflationary pressures in the future, and so the long-term rate will fall. The retail sales news probably added to future inflationary expectations thus raising both short- and long-term interest rates. Lastly, unexpected inflation announcements raised the 10-year rate again due to higher future inflation expectations, but the insignificance on the 3-month rate suggests that the Federal Reserve was not believed to be targetting the CPI. Instead it appears that the

Federal Reserve was believed to be targetting economic activity variables, in sharp contrast to the beliefs about the Reserve Bank of Australia.

Significant news effects are also found in the US conditional variance equations. The conditional variance for the 3-month rate was raised in response to US GDP news, while trade deficit and unemployment news lowered it. The conditional variance of the 10-year rate changes responded only to unemployment news, positively, implying a rise in conditional volatility in contrast to the response of the 3-month rate to the news. This might be due to the injection of new unemployment information coupled with a time-consistent Federal Reserve response calming the market down on the one hand, but introducing more uncertainty regarding the longer-term economic fundamentals leading to greater heterogeneous trading on longer term debt securities.

IV.II Bivariate Modelling

The estimates of the asymmetric response of the conditional variance to unexpected interest rate changes, $\beta_{\varepsilon 1}$, was positive in all cases, and significant only for the long-term interest rate changes, indicating higher conditional volatility in response to an unexpected rise in the rates and lower conditional volatility when there was an unexpected fall in all cases. $\beta_{\varepsilon 2}$ was positive and significant at 1% in all cases which indicates that the bigger the shock, regardless of sign, the higher was the volatility of all future interest rate changes. That is, the magnitude effect was significant and present in all cases, however the positive asymmetric effect, although positive in all cases, was significant only in the two long-term rates. The estimated β_h was highly significant and close to one in all cases (particularly the US 3-month rate) except for the Australian 10-year rate changes indicating that the effects of a shock on the conditional variance were long-lived.[5]

5 Simple tests of a unit root in the conditional variance were rejected in all cases, and restricted estimation (ie forcing β_h for the US rate to be unity) failed to achieve convergence. However, due to the possible presence of distortions associated with hypothesis testing under the null of unit root, the results should be interpreted with caution. The possible non-stationarity in conditional covariances has lead to a recent literature on possible co-persistence between a vector of variables exhibiting this phenomenon - see Bollerslev and Engel (1993).

There were no seasonal effects in the conditional mean equations. Both the Monday and holiday dummies were insignificant except for the 3-month US rate. The conditional volatilities tended to be higher on Mondays for the Australian interest rate changes while the reverse applied to the US rates. The holiday dummy showed similar results. Apparently, Mondays and days immediately after public holidays were associated with higher conditional volatility in Australia due perhaps to an accumulation of information over non-trading days fuelling heterogeneous expectations, whereas lower conditional volatilities for the US rates may be explained by the fact that US securities are traded deeply at all times around the world, so that US weekends and holidays actually involved substantial information accumulation and evaluation elsewhere.

The direct influence of the US interest rate changes on the Australian market was confirmed. Lagged innovations in the US rate changes had significant positive effects on the conditional means of both Australian rates. The conditional volatilities of the Australian interest rate changes were also influenced by the US rate changes. In general, an unexpected change in the US long-term rate raised significantly the future volatility of the corresponding Australian rate changes. An increase in the lagged conditional US volatilities raised the Australian conditional volatilities for both 3-month and 10-year rates. There was also a suggestion of a positive contemporaneous correlation of the conditional variances between the Australian and the US rate changes, as shown by the positive, although insignificant, ρ. This (insignificant) positive correlation would be picking up global phenomena that might have driven volume and price volatility in the markets of the two countries. All of the above confirm the existence of a complex set of strong linkages between the two economies operating through the financial sector.

Lastly, the estimated d was significant and sufficiently small to justify using the conditional standardized t distribution in the case of the 3-month rate estimations. However, there was no evidence of a real advantage of the standardized t over the standardized Normal distribution in the 10-year rate estimations. This lends support to the earlier argument that short-term interest rates are more volatile, being monetary policy instruments and thus subject to more speculative pressures, and having a maturity that has an obviously smaller 'time value' for unwinding the effects of shocks.

