Exchange rate predictability, monetary policy announcements, and the term structure of interest rates

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A thesis submitted in partial fulfillment of the requirements for the degree of

Doctor of Philosophy

Department of Economics

Faculty of Business and Economics

Macquarie University

June 2013

Contents

Statement of Originality

I hereby declare that this thesis is my own work and to the best of my knowledge, it has not been submitted for a higher degree to any other university or institution. The sources of information used and the work of others that have been utilized are acknowledged in the thesis.

I also declare that the intellectual content of this thesis is the product of my own work and that all assistance from others in preparing this thesis was acknowledged.

Anh Tuan Bui

Dedication

To my parents, my wife, and my sons

Acknowledgements

First of all, I am indeed indebted to my supervisors, Professor Lance Fisher and Professor Geoffrey Kingston, and to my adjunct supervisor, Professor Mardi Dungey, of the University of Tasmania for their excellent supervision, guidance, encouragement, and care throughout my candidature. Their invaluable comments on issues related to my research topics as well as on my written work without a doubt helped to improve the quality of the thesis.

I would like to thank Dr. Vitali Alexeev at the University of Tasmania for his econometrics advice. Special thanks to Jeffrey Sheen, Glenn Otto, and other conference participants for their valuable comments

I have greatly benefited from the Vietnam Ministry of Education and Training's scholarship; the Excellence Research Award provided by the Faculty of Business and Economics at Macquarie University; and the funding offered by the Faculty of Business and Economics at Macquarie University to present chapters of my thesis at various conferences. I would also like to thank Mrs. Sharon Raymond for assistance with the written expression.

Lastly, I wish to express my deepest gratitude to my family: my parents for their guidance and encouragement throughout my life, my wife, Dr. Thu Phuong Pham, and our sons, Kendrick and Anthony, for their endless love, tolerance, and sacrifices over this period of study.

Preface

Some of the chapters in this thesis have been presented at conferences and seminars, which are indicated as follows.

Chapter 2

- *Australian Conference of Economists,* Sydney, September 2010
- *Postgraduate EXPO,* Macquarie University, November 2010

Chapter 3

- *Postgraduate EXPO,* Macquarie University, November 2011
- *INFINITI Conference on International Finance*, Dublin, Ireland, June 2012
- *Econometric Society Australasian Meeting,* Melbourne, July 2012
- *Peanut Gallery, School of Economics and Finance*, University of Tasmania, May 2012
- *Department seminar, Department of Economics,* Macquarie University, July 2012

Chapter 4

- *Australian Conference of Economists,* Melbourne, July 2012
- *INFINITI Conference on International Finance*, Dublin, Ireland, June 2012
- *Peanut Gallery, School of Economics and Finance,* University of Tasmania, August 2012

Chapter 5

- *Postgraduate EXPO,* Macquarie University, November 2013

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List of Abbreviations

ABS	Australian Bureau of Statistics
ADF	Augmented Dickey-Fuller
AUD	Australian dollar
CIP	Covered interest parity
CPI	Consumer Price Index
DoC	Direction of change
GDP	Gross domestic product
GEE	Generalized estimating equations
GFC	Global Financial Crisis
GMM	Generalized Method of Moments
HAC	Heteroskedasticity and Autocovariance Consistent
IV	Instrumental variables
MSFE	Mean square forecast error
NAB	National Australia Bank
OLS	Ordinary least squares
OTC	Over-the-counter
RBA	Reserve Bank of Australia
RET	Retail sales growth
RNEMH	risk-neutral efficient-markets hypothesis
SIRCA	Securities Industry Research Centre of Asia Pacific
UE	Unemployment rate
UIP	Uncovered interest rate parity
USD	United States dollar

Abstract

This thesis consists of five key chapters. The first two correspond to papers on exchange rate predictability (Chapters 2 and 3), and the next three focus on the effect of monetary policy announcements on the Australian term structure of interest rates (Chapters 4, 5, and 6).

Chapter 2 estimates the Uncovered Interest Parity condition (UIP) for Australia using the Generalized Method of Moments (GMM) methods. Until recently, estimates of UIP used Ordinary Least Squares (OLS) methods to estimate the correlation However, in the presence of an omitted risk premium, the OLS estimate of the slope coefficient in the relationship will be biased and inconsistent. This chapter instead employs the GMM methods that relate the risk premium to the underlying economic variables to overcome the problem of omitted variables. After accounting for the unobservable risk premium, the slope coefficients are closer to their theoretical value of one. In addition, the GMM estimated equations perform better than the random walk and the OLS estimated equations in forecasting the exchange rate over short horizons.

Chapter 3 undertakes an empirical investigation of information implied in the relative term structure of interest rates on the United States dollar (USD)/Australian dollar (USD/AUD) exchange rate. We interpret the information on macroeconomic fundamentals behind the relative factors of yield curve to account for predictable exchange rate changes. Our results show that the slope and curvature factors of the Australian yield curve relative to the US one can predict the USD/AUD exchange rate movements and excess returns on the AUD from one month to two years ahead. Moreover, our model performs better than the random walk in forecasting the USD/AUD exchange rate at horizons longer than 12 months.

Chapter 4 investigates the effect of the target cash rate announcements on the term structure of interest rates in Australia using daily data. We find that unanticipated changes in the cash rate target significantly impact the entire term structure of interest rates, with the impact becoming smaller for longer maturities. We also compare volatilities across the term structure of interest rates on policy and non-policy announcement days and again find that the impact of monetary policy announcements on interest rate declines with maturity. More specifically, short-term interest rate volatility rises more than triple in the policy days while in the long-term, interest rate volatilities are more or less the same as those for non-policy days.

Chapter 5 narrows the windows around Australian monetary policy announcements by employing intra-day data to mitigate the effect of other news on market interest rates on the announcement days. This method allows for a more precise evaluation of the impact of monetary policy announcements on the term structure of interest rates. Our results from intraday data show the Reserve Bank of Australia (RBA) announcements have significant impacts on the Australian term structure of Treasury bond yields that decline as the term to maturity increases. In addition, the adjustments of Treasury bond yields to the announcements are almost finished only 30 minutes after the announcement.

Chapter 6 investigates whether monetary policy announcements result in jumps in the term structure of Australian Treasury bond yields. Using intraday data on the Australian Treasury bonds yields provided by the Securities Industry Research Centre of Asia-Pacific (SIRCA) for the period from January 1996 to December 2012, we find significant evidence of jumps across the term structure of Australian Treasury bond yields on the days of the release of the monetary policy decision by the RBA. The surprise component in the monetary announcement generates a surge in Treasury bond returns.

Chapter 1 : Introduction

1.1 Background and Motivation

The Uncovered Interest Parity (UIP) condition has long been the cornerstone parity condition for foreign exchange market efficiency. According to the UIP condition, the interest rate differential between the two countries should equal the expected change in the exchange rate between them. However, the existing literature (see Froot & Thaler 1990; Chinn 2006; Isard 2006) provides no evidence to support the UIP condition, although Chinn and Meredith (2004) and Chinn and Quayyum (2012) report some evidence in its favor over long forecasting horizons.

In Chapter 2, we re-examine the UIP condition by taking account of omitted variable bias in the estimated regression. We specify the UIP condition for the US and Australia. Even when we take account of omitted variable bias, a feature not explicitly considered in earlier studies, we still could find little evidence for the UIP condition.

The test of the UIP relation in Chapter 2 only accounts for the interest rate differential between the US and Australia. However, the entire term structure of interest rates in the US and Australia may contain useful information for predicting the USD/AUD exchange rate. The term structure can be summarized by three factors: the level, slope, and curvature factors (Nelson & Siegel 1987).

In Chapter 3, we follow Chen and Tsang (2013) and define relative yield curve factors between the US and Australia as the difference between the US and Australian yield curve factors. We show that these relative yield curve factors have predictive content for the USD/AUD exchange rate. It is important to use all the information in the US and Australian yield curves (summarized by the relative yield curve factors) in exchange rate forecasting, not simply just the interest rate differential between the two countries.

How interest rates at different maturities react to the announcements of target cash rate, the instrument of monetary policy, is of importance for several reasons. For monetary policymakers, an understanding of the reaction of interest rates to the announced target cash rates is an important step in creating effective policy decisions. For financial market participants, having accurate estimates of the response of interest rates at different maturities to the announcements of monetary policy change is crucial in formulating efficient investment portfolios. The majority of empirical studies on this issue has focused on the US market, where the US Federal Reserve influences the supply of and demand for central bank reserves to set the Federal Funds rate. Very little has been done for Australia, however. Chapters 4, 5, and 6 are devoted to the investigation of the effect of monetary policy announcements by the Reserve Bank of Australia (RBA) on the term structure of Australian interest rates.

1.2 Thesis contribution

This thesis seeks to contribute to current empirical findings on the relationship between exchange rates, the term structure of interest rates, and the effect of monetary policy announcements on the term structure of interest rates in Australia. More specifically, Chapter 2 estimates the Uncovered Interest Parity (UIP) condition for Australia using GMM methods. Until recently, estimates of the UIP used OLS methods to the condition. However, in the presence of an omitted risk premium the OLS estimate of the slope coefficients will be biased and inconsistent. This chapter contributes to the current literature by employing the GMM methods that relate the risk premium to underlying economic variables to overcome the problem of omitted variable bias. After accounting for the unobservable risk premium, the slope coefficients are closer to their theoretical value of unity. In addition, the GMM estimated equations perform better than the random walk in forecasting the exchange rate at short horizons

Chapter 3 carries out an empirical investigation of information implied in the term structure of interest rates on the USD/AUD exchange rate. We interpret the information on macroeconomic fundamentals behind the relative factors of the yield curves to account for predictable exchange rate changes. Results from this chapter show that the relative slope and curvature factors of the Australian yield curve relative to the US curve can predict the USD/AUD exchange rate movement and excess returns on the AUD from one month to two years ahead. In addition, our model performs better than the random walk in forecasting exchange rates at a horizon longer than 12 months.

Chapter 4 investigates the effect of the cash rate target announcements on the term structure of interest rates in Australia using daily data. We find that unanticipated changes in the announced target cash rate have significant impacts, which decline with maturity on the term structure of interest rates in Australia. Short-term interest rate volatility raises more than three times in the policy days, while in the long-term, interest rate volatilities are more or less the same as on non-policy days. In Chapter 5, we examine this issue using intraday data. This method allows us to select narrow windows (i.e., narrow time intervals) around Australian monetary policy announcements so that we may mitigate the effect of other news on market interest rates on the announcement days. Results from intraday data confirm the findings in Chapter 4 that the unanticipated component in the announcements has significant impacts on the Australian term structure of Treasury bond yields. Moreover, the adjustments of Treasury bond prices to the announcements have almost finished 30 minutes after the announcement.

The question of whether monetary policy announcements of the target cash rate cause jumps in the Australian term structure of Treasury bond yields is analyzed in Chapter 6. Using intraday data on Australian Treasury bonds, we find significant evidence of jumps across the term structure of Australian Treasury bonds on the days of the release of the monetary policy decisions by the RBA.

1.3 Structure of the thesis

The remainder of this thesis is organized as follows. Chapter 2 re-investigates the Uncovered Interest Parity (UIP) relation for the USD/AUD exchange rate, controlling for omitted variable bias. Chapter 3 examines the predictability of the USD/AUD exchange rate using the relative shape of the US and Australian yield curves. Chapter 4 reports the effect of monetary policy surprises on the term structure of Australian interest rates in daily data. Chapter 5 examines this issue using intraday data so that the impact can be ascertained in narrow time windows around the announcement. Chapter 6 analyzes the effect of monetary policy announcements on the probability of jumps in the term structure of Australian Treasury bonds. Finally, Chapter 7 concludes.

Chapter 2 : Tests of the Uncovered Interest Parity: Evidence from Australian Data

2.1 Introduction

The Uncovered Interest Parity (UIP) condition has long been the cornerstone parity condition for foreign exchange market efficiency. According to the UIP, the interest rate differential between the two countries should equal the expected change in the exchange rate. As a result, a regression of exchange rate changes on the interest rate differentials should produce estimates of the intercept and slope coefficients equal to zero and one, respectively. Until recently, however, empirical studies have reported mixed results. Froot and Thaler (1990), Chinn (2006), and Isard (2006) find the slope coefficients to be estimated with negative signs for short horizons. Alternatively, Chinn and Meredith (2004) and Chinn and Quayyum (2012) report that the UIP holds at long horizons.

This chapter employs the Generalized Method of Moments (GMM) technique to re-examine the UIP condition for the USD/AUD exchange rate. Until recently, the majority of studies on the UIP utilized the Ordinary Least Squares (OLS) method, which can be problematic in the presence of an omitted risk premium in the regression (see Froot & Thaler 1990; Taylor 1995; Chinn 2006; Chen & Tsang 2013). This is because an omitted risk premium may result in biased estimates of the slope coefficients and heteroscedastic variance in the error term. Bias is due to misspecification error while heteroskedasticity means that the OLS standard errors of the coefficients are underestimated rendering the usual t and F tests invalid. One common way to deal with the problem of heteroskedasticity is to use the GMM methods. Estimates of the coefficients under the GMM are consistent in the presence of heteroskedasticity of unknown form. Alternatively, some researchers, for example Christensen (2000) and

Tai (2001), employ the Generalized Autoregressive Conditional Heteroskedasticity (GARCH) framework to model the risk premium. However, the main problem with these "pure statistical" methods is that they do not identify economic determinants of the risk premium.

The chapter reaches two main findings. First, estimates of the slope coefficients under the GMM specification are closer to their theoretical value of one. The slope coefficients are positive compared to estimates of about -0.9 using the OLS method. In addition, except for the coefficient of six-month horizon regression, we cannot reject the null hypothesis that the slope coefficients are equal to 1 at the 5% level of significance. Second, the equations based on the GMM estimates outperform the random walk and also the equations based on the OLS estimates in forecasting exchange rates at short horizons.

The rest of the chapter is organized as follows. Section 2.2 reviews the unbiasedness hypothesis and summarizes the existing theories and empirical results on the UIP condition. Section 2.3 describes the data used in the empirical analysis. Then, in Section 2.4, the empirical methodology is explained and the results are presented. Finally, a brief conclusion is provided in Section 2.5.

2.2 Theoretical framework

The UIP can be derived using the Covered Interest Parity (CIP) condition, the unbiasedness hypothesis, rational expectations, and risk-neutrality assumptions. As long as no arbitrage opportunity exists, the forward discount (the difference between the forward rate and the spot exchange rate at time t) will be equal to the interest rate differential between the two countries. Specifically, we define the exchange rate as the US dollar price of one Australian dollar. A rise in the exchange rate represents an appreciation of the AUD and a depreciation of the USD. Given this definition of the exchange rate, the home country is the US and the foreign country is Australia. We denote the home country's (US) interest rate with m months to maturity as i_t^m and the foreign (Australian) interest rate with m months to maturity as i_t^{m*}. The no-arbitrage condition is as follows:

$$f_{t,t+m} - s_t = i_t^m - i_t^{m*} \tag{2.1}$$

where $f_{t,t+m}$ and s_t denote the natural logarithm of the forward exchange rate for m months ahead and the spot exchange rate at time t, respectively. Equation (2.1) is known as the Covered Interest Parity (CIP) condition. In addition, Equation (2.1) is a risk-free arbitrage condition that holds regardless of investors' preferences. If all market participants are risk neutral and the transaction cost is zero for all transactions, the market will set the forward exchange rate equal to the expected spot rate on the date when the forward contract matures.

To the extent that investors are risk averse, the forward rate may differ from the expected future spot rate so that there is a premium term $\eta_{t,t+m}$ that compensates for the risk of holding foreign assets.

$$\eta_{t,t+m} = f_{t,t+m} - s_{t,t+m}^e \tag{2.2}$$

By substituting Equation (2.2) into Equation (2.1), we obtain the Uncovered Interest Parity condition:

$$s_{t,t+m}^e - s_t = i_t^m - i_t^{m*} - \eta_{t,t+m} \tag{2.3}$$

Under rational expectations, Equation (2.3) can be written as follows:

$$s_{t+m} - s_t = i_t^m - i_t^{m*} - \eta_{t,t+m} + \xi_{t,t+m} \tag{2.4}$$

where $\xi_{t,t+m}$ is the white noise error term that is orthogonal to all information known at time *t*.

The UIP condition in Equation (2.4) can be tested by estimating the following regression:

$$s_{t+m} - s_t = \alpha + \beta(i_t^m - i_t^{m*}) + \varepsilon_{t,t+m} \qquad (2.5)$$

where $\varepsilon_{t,t+m} = \xi_{t,t+m} - \eta_{t,t+m}$. The combination of no risk premium hypothesis and the rational expectation hypothesis is called the "risk-neutral efficient-markets hypothesis" (RNEMH). Under these assumptions, the error term $\varepsilon_{t,t+k}$ is simply the rational expectations' forecast error $\xi_{t,t+k}$ (Chinn 2006). As a result, we can test the UIP condition by testing the joint hypothesis of $\alpha = 0$ & $\beta = 1$ and $\varepsilon_{t,t+k}$ is orthogonal to all information available at time t. A rejection of the UIP condition means one or both hypotheses do not hold (Taylor 1995).

Non-zero values of the constant term in Equation (2.5) can be explained by Jensen's inequality, which states that the expectation of the natural logarithm of the future exchange rate is not the same as the natural logarithm of the expectation of the future exchange rate[1]. When the assumption of risk-neutral investors is relaxed, the constant term also reflects a constant risk premium demanded by investors on foreign versus domestic assets (Chinn & Meredith 2004).

Alper, Ardic, and Fendoglu (2009) highlight that the failure of these assumptions may have two different influences on the empirical evidence on the UIP condition. First, *the failure of rational expectations* means that the forecast error $\xi_{t,t+k}$ in Equation (2.4) depends on the information available at time t, which creates excess returns even when

[1] Engel (1996) shows that in practice, Jensen's inequality is small and can be ignored.

investors are risk neutral (i.e., when $\eta_{t,t+m} = 0$). Second, *the failure of risk neutrality* means that $\eta_{t,t+m} \neq 0$, so that foreign assets involve an exchange rate risk.

Until recently, estimates of Equation (2.5) have been generally unfavorable to the UIP condition. Specifically, the majority of papers report the *forward premium bias* (i.e., both the forward premium and interest rate differential predict the spot exchange rate depreciation in the "wrong" direction. The results are robust to the estimation techniques, period of study, and data sets (see the surveys of Froot & Thaler 1990; Engel 1996; Lucio 2005; Chinn 2006; Isard 2006). For example, a comprehensive survey by Froot and Thaler (1990) on 75 published papers reports the slope coefficients in Equation (2.5) are frequently less than zero with an average of -0.88, and none were equal to or greater than unity.

Chinn and Meredith (2004) show that while the forward bias is very robust when using short-term data (i.e., a small m), estimates of the slope coefficients in long-range data (i.e., a large m) would yield the *"correct"* (positive) sign and are generally closer to unity than to zero. In addition, when the sample is extended, Chinn and Quayyum (2012) find the risk-neutral efficient-markets hypothesis (RNEMH) stills holds better at long horizons; however, the effect is weaker than the finding of Chinn and Meredith (2004).

2.3 Data

2.3.1 Interest rate data

To see whether the validity of the UIP model is sensitive to the maturity of interest rates, we employ 90-day (3-month) and 180-day (6-month) Australian bank accepted bills and 3-month and 6-month US Treasury bills at secondary market rates for short-term maturity. The Australian bank bills and the US Treasury bills were selected as they are the most liquid assets in the Australian and the US markets, respectively. Alternatively, we use Treasury bonds at 5- and 10-year maturities as a constant maturity for the long horizon. Data for yields at short-term and long-term maturities in the Australian and US markets are provided by the Reserve Bank of Australia's (RBA) Web site (http://www.rba.gov.au/statistics/index.html) and the Federal Reserve Bank of St. Louis' (FRED's database) Web site (http://www.stlouisfed.org/), respectively. The sample covers the period from March 1985 to December 2009.

Descriptive statistics for yields on bank accepted bills, Treasury bills, and Treasury bonds are reported in Table 2.1. For Australia, the distributions of yields are characterized by the skewness and the kurtosis measures, which indicate that the sampling distribution of yields can be considered to be non-normal. The volatilities of long-term Treasury bonds are much lower than those of short-term bank bills. The table also presents descriptive statistics for US yields. Their sampling distributions also appear non-normal, and the volatilities of long-maturity Treasury bonds are less than on Treasury bills. The mean of Australian yields are higher than those of the US and have higher standard deviations.

Table 2.1: Descriptive statistics of Australian and US yields on bank accepted bills, Treasury bills, and Treasury bonds.