IV.III Diagnostics

The lower panels of Figures 2 and 3 present the histograms of the standardised residuals from the bivariate EGARCH estimations, while Table 3b reports diagnostics. Both the skewness and excess kurtosis were significantly reduced in size in all cases except for the increased skewness in the Australian 3-month rate. The remaining fat tail/excess at the mean/asymmetry features of this rate probably indicate that further work is required to understand policy reactions of the Reserve Bank. Conditioning for macroeconomic surprises in first and second moments, the use of the Students t distribution and of EGARCH are not sufficient.

The univariate *iid* tests for the 3-month rate estimations show that the distributions of the standardised residuals were still not strictly *iid* in that linear serial correlation remained significant in the Australian 3-month rate changes, although non-linear dependence was eliminated. However, there was no evidence of joint linear and non-linear serial dependence between the Australian and the US standardised residuals.

In the 10-year rate estimations, there was no sign of non-*iid*ness and so both the standardised residuals were individually and jointly *iid*. The significant Engel and Ng sign biases were not present and a unit root was not found in the conditional variances of the Australian rate changes. The conditional variance of the 3-month US rate changes appeared to have a unit root judging from the β_h which was very close to one, however the formal tests were not supportive of the presence of a unit root. In sum, the bivariate EGARCH modelling of the daily changes of Australian and the US interest rates were shown to be reasonably effective in addressing most of the generic statistical properties of the daily changes, while some news announcement variables helped explain the movements of the first and second moments of the daily interest rate changes.

In Figure 4 and 5, we present graphs of the raw daily changes, their conditional variances and the standardised innovations. In the raw data (checking the scale), the most noticeable feature is how much more variable the Australian 3-month rate is than its US counterpart. In the period surrounding October 1987, there was much movement, but after 1990 the market settled. This is partly attributable to the explicit announcements of the target cash rate by the RBA beginning January 1990. Movements in the cash rate unaccompanied by an official statement by the RBA were no longer seen as a source of information regarding the RBA's monetary policy changes, and so the excess volatilities of all short-term rates due to speculation regarding a monetary policy shift died down for the post-1990 period. From mid-1994, volatility picked up. The conditional variance graphs show that the models are successfully demonstrating these features with standardised innovations from them being essentially white noise.

V. Conclusions

This paper examined the financial linkages between Australia and the US through the interactions between short- and long-term interest rates of the two countries. It has been shown that daily changes of the interest rates were leptokurtic and that there was evidence of time-varying conditional volatility of the changes. Although there was no actual time overlap of market trading in the debt instrument markets in the two countries, overlaps were created when daily changes of interest rates were used. Apart from the short-term Australian interest rate, the bivariate EGARCH modelling of the daily changes of both short- and long-term interest rates addressed effectively the statistical properties of the daily changes.

Unexpected changes in the previous day's US interest rates significantly moved the corresponding Australian rates in the same direction (a 1 basis point increase in the previous day's US short-term (long-term) rate led on average to a 0.06 (0.33) basis point increase in the next day's Australian short-term (long-term) rate), while the conditional variance of the long-term rate was significantly raised in response. The conditional variances of the US rate changes had a significant positive influence on the corresponding Australian conditional variances. These exogenous influence of the US interest rate changes on the Australian changes were then further investigated by considering the effects of US macroeconomic announcement news. The US GDP news announcements significant raised the Australian 3-month rate and the trade deficit, GDP and unemployment rate news increased the conditional volatility while retail sales news announcement lowered it. There was no evidence of the Australian 10-year rate responding to any of the US news announcements except for the stimulated conditional volatility in response to the US GDP news announcement.

Macroeconomic news announcements were found to be useful in explaining the daily conditional mean and volatility movements on the days of announcements. Our results suggest that market participants believed that the Reserve Bank of Australia was targetting the CPI, while the Federal Reserve was targetting economic activity and that short- and long-term interest rates, in general, responded differently to some news announcements. Inflation news, in particular, affected the long-term rate more for both Australia and the US. Australian unemployment rate and GDP news also had larger effect on the Australian long-term rate.

Some macroeconomics news announcements led on average to an exciting of these markets by immediately raising the conditional variance of their yield changes; others calmed the markets by reducing the conditional variances. Further some announcements had opposite effects on the conditional volatilities of the short- and long-term rates.

Australian unemployment news, current account news and CPI news significantly raised the conditional volatility of Australian short- and long-term interest rates. In the US, unemployment news excited the US long-term rate (but calmed the short-term one), while GDP news had the opposite effects. US balance of trade news calmed the US short-term interest rate. Australian retail sales news calmed the Australian long-term market, whilst US retail sales news calmed the Australian short-term one (but excited the long-term rate).

Further research is needed to understand the fundamental reasons for these results on the forces affecting volatilities. They are important because they yield critical information for pricing derivative assets based on these underlying government securities - for example, the value of an interest rate option depends on the conditional variances. In addition, they provide new perspectives on the factors driving the second moment characteristics of yield curves.

The shape of the yield curve at any point in time contains information about market perceptions of the stance of monetary policy, the business cycle and the expected evolution of future inflation. The conditional variances of the component interest rates provide further information about confidence intervals for forecasts of the yield curve.

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Figure 1: Time Line of Australian and the US debt Market Trading

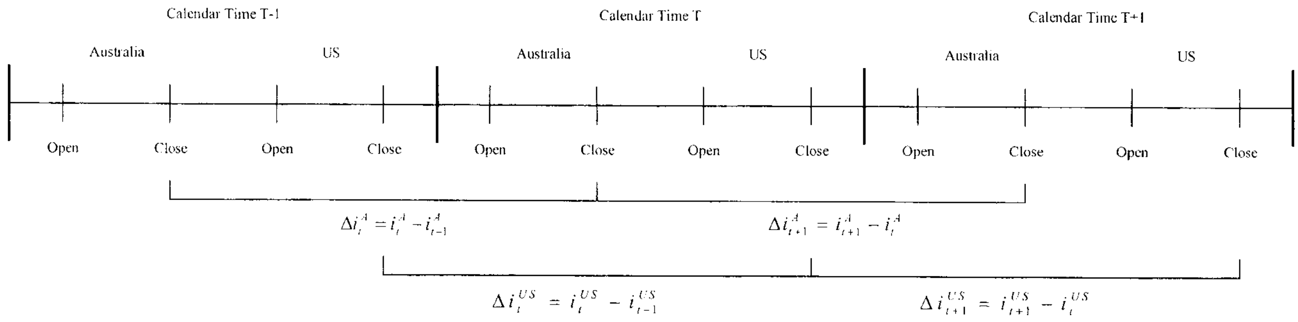


Table 1: Actual and Expected Announcement Data

	Australian Announcements					US Announcements				
	Current Account Deficit (CAD)	Consumer Price Index (CPI)	Gross Domestic Product (GDP)	Unemployment Rate (UE)	Retail Sales Growth (RET)	Balance of Payment (BOT)	Consumer Price Index (CPI)	Gross Domestic Product (GDP)	Unemployment Rate (UE)	Retail Sales Growth (RET)
Frequency of Announcements	Monthly	Quarterly	Quarterly	Monthly	Monthly	Monthly	Monthly	Quarterly	Monthly	Monthly
Source: Actual	ABS No. 301, Balance of Payment, Monthly.	ABS No. 6401, Consumer Price Index, Quarterly.	ABS No. 5206, Quarterly Estimates of National Income and Expenditure.	ABS No. 6203, The Labour Force Australia, Monthly.	ABS No. 8501, Retail Sales of Goods, Monthly	MMS International				
Source: Market Expectations	MMS Australia					MMS International				
Unit of Measurement	$A billion	% change in CPI from previous quarter	% change in GDP from previous quarter	Unemployment Rate, %	% change of gross retail sales from previous month	$ US billion	% change in CPI from previous month	% change in GDP from previous quarter	Unemployment Rate, %	% change of gross retail sales from previous month
Announcement Time: AEST (GMT +10) and USEST (GMT -5)	11:30 AM	9 AM up to the December quarter 1988, and 11:30 AM thereafter	Two at 8 AM and three at 7:30 AM early in the sample, and 11:30 AM thereafter	11:30 AM	11:30 AM	8:30 AM				
Data Period	March 1987 to February 1995	March Quarter 1987 to December quarter 1994	March Quarter 1987 to December quarter 1994	March 1987 to February 1995	August 1988 to February 1995	February 1987 to January 1995	March 1987 to March 1995	First quarter 1987 to fourth quarter 1994	March 1987 to March 1995	March 1987 to March 1995
Total Number of Announcements within Data Period	95	32	32	97	79	83	83	28	83	83
Total Number of MMS Survey	116	32	32	74	64	83	83	28	83	83
Definition of News (deviation of actual announced figures from MMS median expectations)	Log (Actual / MMS Median Expectations)	Actual figure - (MMS Median Survey Expectations)				Log (Actual / MMS Median Expectations)	Actual figure - (MMS Median Survey Expectations)			