	Mean	Median	Std. Dev.	Min	Max	Skewness	Kurtosis
Australia							
3-month	8.173	6.195	4.326	3.055	19.550	1.126	2.849
6-month	8.189	6.250	4.252	2.995	19.080	1.090	2.778
5-year	8.169	6.450	3.343	3.265	15.200	0.750	2.049
10-year	8.326	6.650	3.170	3.985	15.050	0.653	1.881
US							
3-month	4.732	5.140	2.346	0.010	9.860	-0.208	2.293
6-month	4.773	5.050	2.284	0.150	9.900	-0.216	2.319
5-year	5.785	5.780	2.069	1.550	11.550	0.210	2.512
10-year	6.206	6.030	1.924	2.250	11.910	0.474	2.642

Note: This table reports the summary statistics of the yields on Australian 90-day (3-month) and 180-day (6-month) bank accepted bills and 5- and 10-year Treasury bonds; US 3-month and 6-month Treasury bills, and 5- and 10-year Treasury bonds. The sample period is from March 1985 to December 2009. The summary statistics include mean, median, minimum, maximum, standard deviation (measured in annual percentage rates), skewness, and kurtosis.

2.3.2 Exchange rate data

The UIP model is applied to the USD/AUD exchange rate. As indicated earlier, we treat the US as the home country and measure the exchange rate (S) as the US dollar price of one Australian dollar. Therefore, a rise in the exchange rate represents an appreciation of the AUD and depreciation of the USD. In addition, we define the exchange rate change as the difference in the natural logarithm of the USD/AUD exchange rates (s) (i.e., s_{t+m} is the natural logarithm of the exchange rate at time $t+m$). Data on spot exchange rates are provided by the RBA.

In addition, we use the difference in stock returns between Australian and US stock price indices as an instrument variable in the GMM methods. Monthly stock returns are measured by the change in the natural logarithm of the stock price index

$\left(\ln\left(P_t\right)-\ln\left(P_{t-1}\right)\right)$ where P_t is the stock price index at time t. Specifically, the SP500 and the S&P/ASX 200 are used as stock price indices for the US and Australia, respectively, since these indices have been used widely in the literature. Stock price indices are provided by Thomson Reuters Datastream.

All the data are annualized and observed at the last trading day of each month.

2.4 Empirical methodology and results

2.4.1 Methodology

Correlations between interest rates at different maturities of Australian and US bank bills and Treasury bonds are presented in Table 2.2. Interest rates at various maturities across countries exhibit relatively high positive correlations.

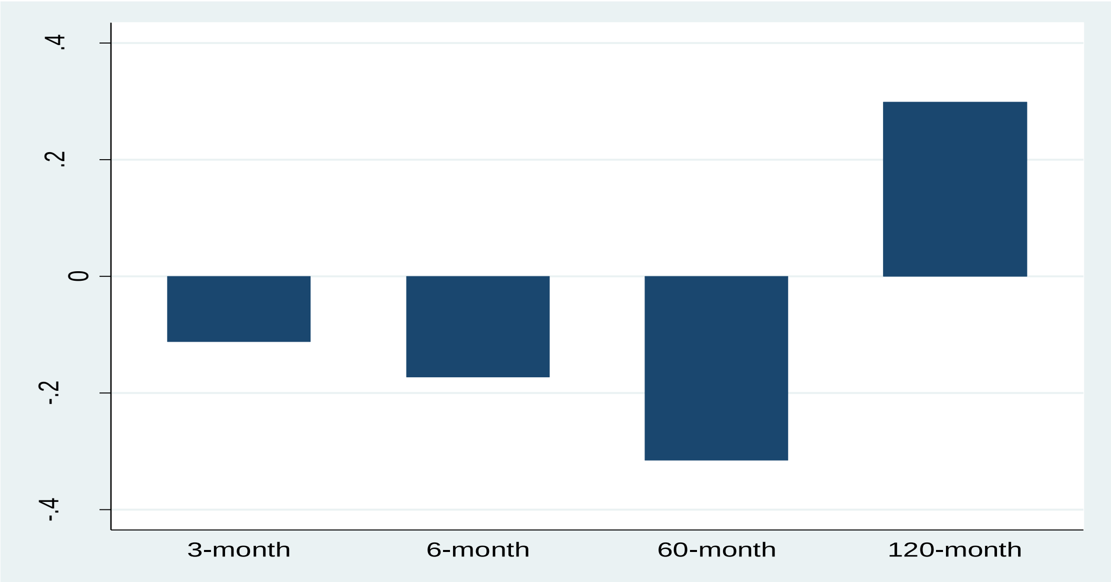
Table 2.2: Correlations between Australian and US interest rates

	i^{3*}	i^{6*}	i^{60*}	i^{120*}	i^{3}	i^{6}	i^{60}	i^{120}
i^{3*}	1.000							
i^{6*}	0.998	1.000						
i^{60*}	0.954	0.960	1.000					
i^{120*}	0.927	0.933	0.995	1.000				
i^{3}	0.747	0.754	0.770	0.758	1.000			
i^{6}	0.739	0.748	0.766	0.755	0.998	1.000		
i^{60}	0.774	0.784	0.868	0.881	0.912	0.919	1.000	
i^{120}	0.786	0.795	0.892	0.911	0.848	0.854	0.987	1.000

Note: This table presents correlations between the Australian (i^{m*}) and US (i^{m}) interest rates at different maturities. The instruments include Australian 90-day (3-month) and 180-day (6-month) bank accepted bills and 5- and 10-year Treasury bonds; US 3-month and 6-month Treasury bills and 5- and 10-year Treasury bonds. The sample period is from March 1985 to December 2009.

Correlations between exchange rate depreciation and interest rate differential are presented in Figure 2.1, which shows negative correlation coefficients at horizons less than 5 years.

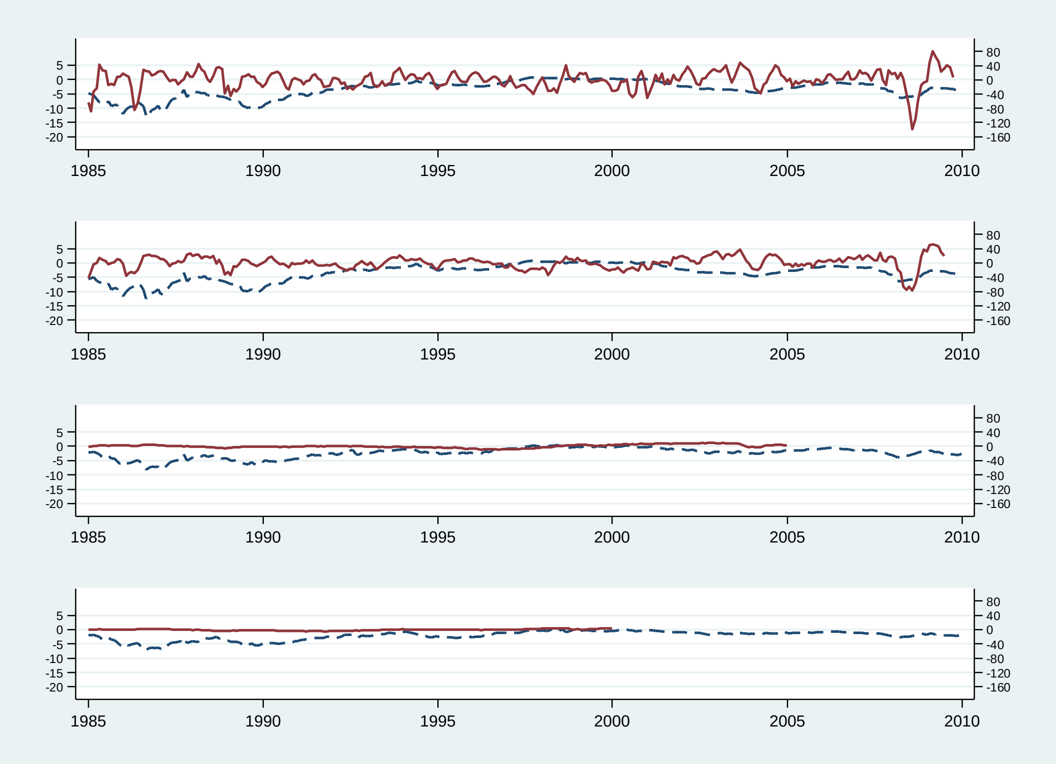
Figure 2.1: Correlations of the USD/AUD exchange rate depreciations and interest rate differentials



Note: This figure shows the correlation between USD/AUD changes and the interest rate differential $(i_t^m - i_t^{m*})$.

In addition, Figure 2.2 plots the movement of the USD/AUD exchange rate depreciation corresponding to interest rate differentials, $(i_t^m - i_t^{m*})$. A casual look at these figures indicates that there is no clear relationship between the interest rate differential and the exchange rate depreciation.

Figure 2.2: Movement of the USD/AUD exchange rate depreciations and interest rate differentials



Note: This figure plots the USD/AUD exchange rate changes corresponding to the US and Australian interest rate differentials (i.e., $i_t^m - i_t^{m*}$ with m = 3, 6, 60, and 120 months). Exchange rate changes (solid line, right axis) are annualized and displayed as percentages. Interest rate differentials (dash line, left axis) are reported as percentages. Figures from the top are at 3-month, 6-month, 5-year, and 10-year horizons, respectively. The sample period is from March 1985 to December 2009.

Unit root test is traditionally used to test order of integration or the stationarity of variables. Among many recent methods, the Augmented Dickey-Fuller's (ADF) and the Phillips and Perron (1988) methods are the most popular. The ADF test, an augmented version of the Dickey and Fuller's (1979) test, always produces a negative value for the test statistic; the more negative it is, the stronger the rejection of the null hypothesis of a unit root. Unlike the ADF test, the Phillips-Perron (PP) test makes a non-parametric correction to the "*t*" test statistic. The test is robust with respect to unspecified autocorrelation and heteroskedasticity in the error term of the test equation. Table 2.3 examines the stationarity of the exchange rate depreciation from time t to $t+m$.

Results from ADF and PP unit root tests indicate that all exchange rate changes under consideration can be considered as stationary.

Table 2.3: Unit- root tests on exchange rate depreciation

Variable (USD/AUD)	**Augmented Dickey-Fuller**		**Phillips-Perron**	
	None	Constant	None	Constant
$s_{t+3} - s_t$	-7.08*	-7.08*	-6.76*	-6.76*
$s_{t+6} - s_t$	-4.40*	-4.43*	-5.28*	-5.29*
$s_{t+60} - s_t$	-1.65**	-1.67	-1.73***	-1.76
$s_{t+120} - s_t$	-2.56**	-2.55	-1.77***	-1.80

Note: *, **, and *** denote significance levels of 10%, 5%, and 1%, respectively.

The table reports the ADF and Phillips-Perron tests for unit root on exchange rate changes at different horizons that appear on the right side of Equation (2.5). The sample period is from March 1985 to December 2009.

Analysis using a longer time horizon needs to address inference bias due to overlapping observations. When the horizon for exchange rate depreciation is more than the frequency of the data (1 month), the left side variable in Equation (2.5) overlaps across observations, and the error term $\varepsilon_{t,t+m}$ in Equation (2.5) will be a moving average process of order $m-1$. As a result, OLS parameter estimates are consistent but inefficient and hypothesis tests are biased (Hansen & Hodrick 1980). One simple way to deal with the problem of overlapping observation is to use a reduced sample where none of the observations overlap. For example, with a 10-year period of monthly data, only 10 annual observations will be used in the non-overlapping sample. This procedure will certainly eliminate the autocorrelation problem, but it is obviously inefficient as it reduces the number of observations. Another more efficient way to deal with this problem is to use the overlapping data, but we account for the moving average error term in hypothesis testing. Harri and Brorsen (2009), who investigated the estimation methods used in three leading journals during the 1996-2004 period to deal with the overlapping observations problem, conclude that the use of OLS non-overlapping data and the Newey-West estimation methods are most often. Thus, in this chapter, we use Heteroskedasticity and Autocovariance Consistent (HAC) standard errors developed by Newey and West (1987) to overcome the problem of overlapping observations. The number of lags of the residual auto-correlations is selected by Schwert's (1989) method.

Alternatively, we estimate the UIP condition by Generalized Method of Moments (GMM), which was first introduced by Hansen (1982). The UIP condition in Equation (2.5) is constructed under the assumption that investors are risk neutral. Recent empirical studies reveal that the risk neutral hypothesis may not be valid. When market participants are risk averse, the UIP regression in Equation (2.5) should include an additional variable as a proxy for time varying risk premium.

If the investors are risk averse, the omitted risk premium in the UIP test using Equation (2.5) makes the error term correlated with the interest rate differential, leading the OLS estimators to be biased. Since the risk premium is unobservable, we are unable to incorporate it into Equation (2.5) directly. Until recently, attempts to model the risk premium have met with little success (see Hodrick 1989 and Christensen 2000). A more effective way is to use the instrumental variables (IV) method to deal with the problem of the omitted variable. The IV approach allows us to decompose the interest rate differential into two parts: the part that is correlated and the part that is not correlated with the omitted risk premium. Only the uncorrelated part of the variability in interest rate differential is used to estimate the relationship between interest rate differential and exchange rate depreciation. Although estimates of the coefficients by the IV specification are consistent in the presence of heteroskedasticity, the standard errors are inconsistent, preventing valid inference. In this chapter, we apply the GMM methods developed by Hansen (1982) to mitigate the impact of heteroskedasticity (note that IV is a special case of GMM). The GMM makes use of the orthogonality conditions to allow for efficient estimation in the presence of heteroskedasticity of unknown form.

Since exchange rates and interest rates are jointly determined, we consider the interest rate differential as an endogenous variable. Hence, Equation (2.5) is a linear model with two endogenous variables: exchange rate depreciation and interest rate differential. The instruments chosen for the two endogenous variables include interest rate differential, long-term interest rate differential, and stock returns differential. These instrumental variables satisfy the two requirements for valid instruments. First, they are correlated with the interest rate differential, and second, they are orthogonal to the error term. We employ the J statistic of Hansen (1982) to test the condition of the overidentifying restrictions. As we will see in Table 2.6, we are unable to reject the null hypothesis of $J = 0$, which implies that these selected instruments satisfy the orthogonality condition. We also employ the $F-$ statistic to check that the instruments are not weak. The first-stage $F-$ statistic, applied when there is only one endogenous regressor, is a measure of information content contained in the instruments. The statistic values are 171.15 and 192.19 for 3 and 6-month horizons, respectively, which indicate that the instruments are not weak[2]. Table 2.4 reports the summary statistics of exchange rate change and interest rate differentials at different horizons. Australian interest rates are on average higher than the corresponding US rates, and long-term interest rate differentials are more variable than short-term interest rate differentials.

[2] As a rule of thumb, if the $F-$ statistic in the first stage regression exceeds 10 then there is no need for concern as the instruments are found not be weak i.e. they can be reliably used. (Stock and Watson, 2010).

Table 2.4: Descriptive statistics of interest rate differentials and exchange rate depreciations

	Mean	Median	Std. Dev.	Min	Max	Skewness	Kurtosis
$i^3 - i^{3*}$	-3.441	-2.890	3.010	-13.060	0.780	-0.854	3.143
$i^6 - i^{6*}$	-3.415	-2.710	2.963	-12.440	0.840	-0.837	3.088
$i^{60} - i^{60*}$	-2.384	-2.070	1.857	-8.150	0.490	-0.899	3.336
$i^{120} - i^{120*}$	-2.120	-1.620	1.623	-7.150	0.180	-1.011	3.285
$s_{t+3} - s_t$	0.601	1.703	25.059	-138.078	81.331	-1.131	7.638
$s_{t+6} - s_t$	0.781	1.503	17.961	-76.384	52.563	-0.780	5.923
$s_{t+60} - s_t$	0.459	0.061	4.563	-9.517	10.202	0.036	2.566
$s_{t+120} - s_t$	-0.390	-0.071	2.157	-4.846	4.503	-0.074	2.430

Note: This table presents the summary statistics of interest rate differentials and exchange rate changes at 3-, 6-, 60-, and 120-month horizons. The exchange rate is the US dollar price of one Australian dollar (USD/AUD). i^m and i^{m*} denote US and Australian interest rates, both with m months to maturity, respectively. The summary statistics include mean, median, minimum, maximum, standard deviation (measured in annual percentage rates), skewness, and kurtosis. The sample period is from March 1985 to December 2009.

2.4.2 Results

Table 2.5 reports the OLS estimates in Equation (2.5) for 3- and 6-month periods. The results are consistent to other studies confirming the failure of the UIP in the short run. Both estimated slope coefficients display the "wrong" (negative) sign compared to the expected value of one under the RNEMH. The slope coefficients of -0.24 and -0.16 are closer to one relative to those reported by Froot and Thaler (1990) and Chinn and Meredith (2004). In addition, the hypothesis that the slope coefficients are equal to unity is strongly rejected at the 5% level of significance. The constant terms are close to zero, which is consistent with the literature and the assumption of risk neutrality. The F statistics corresponding to the null joint hypothesis of $\alpha = 0 \,\&\, \beta = 1$ are presented in the last column of the table, and they show that the UIP condition is strongly rejected for the two maturities. The R^2 statistics of these regressions are very low. The adjusted R^2 statistics (not shown) are also very low and sometimes negative.

Table 2.5: OLS estimates of the UIP condition in the short run

This table reports the results of regressions of the formula

$$s_{t+m} - s_t = \alpha_m + \beta_m \left[\frac{m}{12} \left(i_t^m - i_t^{m*} \right) \right] + \varepsilon_{t+m}$$

where s_{t+m} and s_t are the natural logarithm of the USD/AUD exchange rate at time $t+m$ and at time t, respectively. i_t^m and i_t^{m*} denote domestic (US) and foreign (Australian) interest rates with m-month maturity at time t. The LHS measures the m-month exchange rate change of USD/AUD. The RHS is the measure of the interest rate differential between the US and Australia $(i_t^m - i_t^{m*})$.

	α	β	R^2	$F_{(\alpha=0 \& \beta=1)}$
$s_{t+3} - s_t$	-0.001 (-0.067)	-0.244# (-0.350)	0.001	3.59**
$s_{t+6} - s_t$	0.001 (0.069)	-0.159 (-0.226)	0.001	3.86**

Note: *, **, and *** denote significance levels of 10%, 5%, and 1%, respectively.
# indicates a significant difference from 1 at 5%.
Newey-West standard errors are in brackets.

This table presents the OLS estimates of the UIP condition in Equation (2.5) for Australian 90-day (3-month) and 180-day (6-month) bank accepted bills and US 3-month and 6-month Treasury bills, constant maturity. The sample period is from March 1985 to December 2009.

Table 2.6 presents the GMM estimates of the UIP equation at 3- and 6-month horizons. After accounting for the effect of the part of the interest rate differential that correlates to the unobservable risk premium, the slope coefficients are much closer to their theoretical value of 1 under the rational expectation hypothesis. Both slope coefficients display the "correct" (positive) sign. The two slope coefficients are about 0.55, which is much closer to unity. In addition, the null hypothesis of the slope coefficient equal to unity cannot be rejected at the 5% level of significance at both horizons. However, the joint hypothesis that the intercept is zero and the slope coefficient is one is rejected at the 1% level in both cases.

Table 2.6: GMM estimates of the UIP condition in the short run

This table reports the results of regressions of the formula

$$s_{t+m} - s_t = \alpha_m + \beta_m \left[\frac{m}{12} \left(i_t^m - i_t^{m*} \right) \right] + \varepsilon_{t+m}$$

where s_{t+m} and s_t are the natural logarithm of the USD/AUD exchange rate at time $t+m$ and at time t, respectively; i_t^m and i_t^{m*} denote domestic (US) and foreign (Australian) interest rates with m-month maturity at time t. The LHS measures the m-month exchange rate change of USD/AUD. The RHS is the measure of the interest rate differential between the US and Australia $(i_t^m - i_t^{m*})$.

	α	β	$J_{(1)}$	$F_{(\alpha=0\&\beta=1)}$
$s_{t+3} - s_t$	0.007 (0.956)	0.553 (0.827)	0.148	9.76^{***}
$s_{t+6} - s_t$	0.014 (1.310)	0.537 (1.188)	0.838	24.59^{***}

Note: *, **, and *** denote significance levels of 10%, 5%, and 1%, respectively.
$^{\#}$ indicates significant difference from 1 at 5%.
Newey-West standard errors are in brackets.

This table presents the GMM estimates of the UIP condition in Equation (2.5) for Australian 90-day (3-month) and 180-day (6-month) bank accepted bills and US 3-month and 6-month Treasury bills, constant maturity. The instrumental variables are the interest rate differential, long-term interest rate differential, and stock returns differential. $J_{(1)}$ is the Hansen's J statistic, which has a χ^2 distribution under the null hypothesis that the instruments are valid. $F_{(\alpha=0\&\beta=1)}$ is the F statistic of the Wald test under the null hypothesis that $\alpha = 0$ & $\beta = 1$. The sample period is from March 1985 to December 2009.