Table 2:
Statistical Properties of the Daily Australian and US Interest Rate Changes

	3-Month Treasury Bill		10-Year Bond	
	ΔAUS	ΔUS	ΔAUS	ΔUS
	Summary Statistics			
Mean	-0.0039	0.0000	-0.0018	-0.0001
Variance	0.0095	0.0046	0.0086	0.0046
Skewness	-0.8428	-0.5950	0.3960	-0.2579
Excess Kurtosis	27.3524	15.1544	4.8764	7.0550
	Test of Univariate *iid*[(a)]			
Q(45) : $\chi^2(45)$	162.3510 **	106.5344 **	90.5731 **	53.9359
	{0.0000}	{0.0000}	{0.0001}	{0.1697}
$Q^2(45)$: $\chi^2(45)$	524.8338 **	689.7671 **	265.7375 **	440.4212 **
	{0.0000}	{0.0000}	{0.0000}	{0.0000}
	Test of Bivariate *iid*[(b)]			
$Q_b(45)$: $\chi^2(180)$	2186.4329 **		1867.14 **	
	{0.0000}		{0.0000}	
$Q_b^2(45)$: $\chi^2(180)$	1839.6468 **		717.7663 **	
	{0.0000}		{0.0000}	
	Engel and Ng Sign Bias Tests[(c)]			
Sign Bias	1.1587	1.9202	-1.5739	0.1765
	{0.2467}	{0.0550}	{0.1157}	{0.8599}
Negative Sign Bias	-4.5129 **	-8.5833 **	-1.8526	-2.5241 *
	{0.0000}	{0.0000}	{0.0641}	{0.0117}
Positive Sign Bias	5.4685 **	1.4280	8.1656 **	2.4847 *
	{0.0000}	{0.1535}	{0.0000}	{0.0130}
Joint Test: $\chi^2(3)$	58.4335 **	87.9372 **	84.4262 **	18.9435 **
	{0.0000}	{0.0000}	{0.0000}	{0.0003}
	Test of Unit Root[(d)]			
ADF	-26.2642	-27.2144	-35.7271	-44.0355
Lag	2	2	1	0
P-P Z(t)	-40.1796	-42.8748	-52.3245	-43.7433

Notes: The changes of the daily interest rates are defined as $\Delta i_t = i_t - i_{t-1}$.

(a) Q(45) is the Ljung-Box test statistic for serial correlation of up to 45th order ($\approx \sqrt{N = 2005}$ [redacted]) for the interest rate changes.
$Q^2(45)$ is the Ljung-Box test statistic for the squared interest rate changes.

(b) $Q_b(45)$ is the bivariate Ljung-Box test statistic for joint serial correlation of up to 45[th] order between the Australian and the US interest rate changes.
$Q_b^2(45)$ is the bivariate Ljung-Box test statistic for joint serial correlation of up to 45[th] order between the squared changes of the Australian and the US interest rates.

(c) Sign bias test is the t-test of the slope coefficient of the regression of z_t^2 on S_{t-1}^- [redacted], a dummy which takes on the value of 1 for $\varepsilon_{t-1}<0$, and 0 otherwise.

Negative sign bias is the t-test of the slope coefficient of the regression of z_t^2 on $S_{t-1}^- \cdot \varepsilon_{t-1}$.
Positive sign bias is the t-test of the slope coefficient of the regression of z_t^2 on $S_{t-1}^+ \cdot \varepsilon_{t-1}$.
Joint test is the LM test of joint significance of all three regressors.
(In this case, $\varepsilon_t = \Delta i_t - \mu$ and $z_t^2 = (\varepsilon_t / \sqrt{\sigma^2})^2$, where μ and σ^2 are the unconditional mean and variance of the daily changes.)

(d) ADF denotes Augmented Dicky-Fuller test, and P-P Z(t) denotes Phillips-Perron Z test for unit root with constant and no trend. The Lags in the ADF tests are chosen to obtain white noise residuals.

† means significance at the 10% level
* means significance at the 5% level
** means significance at the 1% level
Numbers in {..}s are asymptotic p-values.

Table 3.a: Bivariate EGARCH(1,1) Modelling of daily Australian and US interest rate changes: Estimations

	3-Month Treasury Bill				10-Year Bond			
	ΔAUS		ΔUS		ΔAUS		ΔUS	
	Coeff	S.E.	Coeff	S.E.	S.E.	Signif	Coeff	S.E.
α_{C}	-0.0012	(0.0010)	-0.0015	(0.0012)	-0.0035	(0.0018)	-0.0026	(0.0016)
α_{MON}	-0.0013	(0.0021)	0.0027	(0.0027)	0.0003	(0.0051)	0.0062 *	(0.0031)
α_{HOL}	-0.0001	(0.0048)	0.0055	(0.0048)	-0.0019	(0.0117)	0.0006	(0.0057)
α_{CAD_AUS}	0.0200	(0.0210)			0.1730 **	(0.0312)		
α_{CPI_AUS}	0.0866 **	(0.0225)			0.3016 **	(0.0624)		
α_{GDP_AUS}	0.0181	(0.0098)			0.0507 **	(0.0195)		
α_{UE_AUS}	-0.0149	(0.0158)			0.0340	(0.0338)		
α_{RET_US}	0.0014	(0.0037)			0.0022	(0.0061)		
α_{TD_US}	0.0217	(0.0309)	0.0025	(0.0191)	-0.0351	(0.0541)	0.0300	(0.0310)
α_{CPI_US}	-0.0104	(0.0232)	0.0440	(0.0359)	0.0229	(0.0680)	0.1813 **	(0.0502)
α_{GDP_US}	0.0159 *	(0.0063)	0.0220	(0.0157)	-0.0021	(0.0308)	0.0081	(0.0156)
α_{UE_US}	0.0076	(0.0310)	-0.1387 **	(0.0195)	0.0073	(0.0423)	-0.1158 **	(0.0307)
α_{RET_US}	-0.0025	(0.0071)	0.0244 *	(0.0113)	0.0204	(0.0223)	0.0282 *	(0.0112)
$\alpha_{us,1}$	0.0599 **	(0.0180)			0.3346 **	(0.0279)		
β_{C}	0.1607 **	(0.0420)	0.0356 *	(0.0153)	-0.5444 **	(0.1183)	-0.2367 **	(0.0660)
$\beta_{\varepsilon 1}$	0.0075	(0.0098)	0.0046	(0.0042)	0.1014 **	(0.0185)	0.0372 **	(0.0137)
$\beta_{\varepsilon 2}$	0.1550 **	(0.0119)	0.0584 **	(0.0069)	0.1370 **	(0.0271)	0.1905 **	(0.0234)
$\beta_{\varepsilon 1}{}^{us}$	0.0146	(0.0120)			0.0486 **	(0.0184)		
$\beta_{\varepsilon 2}{}^{us}$	0.0117	(0.0148)			0.1153 **	(0.0307)		
β_{h}	0.9551 **	(0.0052)	0.9961 **	(0.0012)	0.7999 **	(0.0257)	0.9399 **	(0.0115)
$\beta_{h}{}^{us}$	0.0831 **	(0.0103)			0.0993 **	(0.0260)		
β_{MON}	0.2835 **	(0.0838)	-0.2411 **	(0.0616)	0.2332 **	(0.0804)	-0.5200 **	(0.0757)
β_{HOL}	0.0434	(0.0591)	-0.1837 **	(0.0380)	0.5543 **	(0.0895)	-0.0036	(0.0790)
β_{CAD_AUS}	1.6886 **	(0.3526)			1.7290 *	(0.7096)		
β_{CPI_AUS}	2.3167 **	(0.5142)			5.1008 **	(0.6435)		
β_{GDP_AUS}	0.0563	(0.0858)			0.1208	(0.1753)		
β_{UE_AUS}	2.3749 **	(0.4329)			3.1555 **	(0.7684)		
β_{RET_AUS}	0.0286	(0.0169)			-0.1103 **	(0.0308)		
β_{TD_US}	2.4950 *	(1.1181)	-2.0084 **	(0.6296)	2.4760	(1.7166)	1.6067	(1.6060)
β_{CPI_US}	-0.6880	(2.2774)	-1.7620	(1.2562)	-0.5642	(4.2786)	4.8431	(2.8234)
β_{GDP_US}	0.5393 **	(0.1468)	0.2329 **	(0.0742)	0.4914 *	(0.2307)	-0.0960	(0.2153)
β_{UE_US}	4.2334 **	(1.3802)	-1.7398 **	(0.6728)	-1.0135	(2.0074)	5.9402 **	(1.8680)
β_{RET_US}	-0.7784 **	(0.1818)	0.1005	(0.0875)	0.5918 *	(0.2812)	-0.2229	(0.1903)
ρ	0.0176	(0.0274)			0.0434	(0.0246)		
d	11.0912 **	(0.5686)			76.395 **	(19.01)		
R	10		10		2		0	
Ln L	5760.0				4910.3			