Alternatively, we employ 5- and 10-year Treasury bonds to test the UIP condition for exchange rate changes over long horizons. The OLS estimates of Equation (2.5) for long maturities are presented in Table 2.7. Estimates of the slope coefficients display the "correct" (positive) sign. A 1% increase in the 5-year Treasury bond yield differential (i.e., $i^{60} - i^{60*}$) results in a 0.129% appreciation of the AUD over the next 5 years. Similarly, a 1% increase in the 10-year Treasury bond yield differential results in a 0.358% appreciation of the AUD over the next 10 years. Moreover, the null hypothesis is that the slope coefficients equal unity cannot be rejected at the 5% level of significance in both cases. Although both slope coefficients are closer to 1 compared to those in the short maturity cases, the hypothesis that they are equal to 1 is rejected. The results are somewhat more favorable to the UIP hypothesis for long maturities/horizons as the slope coefficients are positive. Overall the UIP condition is not supported by the data over any horizon. We did not estimate the UIP condition in the long maturity case (i.e., m = 60, 120) by GMM estimation because a set of suitable instruments could not be found.

Table 2.7: OLS estimates of the UIP condition for long maturities

This table reports the results of regressions of the formula

$$s_{t+m} - s_t = \alpha_m + \beta_m \left[\frac{m}{12} \left(i_t^m - i_t^{m*} \right) \right] + \varepsilon_{t+m}$$

where s_{t+m} and s_t are the natural logarithm of the USD/AUD exchange rate at time $t+m$ and at time t, respectively; i_t^m and i_t^{m*} denote domestic (US) and foreign (Australian) interest rates with m-month maturity at time t. The LHS measures the m-month exchange rate change of USD/AUD. The RHS is the measure of the interest rate differential between the US and Australia $(i_t^m - i_t^{m*})$.

	α	β	R^2	$F_{(\alpha=0 \& \beta=1)}$
$s_{t+60} - s_t$	0.039	0.129	0.003	13.80***
	(0.421)	(0.312)		
$s_{t+120} - s_t$	0.058	0.358	0.089	10.04***
	(0.657)	(1.105)		

Note: *, **, and *** denote significance levels of 10%, 5%, and 1%, respectively.

# indicates a significant difference from 1 at 5%.

Newey-West standard errors are in brackets.

This table presents the OLS estimates of the UIP condition in Equation (2.5) for Australian and US Treasury bonds at 5- and 10- year maturities. The sample period is from March 1985 to December 2009.

2.5 Out-of-sample forecasting

To further investigate the difference between the two estimation methods, we compare the out-of-sample forecasting performance of these two specifications. In order to evaluate the performance of the two models in terms of out-of-sample forecast ability, we compare the forecast values with their actual realized values. The full sample is divided into two periods: in-sample and out-of-sample portion. Specifically, the in-sample period is from March 1985 to February 1987, and the out-of-sample period is from March 1987 to December 2009.

In this chapter, we follow the rolling specification to ensure the number of observations and the power of the test remains constant among regressions. We compare the exchange rate forecast ability between the GMM method and the random walk to assess the performance of GMM method. The random walk model has long been used as the conventional benchmark in the exchange rate literature. The driftless random walk model for the exchange rate in level is as follows:

$$e_{t+m} = e_t + \varepsilon_{t+m}, \tag{2.6}$$

where e_t is the nominal USD/AUD exchange rate at time t and m is the forecast horizon measured in months.

We apply two measures to assess the forecast accuracy of the model. We first employ the mean square forecast error (MSFE) approach suggested by Meese and Rogoff (1983). In this method, we estimate the ratios between the MSFE of the GMM model and those of the random walk. If the ratio is smaller than 1, the GMM estimates outperform the random walk and vice versa. We also report the significant level of the Diebold and Mariano’s (1995) statistics that test the null hypothesis of no difference in the accuracy of the two competing forecasts.

An alternative evaluation measure is the direction of change (DoC). The DoC measures the out-of-sample forecasts by comparing the sign of the forecasts with the sign of the true observation. This is also known as the success ratio and is computed as the number of correct predictions of the direction of change over the total number of predictions. A value of DoC above 0.5 indicates a better forecasting performance than a naïve (random walk) model that predicts an equal chance to go up or down of the exchange rate. We also report the significant level corresponding to the hypothesis that the DoC is significantly different from 0.5.

Table 2.8: Comparison of out-of-sample forecasts between GMM methods and the random walk

	3-month	*6-month*
MSE ratio	0.906	0.579**
DoC	0.483	0.474

Note: #, ##, and ### denote a significance level of 10%, 5%, and 1% by Diebold and Mariano's (1995) statistics.

*, **, and *** denote a significant difference from 0.5 at 10%, 5%, and 1%, respectively, by *t* statistics.

This table reports two measures to assess the out-of-sample forecast accuracy of the GMM and the random walk estimations at window sizes of 36 months. The MSE ratio is the ratio of Mean Squared Forecast Error of the GMM estimates to that of the random walk. The direction of change (DoC) statistic is the proportion of "ones" over all forecasting periods. The in-sample period is from March 1985 to February 1987, and the out-of-sample period is from March 1987 to December 2009.

Comparisons of exchange rate forecast ability between the GMM and that of the random walk at 36-month window are presented in Table 2.8. The MSE ratios of the GMM are lower than unity; however, only at 6-month horizon the MSE ratio is statistically different from one showing that the GMM method is better than the random walk at the 6-month horizon. The DoC ratios are smaller than 0.5, but both of them are not significantly different from 0.5. Therefore, in terms of forecasting, the direction of the USD/AUD exchange rate movement, the GMM estimates are not better than those of the random walk. Finally, these results are robust to the selection of window size.

2.6 Conclusions

In this chapter, we employ GMM methods to re-examine the UIP condition for the USD/AUD exchange rate. We show that the GMM estimation produces estimates of the UIP condition that are more consistent with the no-arbitrage condition that underlines it. Using GMM methods, the slope coefficients are positive and much closer to their theoretical value of 1, whereas under OLS the slope coefficients are negative. In addition, results from out-of-sample forecasts indicate that under the MSE criteria, the GMM estimated equation is better than the random walk in forecasting the USD/AUD exchange rates at the 6-month horizon.

Overall, this chapter demonstrates that the UIP condition does not hold at all horizons/maturities. However, the evidence is more favorable when long bonds and long exchange rate horizons are used in tests of the UIP condition.

Chapter 3 : Relative term structure and the predictability of the USD/AUD exchange rate

3.1 Introduction

Exchange rate dynamics is one of the most extensively studied areas in international and monetary economics. Contemporary theoretical and empirical models of exchange rates focus on forecasting the performance of exchange rates. Existing models of exchange rates can be written in the present value asset pricing format (Engel and West 2005). The asset pricing model is based on the argument that the "*nominal exchange rate should be viewed as an asset price and depends on the expectations [of] future variables*" (Obstfeld and Rogoff 1996). The model implies that the exchange rate determination is a weighted average of fundamentals, including economic growth, inflation, money supply, and the expected exchange rate at some future point in time. This approach gives rise to a present value relationship between nominal exchange rates and the discounted sum of current and expected fundamentals.

In conventional asset pricing models, monetary policy is considered to be an exogenous variable. However, if monetary policy is conducted in a systematic way, then the fundamentals determining the exchange rate are different. Modern macroeconomics emphasizes the importance of the Taylor rule in modeling exchange rates[3]. This approach assumes that monetary policy is endogenous and modern central banks use short-term interest rates instead of monetary aggregates as the main instrument. Under the Taylor rule approach, the fundamentals that determine the real exchange rate are the

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[3] The Taylor's reaction function is $i_t = \pi_t + r^* + a_\pi(\pi_t - \pi^*) + a_y(y_t - y_t^*)$ in which i_t is the target short-term nominal interest rate; π_t is the rate of inflation; π^* is the desired rate of inflation, which is equal to 2% in the US economy; y_t is the (natural logarithm) of the real GDP; y_t^* is the potential output; and r^* is the equilibrium real interest rate and equals 2%.

country differentials in the deviation of inflation from the target level and output gap, instead of the difference in level of inflation and output along with other variables.

Empirical studies on exchange rate economics, which relate exchange rates to monetary variables, interest rates, and prices, have not been satisfactory. When comparing various monetary models with a random walk process, Meese and Rogoff (1983) conclude that for out-of-sample forecast accuracy with horizons from 1 to 12 months, the random walk performs better or at least as well as other models.

Although empirical studies do not support the role of fundamentals in determining the exchange rate, one school of thought holds that poor measurement of the macroeconomic fundamentals may be a problem, both in the sense that some variables could be mismeasured and in the sense that we do not include all macroeconomic variables. Thus, this chapter employs an alternative set of fundamentals proposed by Chen and Tsang (2013) contained in the shape of a yield curve. Yield factors have the power to predict fluctuations in real economic activity and inflation in addition to other financial factors, such as government debt. For example, Mishkin (1990a, 1990b) and Fama (1990) find the term structure of interest rates contains significant information about future inflation; Diebold, Rudebusch, and Aruoba (2006) report an increase in the level factor raises capacity utilization, the Federal fund rate and inflation.

The term structure of interest rates literature has long been concerned with how to capture characteristics of the yield curve. In this chapter, we employ Nelson and Siegel's (1987) parametric curves that can describe a whole family of observed term structure shapes. The model is parsimonious, consistent with the factor interpretation of the term structure, and it has been used extensively in both academia and in practice.

In this chapter, we investigate the information contained in the term structure of interest rates both in the US and Australia as a means to predict the USD/AUD exchange rate. The chapter discusses the information on macro fundamentals behind the relative factors of the yield curve to account for the forecast ability of the USD/AUD exchange rate changes and currency excess returns on the AUD. Our results show that the relative slope and curvature factors of cross-country yield curves between the US and Australia can predict exchange rate movements of the USD/AUD and excess returns on the AUD from one month to two years ahead. Our model also outperforms the random walk in forecasting the exchange rate over horizons longer than 12 months.

The rest of this chapter is structured as follows. Section 3.2 reviews the asset pricing model of exchange rates and how to extract relative factors of yield curves. Section 3.3 describes the data used in the empirical analysis. Then, in Section 3.4, the empirical methodology is explained, and the results are presented. Finally, a brief conclusion is provided in Section 3.5

3.2 Exchange rates and yield curves

In this section, we first present a summary of the asset price approach to determine the exchange rate, focusing on recent developments in Taylor-rule type models. We argue that expectations of the future fundamentals are hard to capture and that inappropriate proxies for unobservable fundamentals may cause failures in existing empirical literature on monetary models of the exchange rate. To overcome this problem, we apply the alternative set of fundamentals proposed by Chen and Tsang (2013), which are contained in the shape of yield curves. The differences in yield curve factors are extracted using Nelson and Siegel's (1987) methodology.

3.2.1 Asset pricing model of exchange rate

According to the conventional monetary models[4], the (natural logarithm of) demand for money in both a domestic and a foreign country is assumed to be a function of the (natural logarithm of) real income, the (natural logarithm of the) price level, and the interest rate. When prices in common currency are equal and the purchasing power parity (PPP) holds, the nominal exchange rate is determined by the relative money supply, income, and interest rate

$$s_t = \left(m_t - m_t^*\right) - \Phi\left(y_t - y_t^*\right) + \lambda\left(i_t - i_t^*\right), \tag{3.1}$$

where s_t is the natural logarithm of the nominal exchange rate (domestic price of foreign currency), m_t is the natural logarithm of money supply, y_t is income, i_t is the interest rate, and an asterisk (*) denotes foreign variables. Equation (3.1) shows that the nominal exchange rate is a function of money supply, income, and interest rate differentials.

The conventional monetary exchange rate models explain the movement of exchange rates well during the interwar period. However, when the sample period is extended, it performs poorly. Meese and Rogoff (1983) were the first to compare exchange rate model performance using out-of-sample forecast ability criteria. Their results show that the random walk predicts exchange rates better than or at least as well as any conventional macroeconomic models in the short run[5].

In the conventional monetary models of exchange rate, money supply is the main variable that relates the monetary policy channel to the macro fundamentals.

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[4] Conventional monetary models of exchange rate refer to flexible-price and sticky-price models.

[5] Other studies reaching the same results include Meese (1990) and Cheung, Chinn, and Pascual (2005).

These models consider the money supply as exogenous. However, since the mid-1980s, central banks have used short-term interest rates rather than money supply as their monetary policy instrument. The Taylor rule specifies that the central bank will adjust the short-run nominal interest rate in response to changes in inflation and the output gap. The macro fundamentals are quite different under Taylor rule models.

Interest rate reaction function, under the Taylor rule, in the home (US) and foreign (Australia) countries can be expressed as follows (Engel & West 2006; Engel, Nelson, & West 2007):[6]

$$i_t = \gamma_\pi E\pi_{t+1} + \gamma_y y_t + \delta i_{t-1} + u_{mt} \tag{3.2}$$

$$i_t^* = \gamma_q q_t^* + \gamma_\pi E\pi_{t+1}^* + \gamma_y y_t^* + \delta i_{t-1}^* + u_{mt}^* \tag{3.3}$$

where i_t denotes home (US) nominal interest rate, π is the deviation of expected inflation from the central bank's target in the home country, y is the output gap in the home country, q_t is the real exchange rate, and u_{mt} is the error or shift in the monetary policy rule (an asterisk denotes foreign variable). Additionally, Engel and West (2006) assume that $\gamma_q > 0$, $\gamma_\pi > 1$, $\gamma_y > 0$, and $0 \le \delta < 1$. Their assumptions allow positive weights on each of the exchange rate, inflation, and output gap deviations, and the interest rate persistence is defined to restrict the process to a stationary one. Note that the home country (US) has a similar monetary policy rule, but it does not have the real exchange rate in the reaction function since the US central bank is passive to exchange rate fluctuations.

[6]Engel and West's (2006) monetary policy rule has two deviations from the original Taylor rule in Equation (3.2). First, it includes the real exchange rate, q_t^*. This term is included to capture the fact that the central bank in some countries tends to raise the interest rate when their currency depreciates. Second, it has a forward-looking characteristic.

Assuming both countries assign the same weight to the inflation and output gap deviations (Engel and West 2006), subtract Equation (3.3) from Equation (3.2) to obtain the following:

$$i_t - i_t^* = -\gamma_q q_t^* + \gamma_\pi (E_t \pi_{t+1} - E_t \pi_{t+1}^*) + \gamma_y (y_t - y_t^*) + \delta (i_{t-1} - i_{t-1}^*) + u_{mt} - u_{mt}^*. \qquad (3.4)$$

Engel, Nelson, & West (2007, p.400) derive an expression for the forward looking real exchange rate, shown below as Equation (3.5), from this equation i.e. (3.4) under the assumption that the UIP condition holds and that the monetary authorities follow a Taylor rule in setting interest rates:

$$q_t^* = -\left(\frac{1}{1+\gamma_q}\right) \sum_{j=0}^{\infty} \left(\frac{1}{1+\gamma_q}\right)^j E_t \left[(\gamma_\pi - 1) E_t \hat{\pi}_{t+j+1} + \gamma_y \hat{y}_{t+j} + \delta \hat{i}_{t+j-1} + \hat{u}_{mt+j} - \rho_{t+j} \right] \qquad (3.5)$$

where ρ_t is the exogenous risk premium shock in the UIP condition. Equation (3.5) is forward-looking, unlike Equation (3.1). Engel and West (2006) and Engel, Nelson and West (2007) derive two major implications of Equation (3.5). First, the set of fundamentals that determine real exchange rate movement are the country differentials in the deviation of inflation from their target level and the output gap, while in the conventional monetary model it is the level differentials of inflation and output along with other variables, such as productivity differentials. Second, the sign of the relationship between the inflation gap and the real exchange rate is negative, which is contrary to the conventional monetary model. *Ceteris paribus*, an increase in home relative to foreign inflation, leads to real appreciation because an increase in inflation leads home central banks to increase interest rates, which in turn results in the appreciation of the exchange rate.

The empirical evidence from Engel and West (2006) has two major limitations. One is the role of unobservable shocks to the Taylor rule. The paper ignores the term

$u_{mt} - u^*_{mt} - \rho_{t+j}$, which would appear in Equation (3.5) and considers this term to be an unobservable fundamental. Second, the paper assumes that the UIP condition holds. However, most empirical studies show the condition is violated in general.

Models with Taylor rule fundamentals have important implications for the determination of the real exchange rate. Empirical failures may be the result of using inappropriate proxies for the market expectations of future fundamentals, rather than the failure of the models themselves. To overcome these issues, following Chen and Tsang (2013), we employ a set of latent factors extracted from the shape of yield curves as proxies for macroeconomic fundamentals in the exchange rate model.

3.2.2 The yield curve and Nelson-Siegel latent factors

Substantial research efforts have been devoted to modeling the dynamics of the yield curve. Since yield curves display certain cross-sectional relationships along time and yields of different maturities move closely with one another, it is efficient and parsimonious to exploit the cross-sectional relationships among yields of different maturities and summarize the yield curve in a few factors. Nelson and Siegel's (1987) interpolation method is extremely popular as a means to do this due to its goodness-of-fit, parsimony, and implied conforming behavior of long-term yields. According to this method, the spot interest rate on a zero-coupon bond of maturity m-month, at time t is

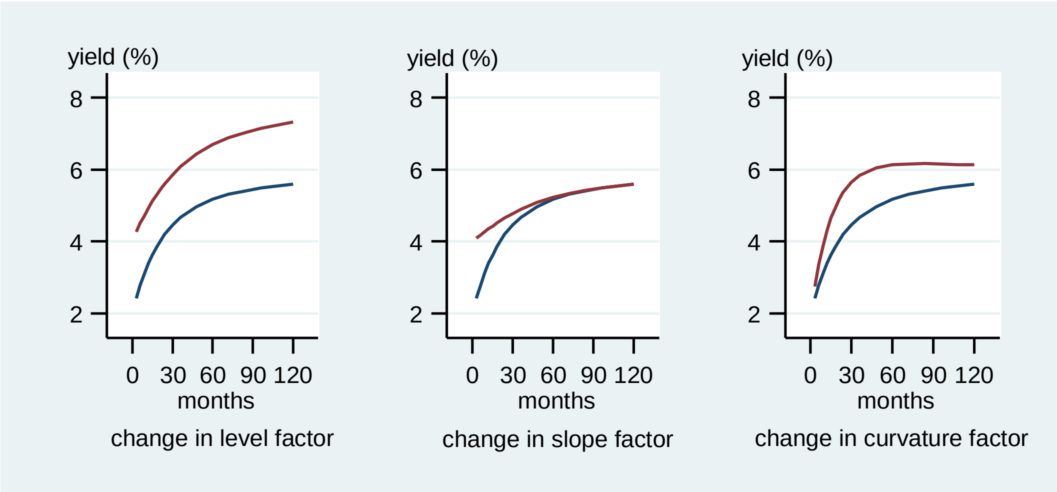
$$i_t^m = L_t + S_t\left(\frac{1-e^{-\lambda m}}{\lambda m}\right) + C_t\left(\frac{1-e^{-\lambda m}}{\lambda m} - e^{-\lambda m}\right) + v_{t,m}, \tag{3.6}$$

where i_t^m denotes the continuously compounding zero-coupon nominal yield at time t on m-month bond; L_t , S_t , C_t and λ are parameters; 1, $\left(\frac{1-e^{-\lambda m}}{\lambda m}\right)$, $\left(\frac{1-e^{-\lambda m}}{\lambda m} - e^{-\lambda m}\right)$ are their loadings; and $v_{t,m}$ is a disturbance with a standard deviation equal to $\sigma_t(m)$.

Diebold and Li (2006) interpret the parameters L_t, S_t, and C_t as dynamic latent factors, corresponding to the level, slope, and curvature factors of the term structure, respectively. The role of the factors is as follows. The level factor L_t, with its loading of 1, has the same impact on the whole yield curve. The loading on the slope factor $\left(\frac{1-e^{-\lambda m}}{\lambda m}\right)$ starts at 1 when $m=0$ and decreases to zero as the maturity increases. An increase in the slope factor S_t means that the yield curve becomes flatter. The curvature factor C_t is a "*medium*" term factor, as its loading is zero for small term to maturity m, increases in the middle maturity range, and then decreases back to zero.

The location of the hump/trough of the term structure at a given term to maturity m is fixed by selecting the "shape" parameter λ to a specific value. This action linearizes the model.