Notes: d is the estimated degrees of freedom parameter of the t distribution for the standardised residuals.
R is the number of moving average terms changes found to be significant in the conditional mean equation.
lnL is log likelihood

Table 3.b: Bivariate EGARCH(1,1) Modelling of daily Australian and US interest rate changes: Diagnostics

	3-Month Treasury Bill		10-Year Bond	
	ΔAUS	ΔUS	ΔAUS	ΔUS
	Summary Statistics on z_t			
Mean	-0.0480	0.0088	0.0085	0.0133
Variance	1.6134	1.2403	1.0277	1.0252
Skewness	-1.7409	-0.1358	0.1777	0.0514
Excess Kurtosis	21.5737	5.6102	1.9990	2.5434
	Test of Univariate *iid*[(a)]			
$Q(45) : \chi^2(45)$	70.1327 ** {0.0096}	47.4449 {0.3733}	42.3168 {0.5863}	47.9787 {0.3530}
$Q^2(45): \chi^2(45)$	55.6865 {0.1320}	32.1166 {0.9254}	44.7609 {0.4820}	17.6921 {0.9633}
	Test of Bivariate *iid*[(b)]			
$Q_b(45) : \chi^2(180)$	190.6862 {0.2785}		134.0939 {0.9957}	
$Q^2{}_b(45): \chi^2(180)$	112.6804 {1.0000}		165.1875 {0.7787}	
	Engel and Ng Sign Bias Tests[(c)]			
Sign Bias	-0.0357 {0.9715}	1.5844 {0.1133}	0.4249 {0.6710}	0.1221 {0.9028}
Negative Sign Bias	-0.0188 {0.9850}	-1.0776 {0.2813}	-0.4944 {0.6211}	-0.1679 {0.8666}
Positive Sign Bias	-0.2847 {0.7759}	-0.1649 {0.8690}	0.5331 {0.5940}	-0.4773 {0.6332}
Joint Test: $\chi^2(3)$	0.1071 {0.9910}	3.1901 {0.3632}	1.1088 {0.7750}	0.2847 {0.9629}
	Test of Unit Root in the Conditional Variance			
$H_0: \beta_h = 1: \chi^2(1)$	75.528 ** {0.0000}	9.8584 ** {0.0017}	60.5927 ** {0.0000}	27.2929 ** {0.0000}

See Notes for Table 2.

Figure 2: Histogram of Australian and US 3-month interest rate changes

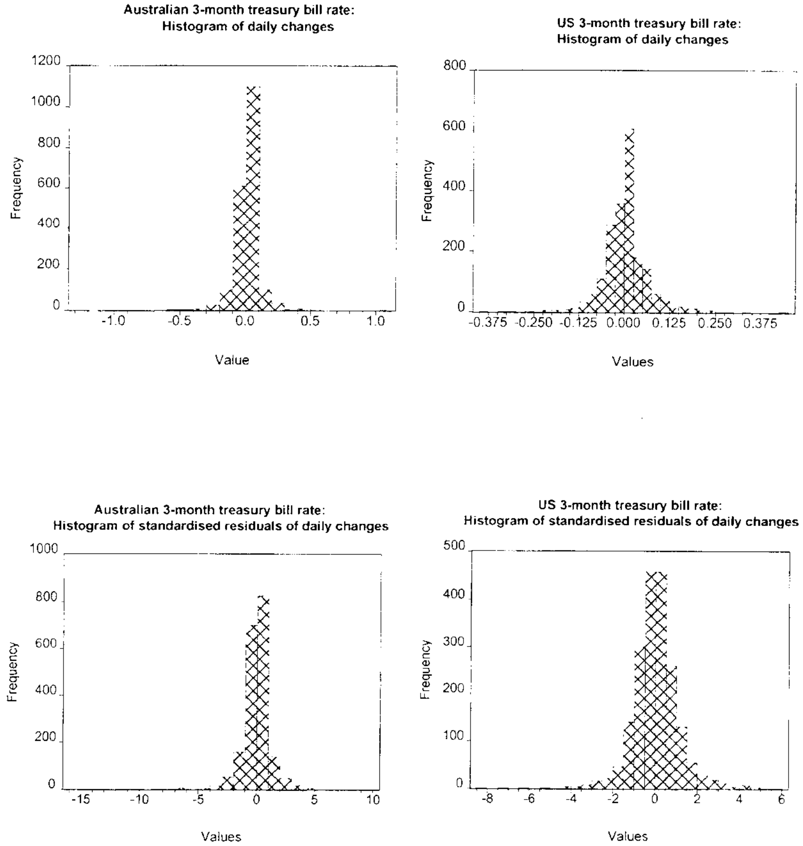


Figure 3 Histogram of Australian US 10-year interest rate changes

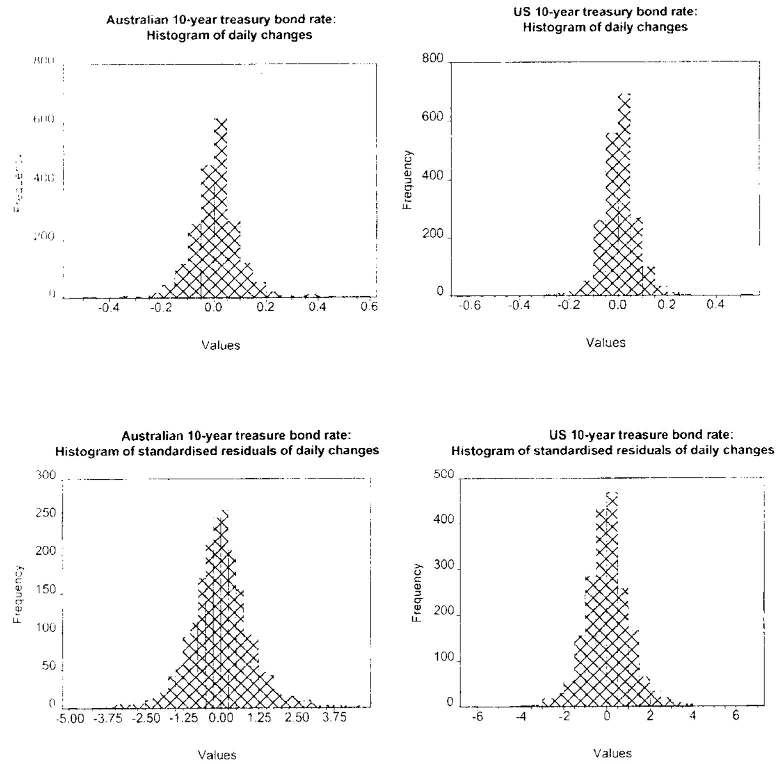