Figure 3.1: Effect of change in a yield curve factor to the shape of the yield curve

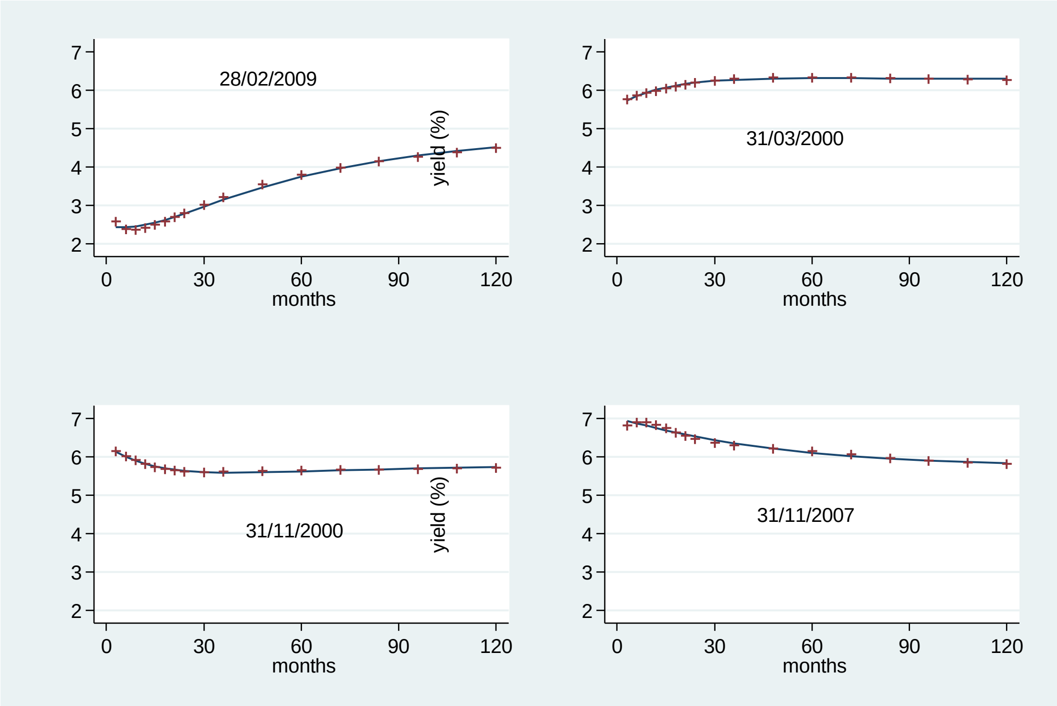


Note: This figure illustrates the effect of a change in a yield curve factor on the shape and position of the yield curve. The blue curves are the original yield curves, and the brown are the new yield curves when there is a change in one curve factor (the other yield curve factors remain the same).

Figure 3.1 illustrates the effect of shocks in yield curve factors on the shape of the yield curve. The blue line is the original yield curve, and the red line is the yield curve after a shock. Panel A illustrates the effect of an increase in the level factor on the yield curve. A level shock changes the yields of all maturities by the same amounts. Panel B illustrates the influence of the slope factor on the yield curve. A rise in the slope factor increases short-term interest rates by much larger amounts than long-term interest rates. Thus, the yield curve after the shock becomes flatter. Panel C presents the response of the yield curve to a rise in the curvature factor. The shock on the curvature falls to medium-term interest rates, and consequently the yield curve becomes more "hump-shaped" than before.

There are three main reasons for us to apply Nelson-Siegel framework. First, Nelson-Siegel framework maps the entire yield curve, period-by-period, into a three-dimensional space that evolves dynamically. The three factors’ loadings allow the model the flexibility to reproduce a variety of shapes of observed yield curves through time, including upward sloping, downward sloping, humped, and inverted humped, which are dependent upon the variation of L_t, S_t , and C_t . Figure 3.2 shows the different combinations of L_t, S_t , and C_t can produce a variety of shapes of the yield curve.

Figure 3.2: Different shapes of yield curves described by different combinations of yield factors



Note: This figure shows that different combinations of yield curve factors can produce a variety of yield curve shapes. The Nelson-Sigel fitted yield curve (the blue line) and the zero-coupon yields (the brown plus sign) are measured in annual percentages. These dates are selected in an Australian market for illustration only.

Second, the Nelson-Siegel model imposes structure on factor loading to improve the precision of estimation. Estimation results using Equation (3.6) month-by-month in both countries produce results that are consistent with other empirical studies. For example, Litterman and Scheinkman (1991) conclude that more than 99% of the movements of various Treasury bond yields are captured by the three factors. Chen and Tsang (2013) find the three factors can capture most of the information in a yield curve.

Third, the three-time varying parameters in the Nelson-Siegel framework can be interpreted as factors, which in turn can be easily used as proxies for expectation of future macro fundamentals in our exchange rate model.

Obviously, the Nelson-Siegel model is capable of replicating a variety of stylized facts of empirical yield curves. However, the model does exhibit difficulties in fitting the yield curve when yield data are dispersed, with multiple interior minima and maxima. Subsequent literature tries to improve the Nelson-Siegel's estimation. For example, Svensson (1994) extends the function to a four-factor model, which results in a better fit at longer maturities. Christensen, Diebold, and Rudebusch (2011) employ a Kalman filter approach rather than a period-by-period framework to obtain an estimate of the shape parameter λ. However, for interest rate forecasting and dynamic analysis, the desirability of extensions of the Nelson-Siegel model is not obvious (Medeiros & Rodriguez 2011). In addition, such extensions may compound the complexity of the estimation problem, especially for the case of multi-country analysis.

Since the fundamentals on the right side of the exchange rate model in Equation (3.4) are cross country differences, proxies for these fundamentals should be differences in their yield curve factors. It is reasonable to assume symmetry in factor loadings for both domestic and foreign countries in Equation (3.6). Symmetry means that the factor loadings are the same for both countries, i.e., λ is the same for both. Subtracting the domestic yield curve in Equation (3.6) from the foreign yield curve counterpart produces the yield difference equation:

$$i_t^m - i_t^{m*} = L_t^R + S_t^R \left(\frac{1-e^{-\lambda m}}{\lambda m} \right) + C_t^R \left(\frac{1-e^{-\lambda m}}{\lambda m} - e^{-\lambda m} \right) + v_{t,m} - v_{t,m}^*, \qquad (3.7)$$

where i_t^m, and i_t^{m*} are the home country (the US) and the foreign (Australia) nominal zero-coupon yields at time t with m months to maturity. We call L_t^R, S_t^R, and C_t^R the relative level, relative slope, and relative curvature, respectively, since they describe the differences between level, slope, and curvature of the two countries.

3.3 Data and methodology

3.3.1 Data

The empirical analysis in this chapter employs monthly data on zero-coupon bond yields for US and Australia bonds at 17 maturities 3, 6, 9, 12, 15, 18, 21, 24, 30, 36, 48, 60, 72, 84, 96, 108, and 120 months. These yields are continuously compounding annual yields and are collected on the last trading day of month from July 1992 to September 2012. Overall, our sample consists of 4,131 monthly observations of yields at 17 maturities for each country. Data on Australia and US zero-coupon yields are provided by the Reserve Bank of Australia (RBA) and the US Federal Reserve on their respective websites. The construction of the data for Australia is described in Finlay and Chambers (2009); we note that they made no attempt to adjust for risk premia. For construction of the US zero-coupon data, refer to Gürkaynak, Sack, and Wright (2006). We also investigate the dataset provided by Thomson Datastream as a robustness check, and the results are presented in Appendices 3.5-3.8.

Consistent with the existing literature, we treat the US as the home country and Australia as the foreign country. We measure exchange rates (S) as the US dollar price of one Australian dollar. Hence a rise in the exchange rate represents an appreciation of the Australian dollar and depreciation of the US dollar. We also define the exchange rate change as the annualized change of the natural logarithm of the USD/AUD exchange rate (s). Data on spot exchange rates are recorded at 4.00 pm (Sydney time) and provided by the RBA.

Table 3.1: Summary statistics of Australia and US zero-coupon yields

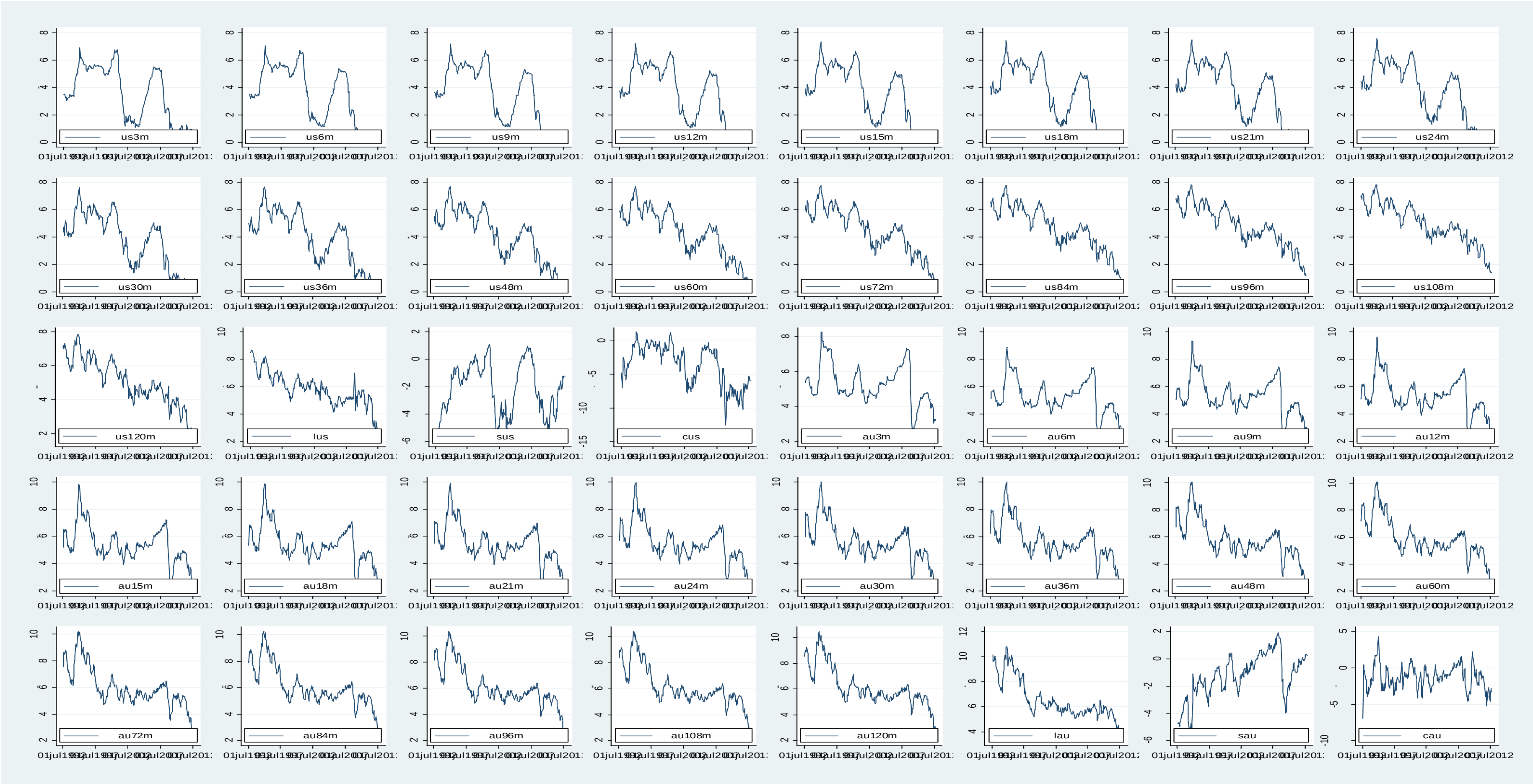
Months	Mean	Maximum	Minimum	Std. Dev.	Skewness	Kurtosis	Stationary
Australia							
3	5.280	8.260	2.590	1.131	0.269	2.986	I(0)
6	5.294	8.890	2.220	1.201	0.283	3.279	mixed
9	5.327	9.350	2.160	1.248	0.323	3.538	I(1)
12	5.360	9.630	2.230	1.276	0.368	3.741	I(1)
15	5.391	9.780	2.330	1.296	0.409	3.875	I(0)
18	5.424	9.850	2.290	1.313	0.442	3.946	I(0)
21	5.457	9.880	2.220	1.329	0.468	3.975	I(0)
24	5.492	9.930	2.170	1.344	0.488	3.977	I(0)
30	5.567	9.990	2.120	1.371	0.512	3.951	mixed
36	5.643	10.030	2.120	1.393	0.528	3.914	I(0)
48	5.782	10.080	2.210	1.423	0.567	3.853	I(0)
60	5.896	10.110	2.350	1.445	0.619	3.781	I(0)
72	5.984	10.180	2.500	1.463	0.683	3.710	I(0)
84	6.054	10.260	2.640	1.477	0.744	3.641	I(0)
96	6.110	10.350	2.770	1.487	0.797	3.586	I(0)
108	6.157	10.420	2.890	1.491	0.843	3.548	I(1)
120	6.198	10.470	2.980	1.491	0.880	3.530	I(1)
The US							
3	3.519	6.903	0.490	1.983	-0.123	1.499	I(1)
6	3.458	7.046	0.384	2.038	-0.156	1.526	I(1)
9	3.431	7.166	0.325	2.076	-0.185	1.568	mixed
12	3.401	7.252	0.131	2.108	-0.214	1.616	I(1)
15	3.453	7.351	0.096	2.104	-0.232	1.658	I(1)
18	3.489	7.421	0.041	2.101	-0.249	1.702	I(1)
21	3.537	7.480	0.027	2.088	-0.264	1.744	I(1)
24	3.653	7.563	0.188	2.046	-0.266	1.777	I(1)
30	3.719	7.606	0.131	2.017	-0.294	1.858	I(1)
36	3.885	7.663	0.306	1.943	-0.303	1.926	I(1)
48	4.101	7.712	0.454	1.834	-0.325	2.066	I(1)
60	4.301	7.742	0.627	1.731	-0.337	2.203	I(1)
72	4.486	7.763	0.815	1.640	-0.340	2.335	I(1)
84	4.654	7.779	1.007	1.561	-0.338	2.457	I(0)
96	4.806	7.797	1.197	1.494	-0.330	2.563	I(0)
108	4.941	7.825	1.380	1.438	-0.318	2.651	I(0)
120	5.060	7.850	1.552	1.392	-0.302	2.719	I(0)

Note: See Appendices 3.1 and 3.3 for a detailed discussion of the unit root test.

This table reports summary statistics of Australian and US zero-coupon yields at 17 maturities from 3 months to 10 years from July 1992 to September 2012. The summary statistics include mean, minimum, maximum, standard deviation (measured in annual percentage rates), skewness, kurtosis, and unit root test.

Table 3.1 presents descriptive statistics of US and Australian zero-coupon yields at maturity from 3 months to 10 years. Table 3.1 shows that average yields are increasing and concave in both countries. Yields rise as maturity lengthens. Average yields in Australia are higher than those in the US at all maturities. Interest rate volatility, measured by the standard deviation of the yields, shows that the long rates are less volatile than the short rates. One explanation for this finding is that it is an implication of the expectations hypothesis. Another explanation is that it could be due to differences in the liquidity of Treasury bonds/bills at different maturities. More liquid securities (i.e. those with shorter terms to maturity) are traded more frequently than less liquid securities (i.e. those with longer terms to maturity) inducing greater volatility in their returns. The bond yield volatilities in the US are much higher than in Australia at all maturities.

Figure 3.3: Australian and US zero-coupon yields from 1992 to 2012

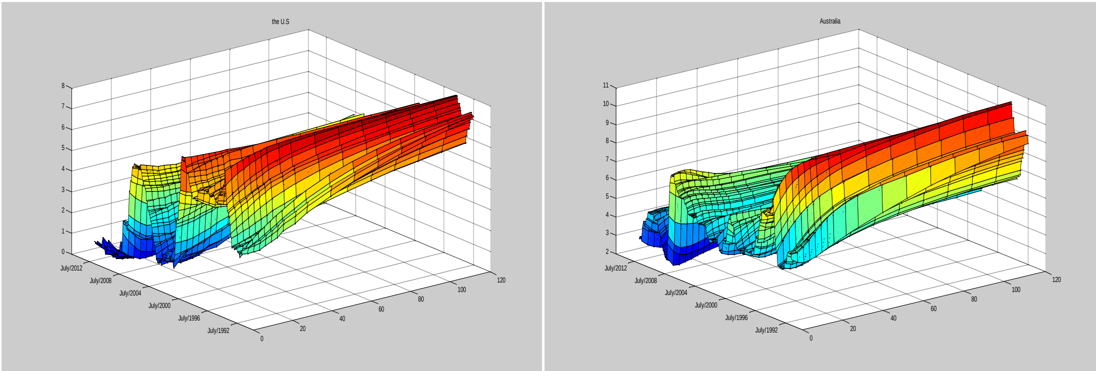


Note: This figure plots the movement of Australian and the US zero-coupon yields at 17 maturities from 3 to 120 months and their yield curve factors. The sample period is from July 1992 to September 2012.

Figure 3.3 plots the US and Australian zero-coupon yields at different maturities and their yield curve factors in the period. Figure 3.3 shows that there are possibly structural breaks in these series. These breaks may come from the global economic crises in 1997 and 2008 and/or from changes in economic policy, as well as regime shifts in the two countries. As a result, the Dickey and Fuller's (1979) unit root test may be biased towards erroneous non-rejections of the unit root hypothesis. In this chapter, we apply the unit root test developed by Kim and Perron (2009) that allows for an unknown break in both the null and alternative hypothesis (see Appendix 3.1 for a detailed explanation of the test). Figure 3.3 also shows the level factors are highly persistent and vary little around their mean. At the same time, the curvature factors are the least persistent and the most volatile of all factors in both countries.

Figure 3.4 provides a three-dimensional plot of the US and Australian estimated yield curves for the period. Variation in the level factor in the US is much bigger than that of Australia. This is consistent with the results in Table (3.1) that Treasury bond yield volatilities in the US are much higher than in Australia for any horizon. In both countries, interest rates fell dramatically in late 1998 and in late 2008. These drops reflect the fact that central banks in both countries cut interest rates during these periods to stimulate their economy's growth. We also see the variation in slope and curvature in both countries during the period.

Figure 3.4: Australian and US yield curves



Note: This figure plots three-dimensional Australian (right panel) and US (left panel) yield curves. The sample period is from July 1992 to September 2012.

3.3.2 Yield curve factors and market expectations

There is long history of using the term structure of interest rates to predict future inflation and output. Mishkin (1990a) and Fama (1990) show the term structure for maturities greater than one year contains predictive power for changes in future inflation. Specifically, when the slope of the yield curve falls, it is an indication that the inflation rate will fall, while a steeply upward sloping yield curve indicates expectations of a rising rate of inflation.

A recent trend in the term structure model is to combine macroeconomic variables as factors in the model. For example, Bernanke, Reinhart, and Sack (2004) apply a standard affine model in which the factors are GDP growth, inflation, the federal funds rate, and survey expectations of future inflation and growth. Smith and Taylor (2009) treat inflation and output gap as factors in the model. They argue that if short-term interest rates are driven by macroeconomic variables, such as inflation and output gap, then according to the expectation hypothesis, the term structure of interest rates ought to reflect the expectation of future inflation and output.

Diebold, Rudebusch, and Aruoba (2006) and Afonso and Martins (2010) find there is a close connection between the slope of the yield curve and the instrument of monetary policy, and Rudebusch and Wu (2008) conclude that factors of the term structure capture expectations about future short rates, which in turn reflect the expectations regarding the future course of the economy. These expectations should be important determinants of current and future macroeconomic variables. The level factor is related to the medium-term central bank inflation target, and the slope factor is related to cyclical variation in inflation and output gaps as the central bank adjusts the short rate in order to achieve its macroeconomic policy goals.

In this section, we investigate the relationship between expected macroeconomic fundamentals and three yield curve factors. We conduct some simple tests using our yield curve factors and data on expectations provided by the Consumer Attitudes, Sentiments and Expectations (CASiE) and the RBA. The CASiE interviews 1,200 households every month on how much they believe the inflation rate, how unemployment would change over the next 12 months as well as how they evaluate their financial condition in the past year and in the next few years. We also investigate the National Australia Bank (NAB) business confidence index, which measures respondents' expectations of business conditions in their industry for the upcoming quarter. The NAB business confidence index is provided by the RBA (see Appendix 3.2 for a detailed description of the variables). To evaluate how information contained in the shape of a yield curve can predict macroeconomic expectations, we run the following simple regressions:

$$E_t\pi_{t+12} = \beta_0 + \beta_1 L_t^{AU} + u_t$$

$$E_t\pi_{t+12} = \beta_0 + \beta_1 L_t^{AU} + \beta_2 (CPI\_a)_t + u_t$$

$$E_t\pi_{t+12} = \beta_0 + \beta_1 S_t^{AU} + u_t$$

$$E_t(CSI)_{t+12} = \beta_0 + \beta_1 S_t^{AU} + u_t$$

$$E_t(Nab\_conf)_{t+3} = \beta_0 + \beta_1 S_t^{AU} + u_t$$

$$E_t(CSI)_{t+12} = \beta_0 + \beta_1 C_t^{AU} + u_t$$
$$E_t(Nab\_conf)_{t+3} = \beta_0 + \beta_1 C_t^{AU} + u_t$$

where $E_t\pi_{t+12}$ denotes the median of consumer inflationary forecast 12 months ahead, $E_t(CSI)_{t+12}$ is the consumer sentiment index for the horizon of 12 months, CPI_a is the actual inflation rate, and $E_t(NAB\_conf)_{t+3}$ is the NAB business confidence index over the next 3 months.

Table 3.2: Surveyed forecasts of macroeconomic fundamentals and the level factor of an Australian yield curve

This table reports the results of regressions of the formula

$$E_t\pi_{t+12} = \beta_0 + \beta_1 L_t^{AU} + u_t$$
$$E_t\pi_{t+12} = \beta_0 + \beta_1 L_t^{AU} + \beta_2 (CPI\_a)_t + u_t$$

where $E_t\pi_{t+12}$ denotes the median of consumer inflationary forecast over the next 12 months, L_t^{AU} is the level factor of the Australian term structure of interest rates, and CPI_a is the actual inflation rate.

	Subsample		**Full sample**	
Level (L_t^{AU})	-0.178**	-0.222**	-0.144*	-0.213***
	(-2.011)	(-3.129)	(-1.943)	(-4.780)
Actual CPI (*CPI_a*)		0.169*		0.207**
		(1.824)		(2.225)
N	175	58	232	77
F	4.044	6.255	3.776	11.692

Note: Newey and West's (1987) t statistics are in brackets.
*, **, and *** denote significance levels of 10%, 5%, and 1%, respectively.
Estimates for constant terms are omitted.

This table presents the relationship between expected inflation, measured by the median of consumers' inflationary expectations over the next 12 months and the level factor of the Australian yield curve. The subsample is from May 1993 to December 2007, and the full sample is from May 1993 to September 2012.

Table 3.2 shows a higher level factor corresponds to a lower inflation expectation in the next 12 months. A 1% increase in the Australian level factor explains the approximately 0.22% drop in the median of expected inflation over the next 12 months. These results are consistent with the level factor of the term structure of interest rates literature (see Rudebusch & Wu, 2008; Chen & Tsang, 2013). The negative relation implies that an increase in the level factor is associated with higher interest rates at the short-end due to a tightening of monetary policy rather than an increase in long rates due to expectations of higher future inflation. Our results are robust to the inclusion of the current inflation rate and hold when the global financial crisis period is included.

Table 3.3 shows that a higher slope factor (the yield curve becomes flatter) forecasts a higher inflation rate. Specifically, a 1% increase in the slope factor predicts approximately a 0.29% increase in the median of inflation in the next 12 months. The business confidence index drops 2.5% in the next quarter when the current slope factor increases by 1%. These results are also similar to other findings in the literature (see Mishkin 1990a; Fama 1990; Moench 2012). A flatter yield curve indicates that short rates are high relative to long rates, which reduces business confidence due to the monetary tightening. It also decreases current inflation so that inflation will be expected to be higher in the future. This may appear inconsistent with the results shown in Table 3.2. which shows inflation will fall over the next 12 months. However, over a much longer horizon (say 5 or 10 years), inflation would be expected to rise because if inflation is low (i.e. below trend) in the near term, it would be expected to increase back to trend in the long run as inflation is a mean reverting process.

Table 3.3: Surveyed forecasts of macroeconomic fundamentals and the slope factor of the Australian yield curve

This table reports the results of regressions of the formulas

$$E_t\pi_{t+12} = \beta_0 + \beta_1 S_t^{AU} + u_t$$

$$E_t\pi_{t+12} = \beta_0 + \beta_1 S_t^{AU} + \beta_2 (CPI\_a)_t + u_t$$

where $E_t\pi_{t+12}$ denotes the median of consumer inflationary forecast over the next 12 months, S_t^{AU} is the slope factor of the Australian term structure of interest rates, and CPI_a is the actual inflation rate.

	Subsample		Full sample	
Slope (S_t^{AU})	0.278***	0.287***	0.294***	0.298***
	(4.214)	(4.487)	(3.945)	(5.498)
Actual CPI (*CPI_a*)		0.083		0.092
		(1.092)		(1.160)
Nob	175	58	232	77
F	17.759	11.056	15.562	16.602

$$E_t(CSI)_{t+12} = \beta_0 + \beta_1 S_t^{AU} + u_t$$

$$E_t(Nab\_conf)_{t+3} = \beta_0 + \beta_1 S_t^{AU} + u_t$$

where $E_t(CSI)_{t+12}$ denotes the consumer sentiment index for the next 12 months and $E_t(NAB\_conf)_{t+3}$ is the NAB business confidence index over the next 3 months. S_t^{AU} is the slope factor of the Australian term structure of interest rates.

	Dependent variable: $E_t(CSI)_{t+12}$		Dependent variable: $E_t(NAB\_conf)_{t+3}$	
	Subsample	Full sample	Subsample	Full sample
Slope (S_t^{AU})	1.310	0.002	-2.550**	-2.485**
	(1.037)	(0.001)	(-3.068)	(-2.837)
Nob	185	242	61	80
F	1.075	0.000	9.410	8.048

Note: Newey and West's (1987) t statistics are reported in brackets. *, **, and *** denote significance levels of 10%, 5%, and 1%, respectively. Estimates for constant term are omitted.

These tables report the relationship between expected inflation, consumer sentiment index, business confidence index, and the slope factor of the Australian yield curve. The subsample is from July 1992 to December 2007, and the full sample is from July 1992 to September 2012.

Table 3.4 reports the relationship between curvature factor and consumer sentiment index together with the business confidence index. A higher curvature factor consistently maps to higher household and business confidence in the next 12 and 4 months, respectively.

Table 3.4: Surveyed forecasts of macroeconomic fundamentals and the curvature factor of the Australian yield curve

This table reports the results of regressions of the formulas

$$E_t(CSI)_{t+12} = \beta_0 + \beta_1 C_t^{AU} + u_t$$

$$E_t(Nab\_conf)_{t+3} = \beta_0 + \beta_1 C_t^{AU} + u_t$$

where $E_t(CSI)_{t+12}$ denotes the consumer sentiment index for the next 12 months, $E_t(NAB\_conf)_{t+3}$ is the NAB business confidence index over the next 3 months, and C_t^{AU} is the curvature factor of the Australian term structure of interest rates.

	Dependent variable: $(E_t(CSI)_{t+12})$		Dependent variable: $(E_t(Nab\_conf)_{t+3})$	
	Subsample	Full sample	Subsample	Full sample
Curvature (C_t^{AU})	1.519**	2.290***	1.716**	2.743***
	(2.387)	(3.761)	(2.189)	(3.605)
Nob	185	242	61	80
F	5.698	14.147	4.792	12.997

Note: Newey and West's (1987) t statistics are reported in brackets.

*, **, and *** denote significance levels of 10%, 5%, and 1%, respectively.

Estimates for constant term are omitted.

This table reports the relationship between Consumer Sentiment index, Business Confidence index and the curvature factor of the Australian yield curve. The subsample is from July 1992 to December 2007 and the full sample is from July 1992 to September 2012.

3.3.3 Model specifications

We estimate the relative yield curve factors between Australia and the US using Equation (3.7):

$$i_t^m - i_t^{m*} = L_t^R + S_t^R \left(\frac{1-e^{-\lambda m}}{\lambda m} \right) + C_t^R \left(\frac{1-e^{-\lambda m}}{\lambda m} - e^{-\lambda m} \right) + v_{t,m} - v_{t,m}^*.$$

The parameter λ is known as a shape parameter and makes the equation linear, which facilitates the estimation. In this thesis, we follow the Nelson and Siegel's (1987) model and select the value of λ which maximizes the loading on the curvature factor when m equals 30 months. That value of λ is 0.0609 and this set the location of the hump of the term structure of interest rates at 30 months.

We estimate the relative level, slope, and curvature month-by-month using Equation (3.7). Specifically, we obtain estimates of L_t^R, S_t^R, and C_t^R for each t by estimating Equation (3.7) by OLS for m running over 17 maturities (i.e., m = 3, 6, 12, 15, 18, 21, 30, 36, 48, 60, 72, 84, 96, 108, and 120). Now t = 1, …, 241 corresponding to data on interest rates running from July 1992 to September 2012. We estimate 241 OLS regressions with Equation (3.7) using 17 cross-sectional observations on interest rates at each t. At the end of the process, we obtain a monthly series of three relative factors, L_t^R, S_t^R, and C_t^R, which represent the differences in the shape of the yield curves for Australia and the US. Equation (3.7) fits the data well with each R^2 of around 0.98. These results are similar to Chen and Tsang (2013), who find the R^2 close to 0.99 in most of the cases.

Summary statistics of country-specific and relative yield curve factors are presented in Table 3.5. On average, all three yield curve factors in Australia are much higher than those in the US. Relative level has the lowest volatility among the three relative factors and is much lower than the volatility of level factors in both countries. The volatility of the relative slope and relative curvature are more or less the same as those of the countries' specific factors. The relative factors are quite persistent. For the full sample, the first-order autocorrelation of the relative level factor is 0.934; the relative slope and curvature factors are 0.976 and 0.902, respectively. These results are similar to the subsample: 0.959, 0.978, and 0.857, respectively. The relative curvature factor is the least persistent of the all the factors, but it is still highly persistent. The Australian and US factors are also highly persistent (not given) with the curvature factor being less persistent than the other two factors. For Australia, the curvature factor is somewhat less persistent than the US curvature factor. For the other two factors, the degree of persistence is very similar, with both countries exceeding 0.96.

On the basis of the Augmented Dickey-Fuller's (ADF) test, the null of a unit root in each of the factors cannot be rejected, suggesting the factors contain a unit root component. However, as it is likely that there has been structural shift in the interest rate data over the sample, the ADF test may have small power. We decided to apply the unit root test of Kim and Perron (2009), which is robust to structural shifts. Table 3.5 shows that the relative level and curvature factors are stationary on the basis of this test while the results are ambiguous for the relative slope factor. We proceed on the basis that the relative factors are stationary but highly persistent.

Table 3.5: Summary statistics of the Australian and US yield curve factors

	Mean	Max	Min	Std. Dev.	Skewness	Kurtosis	Stationary
L^{AU}	6.547	10.804	3.291	1.585	0.912	3.071	I(0)
S^{AU}	-1.264	1.906	-5.622	1.606	-0.488	2.870	I(0)
C^{AU}	-1.316	4.270	-6.945	1.653	0.110	3.465	I(0)
L^{US}	5.786	8.685	2.337	1.203	-0.214	3.582	I(0)
S^{US}	-2.162	1.122	-5.653	1.845	-0.094	1.781	I(1)
C^{US}	-3.599	1.278	-12.607	2.965	-0.527	2.222	I(1)
L^{R}	-0.761	1.226	-3.368	0.759	-1.179	4.307	I(0)
S^{R}	-0.898	2.405	-4.559	1.781	-0.254	1.953	Mixed
C^{R}	-2.283	3.744	-9.255	2.806	-0.510	2.597	I(0)

Note: See Appendices 3.1 and 3.4 for a detailed discussion of the unit root test.

This table reports summary statistics of Australian, US, and relative yield curve factors estimated by Equation (3.6) and (3.7). The summary statistics include mean, minimum, maximum, standard deviation (measured in annual percentage rates), skewness, kurtosis, and unit root test. The sample period is from July 1992 to September 2012.

Since the shape of the yield curves contains information on the expected economic activities, inflation, and other financial factors, differences in the shape of yield curves reflect the differences in the expectation of macroeconomic fundamentals between the two economies.

Table 3.6 reports correlations between country-specific and relative yield curve factors. Level and slope factors are negatively correlated. In contrast, slope and curvature factors move in the same direction. The high positive correlation between slope and curvature factors can be explained as follows: when there is an increase in curvature factor, long rates fall and short rates increase strongly, which results in a flatter yield curve (higher slope factor).

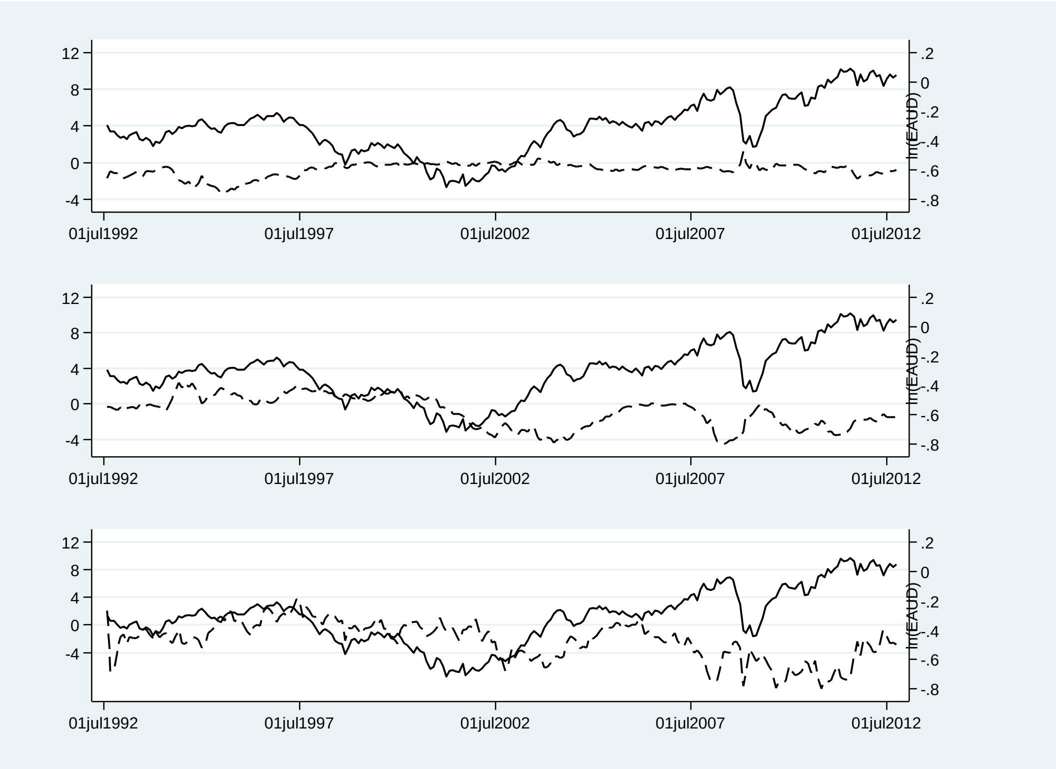
Table 3.6: Correlations between yield curve factors

	L^{AU}	S^{AU}	C^{AU}	L^{US}	S^{US}	C^{US}	L^{R}	S^{R}	C^{R}
L^{AU}	1.000								
S^{AU}	-0.726	1.000							
C^{AU}	0.183	0.017	1.000						
L^{US}	0.887	-0.736	0.252	1.000					
S^{US}	-0.140	0.475	0.139	-0.270	1.000				
C^{US}	0.432	-0.128	0.372	0.385	0.568	1.000			
L^{R}	-0.682	0.349	0.018	-0.268	-0.135	-0.291	1.000		
S^{R}	0.510	-0.410	0.129	0.384	0.608	0.704	-0.455	1.000	
C^{R}	0.348	-0.145	-0.195	0.259	0.518	0.837	-0.318	0.668	1.000

Note: This table presents the correlations between US and Australian yield curve factors. These factors are estimated from Equations (3.6) and (3.7). The sample period is from July 1992 to September 2012.

Figure 3.5 plots the movement of each relative factor along with the natural logarithm of the USD/AUD exchange rate during the period. It is clear from the figure that the relative factors are highly persistent.

Figure 3.5: USD/AUD exchange rate and relative yield curve factors



Note: This figure graphs the movement of the natural logarithm of the USD/AUD exchange rate (solid line, right axis) and the relative yield curve factors (dash line, left axis). The relative yield curve factors are estimated from Equation (3.7). The sample period is from July 1992 to September 2012.

The Uncovered Interest Rate Parity (UIP) condition states that if market participants are risk-neutral and have rational expectations, the expected exchange rate depreciation equals the current interest rate differential. The UIP condition can be expressed as

$$s_{t+m} - s_t = i_t^m - i_t^{m*} + \eta_{t,t+m} + \xi_{t,t+m}, \quad (3.8)$$

where $\eta_{t,t+m}$ is the risk premium and $\xi_{t,t+m}$ is the white noise error term that is, by definition, uncorrelated with all information known at time *t*. However, the UIP condition does not hold in general. This finding is robust to the estimation techniques, period of study, and data sets used (Froot & Thaler 1990; Engel 1996; Lucio 2005; Chinn 2006; Isard 2006).

The currency excess returns, rx_{t+m} by definition, are the difference between the cross-country yields adjusted for the relative currency movements:

$$rx_{t+m} = i_t^{m*} - i_t^m + \Delta s_{t+m}. \tag{3.9}$$

By combining Equations (3.8) and (3.9), the currency excess returns can now be expressed as

$$rx_{t+m} = \eta_{t,t+m} - \xi_{t,t+m}.$$

Thus, under the rational expectations hypothesis, currency excess returns can be interpreted as the risk premium associated with holding foreign interest-bearing securities.

Following Chen and Tsang (2013), we employ the three relative factors extracted from Equation (3.7) to test whether these factors can predict changes in the exchange rate and currency excess returns on the AUD at different horizons from 1 to 24 months. The regression equations for estimation are

$$\frac{1200(s_{t+m} - s_t)}{m} = \beta_{m,0} + \beta_{m,1}L_t^R + \beta_{m,2}S_t^R + \beta_{m,3}C_t^R + u_{t+m} \tag{3.10}$$

$$i_t^{m*} - i_t^m + \frac{1200(s_{t+m} - s_t)}{m} = \varphi_{m,0} + \varphi_{m,1}L_t^R + \varphi_{m,2}S_t^R + \varphi_{m,3}C_t^R + \upsilon_{t+m} \tag{3.11}$$

where the LHS of Equations (3.10) and (3.11) are the annualized change in the exchange rate and currency excess returns on AUD, respectively.

Analysis using longer time horizons will need to address inference bias due to overlapping observations. When the horizon for exchange rate depreciation and excess returns are greater than the frequency of data (1 month), the left side variable overlaps across observations and the error terms u_{t+m} and v_{t+m} in Equations (3.10) and (3.11) will follow the moving average process of order $m-1$. For example, with m equal to 3 in Equations (3.10) and (3.11), a three-month change could be calculated from January to April, another from February to May, etc. As a result, changes from January to April and from February to May overlap by two months. Traditional OLS parameter estimates with overlapping data would be inefficient, and hypothesis testing would be biased (Hansen & Hodrick 1980). One way to fix the problem of overlapping observations is to use a reduced sample where none of the observations overlap. In this example, with a 10-year period of monthly data, only 40 quarterly observations would be used. This method will eliminate the autocorrelation problem, but it is obviously inefficient since it reduces the number of observations.

Another more efficient way to deal with this problem is to use the overlapping data and to account for the moving average of the error term in hypothesis testing. Harri and Brorsen (2009) investigate estimation methods involving the use of overlapping data in regression analysis in the three leading journals[7] from 1996 to 2004, and show that OLS non-overlapping data and Newey-West estimation methods are most frequently used. As previously noted, the OLS with a non-overlapping method is inefficient as it discards information; thus, in this paper, we use the Heteroskedasticity and Autocovariance Consistent (HAC) standard errors developed by Newey and West (1987) to mitigate the impact of overlapping observations. The number of lags of the residual auto-correlations[8] is selected by Schwert's (1989) method. Alternatively, we also report rescaled t statistics suggested by Moon, Rubia, and Valkanov (2004). They demonstrate that the re-scaled t statistic $(t/\sqrt{m})$ is approximately standard normal,

[7] These journals are the Journal of Finance, the American Economic Review, and the Journal of Future Markets.

[8] $n = \text{int}\left\{12(T/100)^{1/4}\right\}$

provided the regressors are highly persistent; therefore, inference based on the rescaled t statistics is likely to be reliable.

Summary statistics of the USD/AUD exchange rate change and currency excess returns on the AUD are presented in Table 3.7. The mean of the exchange rate changes increase as the interval is extended. In addition, a longer interval of exchange rate changes has a lower standard deviation.

Table 3.7: Summary statistics of the USD/AUD exchange rate changes and currency excess returns on the AUD

	Mean	**Max**	**Min**	**Std. Dev.**	**Skewness**	**Kurtosis**	**Stationary**
Exchange rate changes							
AUD1	1.486	102.375	-215.788	39.911	-0.839	6.580	I(0)
AUD3	1.686	81.472	-138.081	25.091	-1.089	8.526	I(0)
AUD6	1.903	52.540	-76.420	19.003	-0.863	6.158	Mixed
AUD12	2.134	33.399	-38.301	13.201	-0.318	3.191	I(0)
AUD18	2.238	22.741	-20.656	10.096	-0.240	2.440	I(0)
AUD24	2.169	22.703	-16.456	8.657	0.107	2.468	I(0)
Currency excess returns							
ERAUD3	3.277	82.672	-133.321	25.274	-0.960	7.773	I(0)
ERAUD6	3.560	53.830	-71.580	19.228	-0.676	5.281	I(0)
ERAUD12	3.902	35.719	-32.801	13.698	-0.229	2.858	I(0)
ERAUD18	3.987	25.576	-20.186	10.792	-0.275	2.415	I(0)
ERAUD24	3.836	24.543	-15.826	9.290	-0.019	2.366	I(1)

Note: See Appendices 3.1 and 3.4 for a detailed discussion of the unit root test.