Figure 4: Time series plots of daily changes of 3-month interest rates

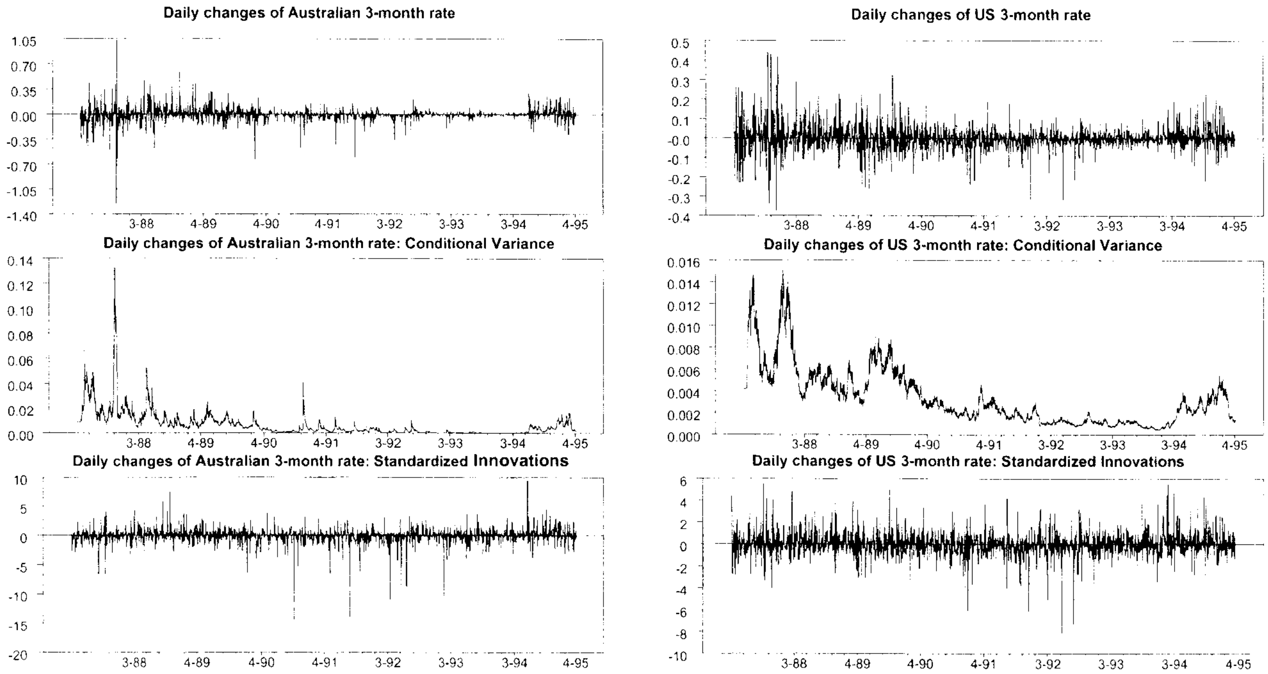
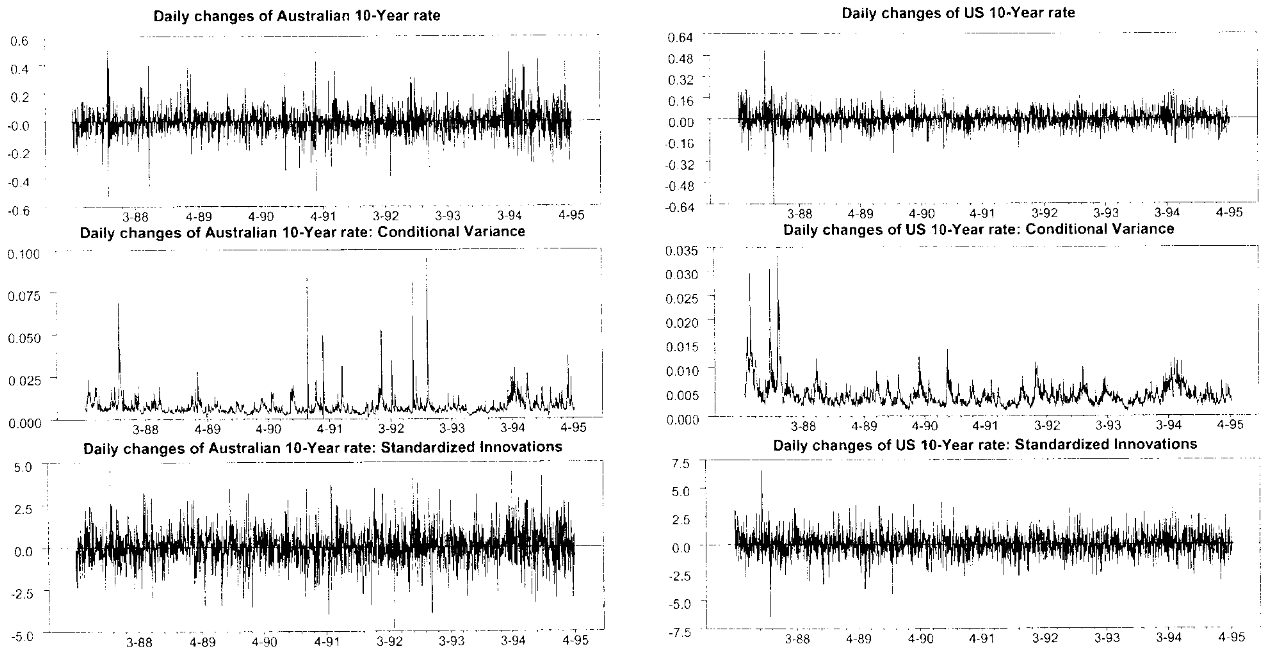


Figure 5: Time series plots of daily changes of 10-year interest rates



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