This table presents summary statistics of the dependent variables in Equations (3.10) and (3.11). Exchange rate changes and currency excess returns are shown as an annual percentage. The period of study is from July 1992 to September 2012. The summary statistics include mean, minimum, maximum, standard deviation (measured in percentages), skewness, kurtosis, and unit root test.

3.4 Results and discussions

3.4.1 Results

The exchange rate predictability using the three relative factors in Equation (3.10) for the subsample (excluding the GFC period) and the full sample are presented in Table 3.8 and Table 3.9, respectively. Table 3.8 shows the relative slope and curvature factors are both statistically and economically significant factors in predicting the USD/AUD exchange rate movements. Specifically, the relative curvature can predict exchange rate movements accurately for horizons of less than six months. The estimates show that a 1% increase in the relative curvature factor predicts a 3.15% depreciation of the AUD over the next month and 2.56% and 1.89% depreciations of the AUD over the next three and six months, respectively. The relative slope factor is better at predicting exchange rate movements beyond six months. A 1% increase in the relative slope factor (i.e., the US yield curve becomes flatter relative to that of Australia) predicts about a 3% annualized depreciation of the AUD in the next 6 and 12 months. In contrast, the relative level has very little predictability for exchange rate movements during the sample period. This low predictability can be partially explained by the low variation of the relative level factor. Table 3.8 also reports the estimates with no overlap data (column (3)) as a robustness check. Results for which there is no data overlap are similar to those of overlap data, which confirms the robustness of our model. These estimates are similar to Chen and Tsang (2013), who report that an increase in three relative yield curve factors predicts a depreciation of the Canadian dollar (CAD), Japanese Yen (JPY), and British Pound (GBP) over subsequent months.

Table 3.8: Australian and US exchange rate change predictions (Subsample)

This table reports the results of regressions of the formula

$$\frac{1200(s_{t+m}-s_t)}{m}=\beta_{m,0}+\beta_{m,1}L_t^R+\beta_{m,2}S_t^R+\beta_{m,3}C_t^R+u_{t+m},$$

where s_t, s_{t+m} denote the natural logarithm of the USD/AUD exchange rate at time t and at time $t+m$, respectively; L_t^R, S_t^R, and C_t^R are the relative level, relative slope, and relative curvature, respectively.

Months (m)	**1**	**3**	**(3)**	**6**	**12**	**18**	**24**
Relative level	-3.973	-3.628	-2.425	-3.185	-2.788	-1.893	-0.873
t	(-1.565)	(-1.441)	(-0.999)	(-1.358)	(-1.402)	(-1.049)	(-0.509)
$t/\sqrt{m}$	[-1.169]	[-1.141]	[-0.491]	[-1.043]	[-0.877]	[-0.565]	[-0.250]
Relative slope	-1.848	-2.428	-1.160	-2.893*	-3.197*#	-2.790*	-2.469*
t	(-1.115)	(-1.469)	(-0.751)	(-2.030)	(-2.417)	(-2.065)	(-1.963)
$t/\sqrt{m}$	[-0.928]	[-1.301]	[-0.399]	[-1.610]	[-1.695]	[-1.397]	[-1.191]
Relative curvature	-3.150*#	-2.558*#	-3.975*#	-1.891*	-1.251	-0.941	-0.638
t	(-2.506)	(-2.297)	(-4.569)	(-2.153)	(-1.583)	(-1.384)	(-0.905)
$t/\sqrt{m}$	[-2.177]	[-1.839]	[-1.740]	[-1.393]	[-0.872]	[-0.619]	[-0.403]
Nob	185	183	61	180	174	168	162
F	5.143	4.593	12.083	3.890	3.828	3.697	3.499

Note: Newey and West's (1987) t and rescale t statistics are reported in parentheses ( ) and in square brackets [ ], respectively.

Estimates for constant terms are omitted.

* and # denote a significance level of 10% or below by Newey and West (1987) and rescale t statistics, respectively.

Column (3) reports estimates from a non-overlapping sample.

This table reports the results obtained from estimating Equation (3.10). Results with no overlapping data are reported in column (3) as a robustness check. US and Australian zero-coupon yields are provided by the FRB and the RBA, respectively. See estimates using zero-coupon bond yields data from Datastream in Appendix 3.5 for a robustness check. The sample period is from July 1992 to December 2007 (excluding the GFC period).

Table 3.9 reports estimates of three yield curve factors for the full sample. Compared to Table 3.8, the three relative factors predict exchange rate in the same direction.

However, the significance of the coefficients decreases dramatically when we include the GFC period.

Table 3.9: Australian and US exchange rate changes prediction (Full sample)

This table reports the results of regressions of the formula

$$\frac{1200(s_{t+m} - s_t)}{m} = \beta_{m,0} + \beta_{m,1} L_t^R + \beta_{m,2} S_t^R + \beta_{m,3} C_t^R + u_{t+m}.$$

where s_t, s_{t+m} denote the natural logarithm of the USD/AUD exchange rate at time t and time $t+m$, respectively; L_t^R, S_t^R, and C_t^R are the relative level, relative slope, and relative curvature, respectively.

Months (m)	1	3	(3)	6	12	18	24
Relative level	-1.096	0.375	2.105	1.954	0.599	-0.092	0.724
t	(-0.356)	(0.098)	(0.499)	(0.439)	(0.189)	(-0.042)	(0.368)
$t/\sqrt{m}$	[-0.285]	[0.095]	[0.313]	[0.472]	[0.143]	[-0.025]	[0.198]
Relative slope	2.361	2.212	3.105	2.221	-1.003	-1.614	-1.360
t	(0.625)	(0.585)	(0.728)	(0.589)	(-0.535)	(-1.228)	(-1.082)
$t/\sqrt{m}$	[1.132]	[1.028]	[0.830]	[0.986]	[-0.443]	[-0.806]	[-0.694]
Relative curvature	-3.353*#	-2.907*#	-3.391*	-2.567*#	-0.667	-0.695	-0.728
t	(-1.968)	(-2.008)	(-2.702)	(-2.036)	(-0.874)	(-1.002)	(-1.109)
$t/\sqrt{m}$	[-2.696]	[-2.268]	[-1.552]	[-1.917]	[-0.499]	[-0.578]	[-0.594]
Nob	242	240	80	237	231	225	219
F	2.932	3.232	7.318	3.265	0.880	2.537	4.232

Note: Newey and West's (1987) t and rescale t statistics are reported in parentheses ( ) and in square brackets [ ], respectively.

Estimates for constant term are omitted.

* and # denote a significance level of 10% or below by Newey and West (1987) and rescale t statistics, respectively.

Column (3) reports estimates from a non-overlapping sample.

This table reports the results obtained from estimating Equation (3.10). Results with no overlapping data are reported in column (3) as a robustness check. US and Australian zero-coupon yields are provided by the FRB and the RBA, respectively. See estimates using zero-coupon bond yields data from Datastream in Appendix 3.6 for a robustness check. The sample period is from July 1992 to September 2012 (including the GFC period).

Tables 3.10 and 3.11 report the predictability of currency excess returns in Equation (3.11) for the subsample and the full sample, respectively. All three relative factors have a high predictability power for currency excess returns. An increase in the relative level factor (i.e., the whole yield curve of the US shifts up relative to that of the Australian) implies that the market expects a rise in inflation in Australia compared with the US. If everything else remains the same, the demand for the AUD will decrease; the dollar will face depreciation pressure according to the present value relation. Table 3.10 shows that a 1% increase in the relative level factor can predict 4.18 and 3.80% depreciation of AUD over the next 6 and 12 months, respectively. The predictability of relative slope and curvature factors is consistent with the exchange rate model. Our results indicate that the currency excess returns on the AUD respond strongly to relative slope at all horizons and to relative curvature up to a horizon of 18 months. For example, a 1% increase in the relative slope predicts a 3.40 and 2.98% decrease in the excess returns over the next 18 and 24 months, respectively.

Table 3.10: Australian and US currency excess returns prediction (Subsample)

This table reports the results of regressions of the formula

$$i_t^{m*} - i_t^m + \frac{1200(s_{t+m} - s_t)}{m} = \gamma_{m,0} + \gamma_{m,1}L_t^R + \gamma_{m,2}S_t^R + \gamma_{m,3}C_t^R + \nu_{t+m}.$$

where i_t^m, i_t^{m*} are the US and Australian nominal zero-coupon yields at time t and m months to maturity; s_t, s_{t+m} denote the natural logarithm of the USD/AUD exchange rate at time t and time $t+m$, respectively; and L_t^R, S_t^R, and C_t^R are the relative level, relative slope, and relative curvature, respectively.

Months (m)	3	(3)	6	12	18	24
Relative level	-4.613*	-3.411	-4.181*	-3.802*	-2.902	-1.871
t	(-1.837)	(-1.411)	(-1.782)	(-1.906)	(-1.608)	(-1.091)
$t/\sqrt{m}$	[-1.451]	[-0.691]	[-1.370]	[-1.195]	[-0.867]	[-0.536]
Relative slope	-3.319*#	-2.055	-3.739*#	-3.924*#	-3.397*#	-2.980*
t	(-2.006)	(-1.326)	(-2.626)	(-2.975)	(-2.514)	(-2.361)
$t/\sqrt{m}$	[-1.780]	[-0.707]	[-2.081]	[-2.080]	[-1.701]	[-1.436]
Relative curvature	-2.636*#	-4.051*#	-2.033*	-1.480*	-1.217*	-0.932
t	(-2.377)	(-4.658)	(-2.313)	(-1.866)	(-1.789)	(-1.321)
$t/\sqrt{m}$	[-1.895]	[-1.774]	[-1.497]	[-1.031]	[-0.800]	[-0.588]
Nob	183	61	180	174	168	162
F	6.101	14.579	5.423	5.611	5.797	5.491

Note: Newey and West's (1987) t and rescale t statistics are reported in parentheses ( ) and in square brackets [ ], respectively.

Estimates for constant terms are omitted.

* and # denote a significance level of 10% or below by Newey and West (1987) and rescale t statistics, respectively.

Column (3) reports estimates from a non-overlapping sample.

This table reports the results from estimating Equation (3.11). Results with no overlapping data are shown in column (3) as a robustness check. The US and Australian zero-coupon yields are provided by the FRB and the RBA, respectively. See estimates using zero-coupon bond yields data from Datastream in Appendix 3.7 for a robustness check. The sample period is from July 1992 to December 2007 (excluding the GFC period).

Table 3.11: Australian and US currency excess returns prediction (Full sample)

This table reports the results of regressions of the formula

$$i_t^{m*} - i_t^m + \frac{1200(s_{t+m} - s_t)}{m} = \gamma_{m,0} + \gamma_{m,1} L_t^R + \gamma_{m,2} S_t^R + \gamma_{m,3} C_t^R + \nu_{t+m}.$$

where i_t^m, i_t^{m*} are the US and Australian nominal zero-coupon yields at time t and m months to maturity; s_t, s_{t+m} denote the natural logarithm of the USD/AUD exchange rate at time t and time $t+m$, respectively, and L_t^R, S_t^R and C_t^R are the relative level, relative slope, and relative curvature, respectively.

Months (m)	**3**	**(3)**	**6**	**12**	**18**	**24**
Relative level	-0.599	1.139	0.956	-0.422	-1.104	-0.273
t	(-0.156)	(0.269)	(0.215)	(-0.133)	(-0.507)	(-0.139)
$t/\sqrt{m}$	[-0.151]	[0.169]	[0.231]	[-0.101]	[-0.296]	[-0.075]
Relative slope	1.334	2.227	1.374	-1.737	-2.226*	-1.872
t	(0.352)	(0.521)	(0.364)	(-0.929)	(-1.695)	(-1.486)
$t/\sqrt{m}$	[0.619]	[0.595]	[0.610]	[-0.768]	[-1.111]	[-0.954]
Relative curvature	-2.995*#	-3.477*	-2.710*#	-0.893	-0.967	-1.018
t	(-2.062)	(-2.761)	(-2.149)	(-1.173)	(-1.395)	(-1.549)
$t/\sqrt{m}$	[-2.335]	[-1.591]	[-2.024]	[-0.668]	[-0.803]	[-0.828]
Nob	240	80	237	231	225	219
	4.304	8.894	4.543	1.487	4.317	6.638

Note: Newey and West's (1987) t and rescale t statistics are reported in parentheses ( ) and in square brackets [ ], respectively.

Estimates for constant terms are omitted.

* and # denote a significance level of 10% or below by Newey and West (1987) and rescale t statistics, respectively.

Column (3) reports estimates from a non-overlapping sample.

This table reports the results from estimating Equation (3.11). Results with no overlapping data are reported in column (3) as a robustness check. US and Australian zero-coupon yields are provided by the FRB and the RBA, respectively. See also estimates using zero-coupon bond yields data from Datastream in Appendix 3.8 for a robustness check. The sample period is from July 1992 to September 2012 (including the GFC period).

Table 3.11 presents results for the full sample. Similar to the exchange rate changes model, the significance of the coefficients decreases dramatically when we include the

GFC period. Both the relative level and slope factors have no predictability for the excess returns on the AUD at all horizons at the 10% level with one possible exception. On the basis of the Newey-West t statistic, some predictability from the slope factor at 18 months may exist, but not on the basis of the rescaled t statistic.

3.4.2 Out-of-sample forecasting

In this section, we examine the out-of-sample forecasting performance of our factor model. It is reasonable to assume that the exchange rate change in period t is a function of the information available in period $t-1$ only. In order to evaluate the performance of the model in the view of out-of-sample forecasts, we compare the expected exchange rates with their actual realized values. Following Meese and Rogoff (1983), we split the sample into two periods: in-sample and out-of-sample portions.

Two ways to calculate the forecast are recursive and rolling methods. In the former method, the first regression uses the first T observations then makes the forecast for period $T+1$. The second regression moves one month ahead, using the $T+1$ observations to make another forecast for period $T+2$. This process continues until all out-of-sample observations are exhausted. The disadvantage of this method is the power of the test increases as the sample size increases. In the second method, out-of-sample forecasts are produced on the basis of T observations each time. The second regression is based on the sample, which drops the first observation and adds the first out-of-sample observations. This process is repeated until all out-of-sample observations are used while keeping the number of observations in the sample constant. In this chapter, we apply this rolling procedure to ensure the power of the test is constant. We report results for a rolling window, which produces a constant-sized sample of 24 and 30 months.

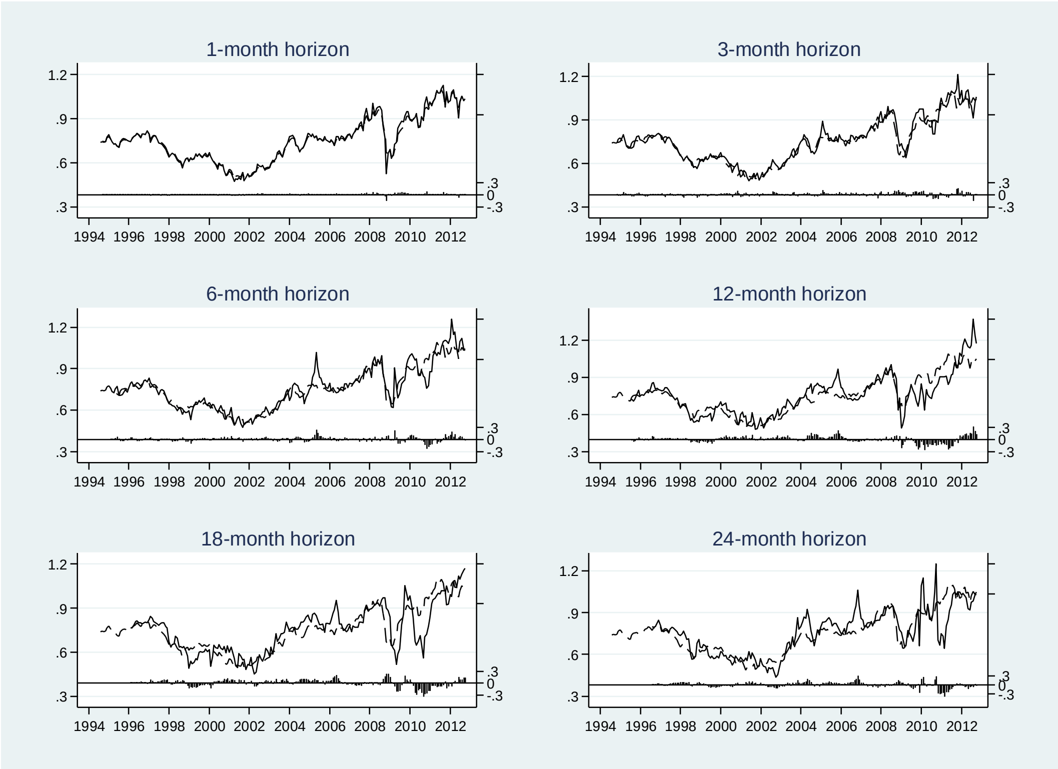
To determine the performance of the model, we compare out-of-sample results with those of the random walk model. The random walk model is used as a conventional benchmark in the exchange rate literature. The driftless random walk model for exchange rate by level is as follows:

$$e_{t+m} = e_t + \varepsilon_{t+m}, \quad (3.12)$$

where e_t is the nominal exchange rate at time t and m is the forecast horizon measured in months.

Figure 3.6 plots the actual and out-of sample forecast of the nominal exchange rate at a horizon from 1 to 24 months. The two lines move very closely during the period of study. The factor model predicts the movement in exchange rate in the pre-crisis period much better than it does during the crisis, which started in December 2007, and this is consistent with our estimation results in Tables 3.6 and 3.7.

Figure 3.6: Out-of-sample forecast of the USD/AUD exchange rate movement



Note: This figure plots the movement of the actual exchange rate (solid line) and the out-of-sample forecast values (dashed line). We employ rolling specifications to estimate the expected exchange rate at horizons from one month to two years. The bar measures the exchange rate forecast error.

We apply two measures to assess the forecast accuracy of the model. We first employ the mean square forecast error (MSFE) approach suggested by Meese and Rogoff (1983). The MSFE approach is the standard measure of forecast accuracy due to its intuitive interpretation and broad applicability (Clements & Hendry 1999). We calculate ratios between the MSFE of the factor model and those of the random walk. If the ratio is smaller than one, the factor model performs better than the random walk. We also employ Diebold and Mariano's (1995) statistic to test the null hypothesis of no difference in the accuracy of the two competing forecasts. Diebold and Mariano's statistic is the ratio between the sample's mean loss differential and an estimate of its standard error and is asymptotically distributed as standard normal.

An alternative evaluation measure is the direction of change (DoC) statistic. The DoC measures the number of correct predictions of the direction of change over the total number of predictions. Since the random walk predicts the direction of the exchange rate movement 50% of the time, a DoC statistic greater than 0.5 indicates that the factor model is better than the random walk model. We also report the significance level corresponding to the hypothesis that the DoC is significantly different from 0.5.

Table 3.12: Out-of-sample forecast of exchange rate changes

	m=1	**m=3**	**m=6**	**m=12**	**m=18**	**m=24**
24-month window						
MSE ratio						
Subsample	0.356###	0.824	0.705	0.518	0.385##	0.348##
Full sample	0.490###	0.681	0.572	0.650	0.583##	0.46###
Direction of change						
Subsample	0.944***	0.547	0.571*	0.64***	0.556	0.594**
Full sample	0.936***	0.569**	0.563*	0.614***	0.542	0.59**
30-month window						
MSE ratio						
Subsample	0.277###	0.817	0.792	0.649	0.593	0.494
Full sample	0.366###	0.73	0.613	0.811	0.644#	0.739
Direction of change						
Subsample	0.942***	0.503	0.52	0.611***	0.514	0.576*
Full sample	0.934***	0.533	0.541	0.597***	0.523	0.577**

Note: #, ##, and ### denote significance levels of 10%, 5%, and 1% by Diebold and Mariano's (1995) statistics

*, **, and *** denote significantly different from 0.5 at 10%, 5%, and 1% levels by t statistics

This table reports two measures to assess the out-of-sample forecast accuracy of our model at window sizes of 24 and 30 months. The MSE ratio is the ratio of the Mean Squared Forecast Error of the factors model to that of the random walk. The direction of change (DoC) statistic is the proportion of "ones" over all forecasting periods. The forecasting period is up to December 2007 for the subsample and up to September 2012 for the full sample.

Table 3.12 shows the out-of-sample forecast accuracy statistics for exchange rate changes from 1 to 24 months. Both criteria confirm the factor model outperforms the random walk at all horizons from 1 month to 24 months. Moreover, the results are consistent with the selection of window size.

3.4.3 Further discussion

When no systematic market expectation errors are present, currency excess returns can be considered as the risk premium of holding foreign currency, in this case, the AUD. Tables 3.10 and 3.11 show the risk premium of holding foreign currency (AUD) is highly correlated with the relative yield curve factors. More specifically, when market participants expect an economic downturn in Australia, the Australian slope factor increases and the relative slope factor decreases (assuming that the expectation on the US output remains constant); therefore, they require higher risk premium for holding AUD. If the risk premium term $\eta_{t,t+k}$ in Equation (3.8) is high enough, foreign currency (AUD) may appreciate instead of depreciate as expected by the UIP condition. This trend suggests that the UIP puzzle may be caused by the problem of omitting important variables.

In order to test if the inclusion of the risk premium term in the UIP regression changes the sign of the estimated slope coefficient, we estimate the UIP equation both with and without the risk premium term. Following the literature, we employ a five-year interest differential as a proxy for the risk premium term.

$$\Delta s_{t+m} = \alpha_m + \beta_m \left(i_t^m - i_t^{m*} \right) + \varepsilon_{t+m} \tag{3.13}$$

$$\Delta s_{t+m} = \alpha_m + \beta_m \left(i_t^m - i_t^{m*} \right) + \delta_m \rho_{t+m}^F + \varepsilon_{t+m} \tag{3.14}$$

Equation (3.13) is a traditional UIP regression equation, and Equation (3.14) is the UIP with the inclusion of the risk premium term ρ_{t+m}^F.

Table 3.13: Uncovered Interest Rate Parity with and without controlling for risks

This table reports the results of regressions of the formulas

$$\Delta s_{t+m} = \alpha_m + \beta_m \left(i_t^m - i_t^{m*} \right) + \varepsilon_{t+m}$$

$$\Delta s_{t+m} = \alpha_m + \beta_m \left(i_t^m - i_t^{m*} \right) + \delta_m \rho_{t+m}^F + \varepsilon_{t+m}$$

where Δs_{t+m} denotes the change in the USD/AUD exchange rate from time t to time $t+m$, i_t^m and i_t^{m*} are the US and Australian nominal zero-coupon yields at time t and m months to maturity, and ρ_{t+m}^F is the risk premium term.

	3-month		6-month		9-month	
	without long rates	with long rates	without long rates	with long rates	without long rates	with long rates
α_m	-0.152	-1.196	-0.043	-1.495	-0.396	-0.777
	(0.876)	(0.881)	(1.680)	(1.614)	(2.263)	(2.250)
β_m	-0.347$^{\#\#}$	0.630	-0.546	0.893	-1.024	-0.605
	(0.575)	(1.044)	(1.032)	(1.889)	(1.299)	(2.103)
$F(\alpha_m = 0$ and $\beta_m = 1)$	5.866***	1.052	2.936*	0.429	2.791**	0.306
R^2	0.008	0.031	0.009	0.028	0.022	0.022
Nobs	240	240	237	237	234	234

Note: Newey and West's (1987) t statistics are reported in brackets.

$^{\#}$, $^{\#\#}$, and $^{\#\#\#}$ are significantly different from 1 $(H_0 : \beta_m = 1)$ at 10%, 5%, and 1% levels, respectively.

*, **, and *** denote significance levels of 10%, 5%, and 1%, respectively.

Estimates for risk premium term are omitted.

This table reports the UIP regressions with and without risk premium term, ρ_{t+m}^F.We employ a five-year interest rate differential as a proxy for the risk premium. The sample period is from July 1992 to September 2012.

Table 3.13 reports UIP estimates of the coefficients in Equations (3.13) and (3.14). All slope coefficients are negative and significantly different from one in the traditional UIP model. Moreover, we can reject the UIP condition using the joint hypothesis of $H_0 : \alpha = 0 \,\&\, \beta = 1$. These results are consistent with the current literature. However, when the proxy for risk premium is included in the model, all the slope coefficients become positive and are significantly different from zero. Therefore, the joint hypothesis of $H_0 : \alpha = 0 \,\&\, \beta = 1$ cannot be rejected.

Results in Table 3.13 confirm that exchange rate forecasts from traditional UIP condition can be improved if we look at other information contained in the yield curves, such as term structure, as proxies for the time varying risk premium.

3.5 Conclusions

In this chapter, we carried out an empirical investigation of the predictive content of Nelson and Siegel's (1987) factors extracted from Australian and US zero-coupon yield curves for changes in the USD/AUD exchange rate and currency excess returns on the AUD.

Specifically, the relative slope and curvature factors have some explanatory power for the USD/AUD exchange rate and for excess returns on the AUD in the subsample, which excludes the GFC period. The relative slope factor has predictive power from 6 to 24 months ahead for both the USD/AUD and returns on the AUD, while the curvature factor has predictive power for both at short horizons up to 3 months. The level factor has no predictive power at all horizons. The results deteriorate when the financial crisis period is included in the sample, with only the curvature factor having some explanatory power.

We conclude with two observations. First, the absence of predictive power from the relative level factor may be due to the failure of the UIP condition at short horizons and to its only modest success at long horizons. Second, the overall and somewhat weak results may be due in part to the Australian currency being a "commodity currency" so that at least over long horizons, the currency mainly responds to the world price of its primary commodity exports.

Appendix 3.1: Kim and Perron's (2009) unit root test

Since our sample spans a long period from 1992 to 2012, the possibility of structural breaks in the economic series is very high. These breaks may come from the two crises in 1997 and 2008 or from policy changes in Australia and the US. Perron (1989, 1997) and Kim and Perron (2009) argue that the Dickey and Fuller's (1979) unit root test is not consistent if the alternative hypothesis of a stationary component contains a break in the slope of the deterministic trend. As a result, the test may be biased towards erroneous non-rejections of the unit root hypothesis. Perron (1989) proposes a unit root test, which allows for the possibility of a break under both the null and alternative hypotheses. However, to perform this test, the break date should be chosen independently from the series. An imprecise break date may cause size distortions and power loss when applied to non-trending data (Hecq & Urbain 1993). Kim and Perron (2009) extend Perron's (1997) unit root test, allowing for an unknown break in both the null and alternative hypotheses. The test is similar to Perron's (1989) unit root test except that an estimate of the break date from the series is used instead of a pre-specified one.

Based upon the method of Kim and Perron (2009), we perform the unit root test in our series using the following steps:

Step 1: Test the existence of break date

We apply Perron and Yabu's (2009) test for the existence of a break in our series. We consider all three models involving a change of intercept and/or the slope in the trend function.

Model 1: Structural change in intercept

$$y_t = \mu_0 + \mu_1 * DU_t + \beta_0 * t + u_t \qquad H_0 : \mu_1 = 0$$

Model 2: Structural change in slope

$$y_t = \mu_0 + \beta_0 * t + \beta_1 * DT_t + u_t \qquad H_0 : \beta_1 = 0$$

Model 3: Structural change in both intercept and slope

$$y_t = \mu_0 + \mu_1 * DU_t + \beta_0 * t + \beta_1 * DT_t + u_t \qquad H_0 : \mu_1 = \beta_1 = 0 ,$$

where $u_t = \alpha * u_{t-1} + e_t$; $e_t \sim iid\left(0, \sigma^2\right)$; and $\mu_0, \mu_1, \beta_0,$ and β_1 are unknown parameters; $DU_t = 1(t > T_1)$; $DT_t = 1(t > T_1)(t - T_1)$, and T_1 is the break date.

We estimate the average exponential Wald test statistic, $Exp - W_{FS}$ and then compare it with its critical values. The codes to generate $Exp - W_{FS}$ test statistics are kindly provided by the authors. $Exp - W_{FS}$ test statistics for our series are presented in Appendices 3.3 and 3.4.

Step 2: Estimation of the break date

Outliers in economic series can be classified as an Additive Outlier (AO) and an Innovation Outlier (IO). An AO occurs when there is a shock to a particular observation but the subsequent observations in the time series are not affected. IOs are produced when the effect of a large innovation is perpetrated through the dynamics of the model (Fox 1972). Given the nature of the data, we consider the AO version of the test. We select the model by the significance of the $Exp - W_{FS}$ test statistics in step 1 (see the Models column in Appendices 3.3 and 3.4).

The estimate of break date $\left(\hat{T}_1\right)$ is the sample size (T) times λ_1^{AO} defined around Equation (5) of Kim and Perron (2009). We apply the "breakestimate.m" program provided by the authors to estimate the break date in the series.

Step 3: Select the number of lags

We use the "MIC.m" program provided by the authors to select the number of lags for the AO models. These lags are simply the number of lags of the differences of the dependent variable for the AO model based on Equation (2) of Kim and Perron (2009). Moreover, in this chapter we employ the AIC criteria to choose the number of lags.

Step 4: Unit root test

We employ three programs provided by the authors to estimate the value of t-statistics for our unit root test. More specifically, we apply "URdfk.m" for the standard ADF test without any break in the deterministic trend (Model 1), "UR2k.m" for Model 2, and "UR3k.m" for Model 3. These programs were constructed from Equation (2) of Kim and Perron (2009), which is similar to that of Perron's (1989) procedure.

At the end of the process, we obtain the value of the t-statistics to test for a unit root under these specifications from the above programs. The relevant asymptotic critical values for Model 3 can be found in Perron's (1989) Tables IV.B and VI.B, while those for Model 2 from Perron and Vogelsang (1993) are given in Table 1. These results of the unit root tests are shown in Appendices 3.3 and 3.4.

Appendix 3.2: Definition of variables

Variable	Period	Definition	Source
$E_t\pi_{t+12}$	Monthly: May 1993- Sept. 2012	***Consumer Inflationary Expectations*** (in percentages) measure (median) consumers' inflationary expectations over the next 12 months; 1,200 households are asked whether, and by how much, they believe prices will change over the coming 12 months.	*CASiE*
$E_t(CSI)_{t+12}$	Monthly: July 1992- Sept. 2012	***Consumer Sentiment Index*** is measured by the percentage of optimistic households minus the percentage of pessimistic households plus 100. It reflects consumers' evaluations of their household financial situations over the past year and the coming year, as well as the anticipated economic conditions over the coming year and the next five years.	*CASiE*
CPI_a	Quarterly: Sept. 1992- June 2012	***Actual annualize inflation rate*** (in percentages) is an all groups' measure on a non-seasonally adjusted basis.	*RBA*
$E_t(NAB\_conf)_{t+12}$	Sept. 1992- June 2012	***NAB business confidence index*** is collected by the National Australia Bank in its Quarterly Business Survey. The index measures respondents' expectations of business conditions in their industry for the upcoming quarter.	*RBA*
S_t	Monthly: July 1992- Sept. 2012	***Exchange rate*** is measured by the US dollar price of one Australian dollar.	*RBA*
s_t	Monthly: July 1992- Sept. 2012	Natural logarithm of the USD/AUD exchange rate	*RBA*
$i_t^m; i_t^{m*}$	Monthly: July 1992- Sept. 2012	***US and Australian zero-coupon bond yields*** at time t and m months to maturity are continuously compounded annual yields.	*RBA, FRB*

Note: All data are recorded at the last trading day of the month for monthly data and at the last trading of the quarter for quarterly data.

Appendix 3.3: Unit root test of zero-coupon yields

series	P&Y's test $(Exp-W_{FS})$			Models	ADF	K&P's (2009) test			Stationary
	Crash	*Changing growth*	*Mixed model*			*Crash*	*Changing growth*	*Mixed model*	
Australian zero-coupon yields									
3m	-0.261	0.047	0.199	DF	-3.217*	-	-	-	I(0)
6m	-0.196	4.608***	7.426***	A2,A3	-	-	-3.823*	-2.861	mixed
9m	-0.176	0.721	1.675	DF	-3.114	-	-	-	I(1)
12m	0.447	-0.026	0.628	DF	-3.069	-	-	-	I(1)
15m	3.187***	10.74***	12.296***	A3	-	-	-	-4.066**	I(0)
18m	-0.279	2.95**	3.676**	A2,A3	-	-	-3.794**	-4.073**	I(0)
21m	0.032	17.11***	24.671***	A2,A3	-	-	-3.797**	-4.094**	I(0)
24m	-0.305	19.782***	40.089***	A2,A3	-	-	-3.785**	-3.695*	I(0)
30m	-0.274	12.724***	33.072***	A2,A3	-	-	-3.363	-3.723*	mixed
36m	-0.305	7.312***	7.847***	A2,A3	-	-	-3.787**	-3.736*	I(0)
48m	-0.308	1.474*	1.239	A2	-	-	-3.579*		I(0)
60m	0.473	6.073***	8.761***	A2,A3	-	-	-3.589*	-4.009**	I(0)
72m	-0.302	11.132***	19.811***	A2,A3	-	-	-3.605*	-4.174**	I(0)
84m	0.433	2.634**	8.364***	A2,A3	-	-	-3.595*	-4.349**	I(0)
96m	-0.265	11.999***	17.064***	A2,A3	-	-	-3.607*	-4.092**	I(0)
108m	-0.271	-0.278	-0.218	DF	-2.305	-	-	-	I(1)
120m	-0.286	-0.256	-0.194	DF	-2.34	-	-	-	I(1)
The US zero-coupon yields									
3m	-0.130	-0.144	4.83***	A3	-	-	-	-1.730	I(1)
6m	-0.07	-0.08	0.179	DF	-2.497	-	-	-	I(1)
9m	0.031	1.936**	7.436***	A2,A3	-	-	-3.504*	-2.279	mixed
12m	-0.087	0.067	1.597	DF	-2.567	-	-	-	I(1)
15m	-0.214	-0.047	0.095	DF	-2.24	-	-	-	I(1)
18m	-0.063	-0.27	-0.171	DF	-2.314	-	-	-	I(1)
21m	-0.245	-0.164	-0.034	DF	-2.383	-	-	-	I(1)
24m	-0.187	0.324	0.658	DF	-2.423	-	-	-	I(1)
30m	0.631	1.614*	2.096	A2	-	-	-2.599	-	I(1)
36m	0.229	0.156	0.712	DF	-	-	-	-	I(1)
48m	-0.223	0.2	0.387	DF	-	-	-	-	I(1)
60m	-0.249	0.387	0.686	DF	-	-	-	-	I(1)
72m	0.255	1.185	1.713	DF	-	-	-	-	I(1)
84m	0.464	-0.066	0.973	DF	-	-	-	-	I(0)
96m	-0.198	3.182***	5.325***	A2,A3	-3.532**	-	-4.258**	-4.397**	I(0)
108m	-0.295	0.257	0.536	DF	-3.669**	-	-	-	I(0)
120m	0.075	1.005	1.199	DF	-3.797**	-	-	-	I(0)

Note: *, **, and *** denote significance levels of 10%, 5%, and 1%, respectively.

Appendix 3.4: Unit root test of yield curve factors, exchange rate change, and currency excess returns

Series	P&Y's test $(Exp - W_{FS})$			Models	ADF	K&P's(2009) test			Stationary
	Crash	*Changing growth*	*Mixed model*			*Crash*	*Changing growth*	*Mixed model*	
Australia's yield curve factors									
Level	1.337*	0.895	4.18**	A1,A3	-	-4.077**	-	-4.077**	I(0)
Slope	-0.299	-0.146	-0.038	DF	-2.610***	-	-	-	I(0)
Curvature	-0.253	-0.003	4.692***	A3	-	-	-	-5.659***	I(0)
US yield curve factors									
Level	-0.317	0.717	4.225**	A3	-	-	-	-4.755***	I(0)
Slope	1.948**	0.333	2.131	A1	-	-2.406	-	-	I(1)
Curvature	-0.121	3.962***	7.764***	A2,A3	-	-	-2.4192	-2.932	I(1)
Relative yield curve factors									
Level	-0.311	6.294***	8.655***	A2,A3	-	-	-4.0615**	-4.399**	I(0)
Slope	-0.265	1.856**	2.716*	A2,A3	-	-	-3.163	-3.953*	mixed
Curvature	-0.213	8.571***	28.235***	A2,A3	-	-	-3.6751*	-3.960*	I(0)
Exchange rate changes									
1-month	0.177	-0.293	0.472	DF	-14.208***	-	-	-	I(0)
3-month	0.13	-0.293	0.633	DF	-6.018***	-	-	-	I(0)
6-month	6.804***	-0.185	7.682***	A1,A3	-	-5.686***	-	-3.617	mixed
12-month	4.629***	-0.06	7.031***	A1,A3	-	-5.627***	-	-5.627***	I(0)
18-month	1.661*	-0.268	1.820	A1	-	-4.765***	-	-	I(0)
24-month	3.905***	-0.197	4.058**	A1,A3	-	-3.619*		-4.559**	I(0)
Currency excess returns									
3-month	0.267	-0.26	0.763	DF	-5.718***	-	-	-	I(0)
6-month	2.913**	-0.266	5.969***	A1,A3	-	-5.500***	-	-5.540***	I(0)
12-month	5.701***	-0.052	8.167***	A1,A3	-	-5.372***	-	-5.372***	I(0)
18-month	4.377***	-0.22	4.625***	A1,A3	-	-3.914**	-	-4.550**	I(0)
24-month	1.846**	-0.217	1.994	A1	-	-3.368	-	-	I(1)

Note: *, **, and *** denote significance levels of 10%, 5%, and 1%, respectively.

Appendix 3.5: Australian and US exchange rate changes prediction using Datastream zero-coupon yields (subsample)

This table reports the results of regressions of the formula

$$\frac{1200(s_{t+m} - s_t)}{m} = \beta_{m,0} + \beta_{m,1} L_t^R + \beta_{m,2} S_t^R + \beta_{m,3} C_t^R + u_{t+m}.$$

where s_t, s_{t+m} denote the natural logarithm of the USD/AUD exchange rate at time t and time $t+m$, respectively; L_t^R, S_t^R, and C_t^R are the relative level, relative slope, and relative curvature, respectively.

Months (m)	**1**	**3**	**6**	**12**	**18**	**24**
Relative level	-3.519	-4.107	-5.249	-3.768	0.203	3.494
t	(-0.834)	(-0.913)	(-1.226)	(-1.092)	(0.057)	(1.052)
$t/\sqrt{m}$	[-0.538]	[-0.692]	[-0.885]	[-0.582]	[0.025]	[0.418]
Relative slope	-0.853	-0.799	-1.759	-1.857	-2.498	-3.133*
t	(-0.478)	(-0.522)	(-1.092)	(-1.018)	(-1.294)	(-2.183)
$t/\sqrt{m}$	[-0.334]	[-0.329]	[-0.688]	[-0.647]	[-0.670]	[-0.799]
Relative curvature	-4.328*#	-4.771*#	-3.283*	-2.816*	-1.203	0.282
t	(-2.633)	(-5.109)	(-1.855)	(-1.909)	(-1.007)	(0.312)
$t/\sqrt{m}$	[-1.904]	[-2.038]	[-1.288]	[-0.990]	[-0.331]	[0.076]
N	105	105	105	105	105	105

Note: Newey and West's (1987) t and rescale t statistics are reported in parentheses ( ) and in square brackets [ ], respectively.

Estimates for constant terms are omitted.

* and # denote a significance level of 10% or below by Newey and West's (1987) t and rescale t statistics, respectively.

This table reports the results from estimating Equation (3.10). The US and Australian zero-coupon yields are provided by Datastream. The sample period is from April 1999 to December 2007 (excluding the GFC).

Appendix 3.6: Australian and US exchange rate changes prediction using Datastream zero- coupon yields (full sample)

This table reports the results of regressions of the formula

$$\frac{1200(s_{t+m} - s_t)}{m} = \beta_{m,0} + \beta_{m,1}L_t^R + \beta_{m,2}S_t^R + \beta_{m,3}C_t^R + u_{t+m}.$$

where s_t, s_{t+m} denote the natural logarithm of the USD/AUD exchange rate at time t and time $t+m$, respectively; L_t^R, S_t^R, and C_t^R are the relative level, relative slope, and relative curvature, respectively.

Months (m)	**1**	**3**	**6**	**12**	**18**	**24**
Relative level	-1.785	0.022	-0.942	-2.159	-1.764	-0.814
t	(-0.438)	(0.004)	(-0.169)	(-0.659)	(-0.647)	(-0.282)
$t/\sqrt{m}$	[-0.426]	[0.005]	[-0.173]	[-0.412]	[-0.355]	[-0.159]
Relative slope	0.881	2.271	1.453	-2.357	-2.530	-1.861
t	(0.355)	(0.614)	(0.403)	(-1.242)	(-1.530)	(-1.414)
$t/\sqrt{m}$	[0.308]	[0.747]	[0.432]	[-0.744]	[-0.903]	[-0.672]
Relative curvature	-2.365*	-3.347*	-1.596	0.983	0.330	0.346
t	(-2.013)	(-1.987)	(-1.053)	(0.704)	(0.314)	(0.602)
$t/\sqrt{m}$	[-1.106]	[-1.446]	[-0.611]	[0.399]	[0.149]	[0.156]
Nob	152	150	147	141	135	129

Note: Newey and West's (1987) t and rescale t statistics are reported in parentheses ( ) and in square brackets [ ], respectively.

Estimates for constant terms are omitted.

* and # denote a significance level of 10% or below by Newey and West's (1987) t and rescale t statistics, respectively.

This table reports the results from estimating Equation (3.10). US and Australian zero-coupon yields are provided by Datastream. The sample period is from April 1999 to July 2012 (including the GFC).

Appendix 3.7: Australian and US currency excess return prediction using Datasteam zero-coupon yields (subsample)

This table reports the results of regressions of the formula

$$i_t^{m*} - i_t^m + \frac{1200(s_{t+m} - s_t)}{m} = \gamma_{m,0} + \gamma_{m,1} L_t^R + \gamma_{m,2} S_t^R + \gamma_{m,3} C_t^R + \nu_{t+m}.$$

where i_t^m, i_t^{m*} denote the US and Australian nominal zero-coupon yields at time t and m months to maturity; s_t, s_{t+m} are the natural logarithm of the USD/AUD exchange rate at time t and time $t+m$, respectively; L_t^R, S_t^R, and C_t^R are the relative level, relative slope, and relative curvature, respectively.

Months (m)	**3**	**6**	**12**	**18**	**24**
Relative level	-5.117	-6.252	-4.767	-0.784	2.522
t	(-1.137)	(-1.459)	(-1.384)	(-0.219)	(0.757)
$t/\sqrt{m}$	[-0.862]	[-1.054]	[-0.737]	[-0.098]	[0.300]
Relative slope	-1.698	-2.595	-2.575	-3.120	-3.655
t	(-1.110)	(-1.611)	(-1.411)	(-1.615)	(-2.539)
$t/\sqrt{m}$	[-0.697]	[-1.014]	[-0.897]	[-0.837]	[-0.929]
Relative curvature	-4.840*#	-3.424*	-3.055*	-1.474	-0.016
t	(-5.187)	(-1.934)	(-2.069)	(-1.233)	(-0.018)
$t/\sqrt{m}$	[-2.067]	[-1.343]	[-1.074]	[-0.405]	[-0.004]
Nob	105	105	105	105	105

Note: Newey and West's (1987) t and rescale t statistics are reported in parentheses ( ) and in square brackets [ ], respectively.

Estimates for constant terms are omitted.

* and # denote a significance level of 10% or below by Newey and West's (1987) t and rescale t statistics, respectively.

This table reports the results from estimating Equation (3.11). The US and Australian zero-coupon yields are provided by Datastream. The sample period is from April 1999 to December 2007 (excluding the financial crisis that started in January 2008).

Appendix 3.8: Australian and US currency excess returns prediction using Datasteam zero-coupon yields (full sample)

This table reports the results of regressions of the formula

$$i_t^{m*} - i_t^m + \frac{1200(s_{t+m} - s_t)}{m} = \gamma_{m,0} + \gamma_{m,1} L_t^R + \gamma_{m,2} S_t^R + \gamma_{m,3} C_t^R + \nu_{t+m}.$$

where i_t^m, i_t^{m*} denote the US and Australian nominal zero-coupon yields at time t and m months to maturity; s_t, s_{t+m} are the natural logarithm of the USD/AUD exchange rate at time t and time $t+m$, respectively; L_t^R, S_t^R, and C_t^R are the relative level, relative slope, and relative curvature, respectively.

Months (m)	**3**	**6**	**12**	**18**	**24**
Relative level	-0.989	-1.967	-3.155	-2.761	-1.793
t	(-0.200)	(-0.354)	(-0.966)	(-1.013)	(-0.620)
$t/\sqrt{m}$	[-0.212]	[-0.361]	[-0.603]	[-0.556]	[-0.349]
Relative slope	1.374	0.619	-3.078	-3.152*	-2.380*
t	(0.371)	(0.172)	(-1.623)	(-1.904)	(-1.805)
$t/\sqrt{m}$	[0.452]	[0.184]	[-0.973]	[-1.125]	[-0.858]
Relative curvature	-3.410*	-1.745	0.741	0.058	0.048
t	(-2.022)	(-1.154)	(0.531)	(0.055)	(0.083)
$t/\sqrt{m}$	[-1.473]	[-0.669]	[0.301]	[0.026]	[0.022]
Nob	150	147	141	135	129

Note: Newey and West's (1987) t and rescale t statistics are reported in parentheses ( ) and in square brackets [ ], respectively.

Estimates for constant terms are omitted.

* and # denote a significance level of 10% or below by Newey and West (1987) and rescale t statistics, respectively.

This table reports the results from estimating Equation (3.11). The US and Australian zero-coupon yields are provided by Datastream. The sample period is from April 1999 to July 2012 (including the GFC).

Chapter 4 : Monetary policy surprises and the term structure of interest rates: Evidence from Australia

4.1 Introduction

How interest rates at different maturities react to changes in monetary policy is of importance for several reasons. For monetary policy makers, a reliable estimate of the reaction of interest rates to policy instruments is an important step in creating effective policy decisions. For financial market participants, having accurate estimates of the response of interest rates at different maturities to the announcements of monetary policy change is crucial in formulating efficient investment portfolios.

This chapter empirically assesses the anticipated and unanticipated (surprise) components of monetary policy changes in Australia and the effects these changes have on the term structure of interest rates. First, we follow Kearns and Manners (2006) to measure the unanticipated part of monetary policy change by the change in the short-end money market interest rate. We find market interest rates respond to the surprise component only and these effects decline with maturity. We also discover that increases in the cash rate by the Reserve Bank of Australia (RBA) have a larger impact on market interest rates than rate cuts. Second, we propose the use of a volatility curve to assess the impact of the policy on the term structure of interest rates. The volatility curve is the relation between sample standard deviations of daily yield changes and the time to maturity of debts (Piazzesi 2001). Differences in the shape of volatility curves on policy days and on non-policy days provide a clear picture of the effect of monetary changes on the term structure of interest rate volatilities. We find the policy announcement induces more volatility in the short end of the yield curve, while interest rate volatilities at the long end are the same compared with those of non-policy days.

Expectation theory has long been an important building block for explaining the impact of news on the term structure of interest rates. The theory postulates that macroeconomic news that impacts bond prices should affect all maturities. The drawback of expectation theory is that it relies on risk neutrality, which is regarded as unrealistic. Dungey, McKenzie, and Smith (2009) summarize two alternative explanations for the term structure of interest rates: liquidity preference theory and market segmentation theory. Liquidity preference theory suggests that long bond prices are more responsive to the news than those with a shorter maturity due to the presence of a liquidity risk premium, which depends on the maturity of the bond. Alternatively, market segmentation theory argues that there is no clear relationship between risk premium and bond maturity, and investors are assumed to operate solely within a particular segment of the yield curve. Market segmentation theory suggests that news in the market generates more volatility at the short end than at longer maturities since speculators may prefer short-term maturities. Our results support the market segmentation theory in explaining the change in the term structure of interest rates in Australia due to changes in monetary policy.

The first paper that assesses market reaction to monetary policy is that of Cook and Hahn (1989), which estimates the effect of changes in the target federal funds rate on market interest rates in the US market during the 1970s. Cook and Hahn (1989) find that changes in the target rates cause movement in interest rates at all maturities. However, Cook and Hahn's (1989) model faces some conceptual problems. Bond yields set in forward-looking markets should respond differently to the anticipated and unanticipated elements of monetary policy actions. If the market has predicted the change in the target rate many days before the changes, those expectations have already been incorporated into interest rates before the change is announced (Kuttner 2001).

Kuttner (2001), Poole, Rasche, and Thornton (2002), and Hamilton (2008) find market interest rates respond only to the unanticipated element of monetary policy changes.

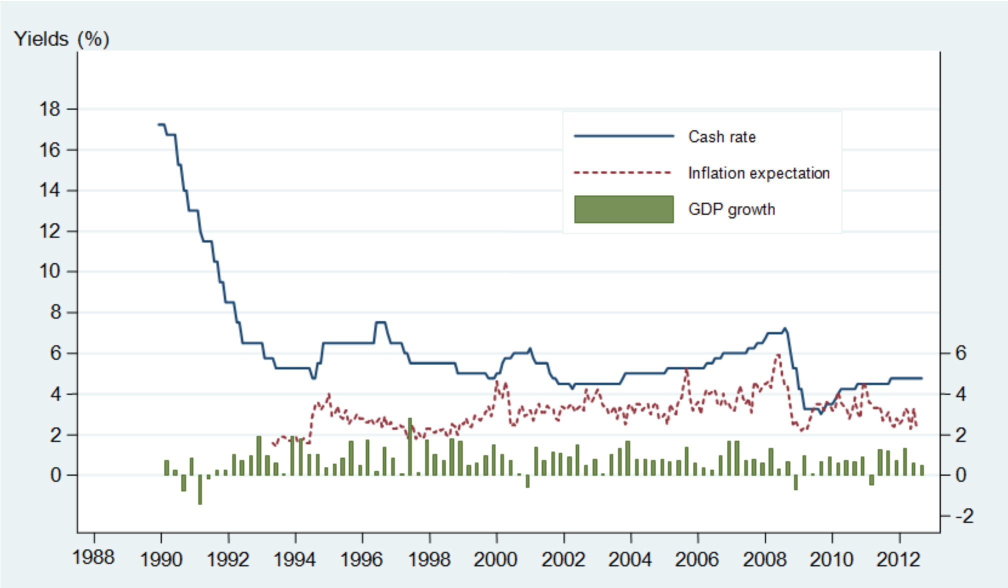
The remainder of this chapter is organized as follows. In section 4.2, we introduce how the central bank in Australia implements its monetary policy together with how we decompose the change in the cash rate target into expected and unexpected components. Section 4.3 contains our model and empirical results, whereas Section 4.4 discusses the implication for the term structure of interest rate volatilities. Finally, we provide some concluding remarks and future research in Section 4.5.

4.2 Monetary policy in Australia

4.2.1 Cash rate as the instrument in setting monetary policy

In Australia, the RBA is responsible for monetary policy, which changed from money targeting to inflation targeting in the early 1990s. The RBA focuses on maintaining consumer price inflation between 2 and 3%, on average, over the cycle (Grenville 1997). In practice, the monetary policy aims to achieve this range over the medium term to encourage strong and sustainable growth in the economy and to maintain the value of the AUD. In the long run, this is the principal way to form a sound basis for long-term growth in the economy (Debelle 2003). In order to reach the target, the RBA uses the cash rate (the overnight interest rate at which financial institutions pay to borrow or charge to lend funds in the money market) as its main operational instrument (Battellino, Broadbent, & Lowe, 1997). The RBA sets monetary policy by announcing the target level of the cash rate each time monetary policy is changed. To keep the actual cash rate close to its target level, the RBA is involved in transactions to buy (or sell) securities to add funds to (or withdraw funds from) the banking system where necessary (see Otto 2007 for a detailed exposition of the operation of monetary policy in Australia). The RBA has been very successful in keeping the actual cash rate close to its target level. The daily difference between the two rates lies within a few basis points. Figure 4.1 shows the movement of the cash rate target, the inflation expectation, and the GDP growth.

Figure 4.1: The cash rate, inflation expectations, and GDP growth in Australia from 1990 to 2012



Note: This figure plots the movement of the cash rate target (the blue line, left axis), the median of expected inflation over the next 12 months (brown line, right axis), and the quarterly GDP growth (blue bar, right axis). Both vertical lines are measured in percentages. The sample period is from January 1990 to December 2012.

Figure 4.1 shows that when the country faced inflationary pressure, which was evidenced as high economic growth and high inflation forecasts, the RBA raised its cash rate target, and vice versa.

Table 4.1 illustrates the movement in the RBA's target cash rate from January 1990 to December 2012. The Bank acted to reduce the cash rate 33 times in five periods with an average reduction of 65.2 basis points each. It also raised the cash rate 27 times with an average increase of 50.8 basis points each. Table 4.1 shows that the average number of days between changes in the easing period is much smaller than those of tightenings.

Table 4.1: Characteristics of cash target changes in Australia

From	To	Number of moves	Average days	Mean	Std. Dev	Min	Max
Easings							
4-Apr-90	30-Jul-93	13	93.308	-0.923	0.296	-1.50	-0.50
31-Jul-96	2-Dec-98	6	142.333	-0.458	0.102	-0.50	-0.25
7-Feb-01	5-Dec-01	6	50.167	-0.333	0.129	-0.50	-0.25
3-Sep-08	8-Apr-09	6	36.167	-0.708	0.368	-1.00	-0.25
2-Nov-11	7-Dec-11	2	17.500	-0.250	0.000	-0.25	-0.25
Subtotal		33	79.394	-0.652	0.353	-1.50	-0.25
Tightenings							
17-Aug-94	14-Dec-94	3	39.667	0.917	0.144	0.75	1.00
3-Nov-99	2-Aug-00	5	54.600	0.300	0.112	0.25	0.50
8-May-02	5-Mar-08	12	177.333	0.250	0.000	0.25	0.25
7-Oct-09	3-Nov-10	7	56.000	0.250	0.000	0.25	0.25
Subtotal		27	107.852	0.333	0.219	0.25	1.00
Total		60	92.200	0.508	0.338	0.25	1.5

Note: This table shows the movement in the cash rate target in Australia. The cash rate target changes are measured in percent per year. Values in the row total are calculated using the absolute value of the changes. The sample period is from January 1990 to December 2011.

Since December 1998, all changes (or no-change decisions) have been announced at 9:30 a.m. on the day after the meeting[9]. In the sample period, the RBA made 106 no-change announcements, which make up 73.1% of the total announcements.

Figure 4.2A shows the number of changes at different sizes. In the sample, the RBA has uniformly changed the cash rate as a multiple of 25 basis points. The most frequent change is to increase the cash rate by 25 basis points. An interesting aspect

[9] Since February 2008, the bank has announced its monetary policy at 2:30 p.m. on the day of the meeting.

from figure 4.2A is that when the RBA intends to ease monetary policy, it reduces the cash rate dramatically. Meanwhile, when the RBA wants to tighten monetary policy, it increases the cash rate slowly. The only exception is the two consecutive tightenings of 100 basis points in the second half of 1994 when the Australian economy faced high inflationary pressure. The RBA then decided to raise the cash rate by 200 basis points in two consecutive moves to curtail the upward movement in inflation. These properties of the cash rate target movement are also observed by Valadkhani and Anwar (2012), who show that the distribution of the cash rate target is positively skewed and leptokurtic.

Figure 4.2: History of cash rate target changes in Australia

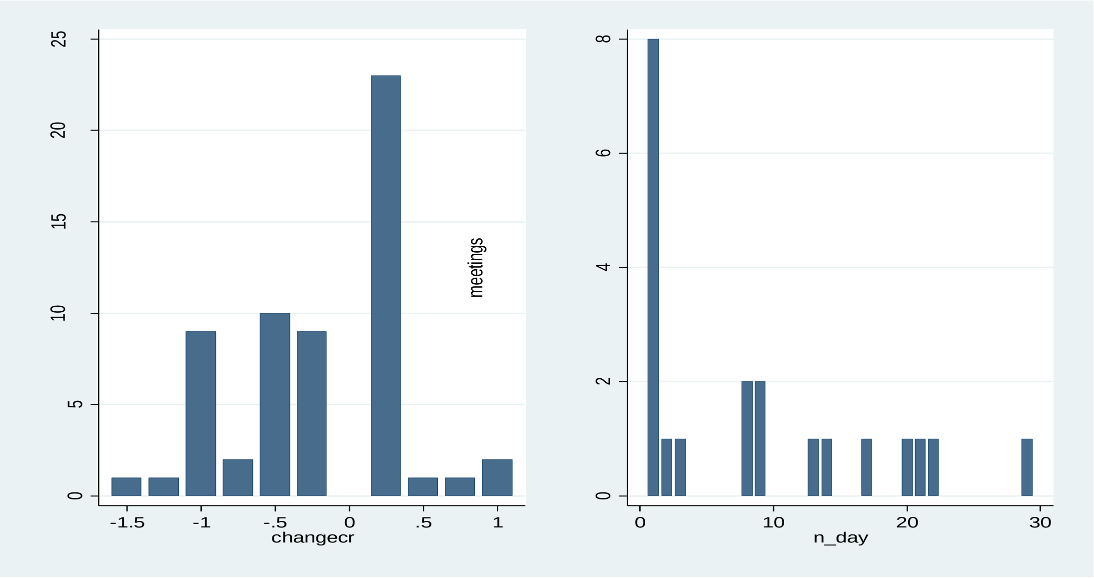


Figure 4.2A **Figure 4.2B**

Figure 4.2A graphs the number of cash target changes at different sizes from January 1990 to December 2011. Figure 4.2B plots the number of days the RBA announces its policy changes from the last Board meeting in January 1990 to the start of regular announcements in December 1998.

Table 4.2 shows the average size of the cash rate change, which is measured by the mean absolute changes, has fallen dramatically since 1985. The average change in the cash rate was 129 basis points in the pre-announcement period; this change was reduced to 80.7 and 43.2 basis points in the pre-regular and the regular announcement periods, respectively. The direction of the cash rate target move is also different between the two periods. In the pre-announcement period, the number of continuations (successive moves in the same direction) was 14, which were twice as many as the number of reversals (successive moves in opposite directions). The number of continuations was equal to five times that of reversals in the announcement period, reflecting the fact the RBA is more capable in forecasting and in dealing with external shocks.

Table 4.2: Descriptive statistics of monetary policy changes

	Pre-announcement (July 1985 - Jan. 1990)	Announcement (Jan. 1990 – Nov. 2011)	Pre-regular Announcement (Jan. 1990 – Nov. 1998)	Regular Announcement (Dec. 1998 – Nov. 2011)
Number of cash moves	20	60	22	38
- Continuations	14	50	18	32
- Reversals	6	10	4	6
- No-change announcement	n/a	105	n/a	105
Mean absolute changes	1.29	0.51	0.81	0.34
Average no. of weeks since the previous change	10.7	18.9	17.8	19.6
Max (weeks)	35.4	85.0	85.0	74.0
Min (weeks)	1.8	3.3	3.3	4.0

Note: This table provides descriptive statistics of monetary policy changes in Australia. The cash rate movement in the pre-announcement period is extracted from Dungey and Hayward (2000). The sample period is from July 1985 to November 2011.

Announcement of the monetary policy

Prior to January 1990, the RBA did not announce its monetary policy stance even when the changes were implemented. Market participants observed the change through fluctuations in overnight interest rates. The disadvantage of this process is that changes in monetary policy were not always immediately obvious to the market due to the noise in the overnight cash rate (Battellino, Broadbent, & Lowe 1997; Dungey & Hayward 2000).

From January 1990 to December 1998, although the dates of the board meetings were specified (usually falling on the first Tuesday of each month from February to December), monetary policy decisions were typically not announced or implemented immediately after each meeting. Whenever the cash rate was changed, the Governor issued a statement at 9:30 a.m. Australian Eastern Standard Time (EST) on the day at which the change took effect. This development marked the start of the transparency period of the monetary policy in Australia.

From December 1998 to November 2007, all changes in the monetary policy were announced on the day after the board meeting at 9:30 a.m. Australian EST (and not between meetings), although the RBA retains the ability to make announcements between meetings. A one-line, no-change statement was also released at 9:30 a.m. on the day following a board meeting when the decision was not to make a change.

Since February 2008, in order to increase transparency, the RBA releases a statement at 2:30 p.m. Australian EST on the day of the board meeting. These statements include information on the cash rate change, which will take effect at 9:30 a.m. Australian EST the next day, and an assessment of the current and expected economic growth and inflation.

4.2.2 Measuring expected and unexpected changes in the cash rate

Since bond yields set in forward-looking markets respond very differently to the anticipated and unanticipated elements of monetary policy actions, the key issue is how to measure and distinguish the two parts of the information regarding the cash rate target announcement: the expected and unexpected components.

Market expectations of changes in monetary policy are unobservable, but we can find some market-based interest rates as proxies for those expectations. The efficient market hypothesis implies that the asset price observable immediately prior to the announcement of changes in monetary policy contains information on the market expectation of the change in the cash rate. In the US market, most of the research employed the Fed funds futures price as a market-based proxy for expected change in Federal Reserve policy (see, for example Kuttner 2001; Hamilton 2008; Hamilton 2009). Unfortunately, until August 2003, there was no market for the interbank cash rate futures in Australia.

In this chapter, we employ information on the short-end money market interest rate, a 30-day bank bill to isolate the expected and unexpected components in the cash rate target change. We choose the 30-day bank bill since its yield fully reflects the changes in central bank's policy target rate in Australia. (see, for example Lu, In, & Kou 2009; Kearns & Manners 2006)[10]. In this chapter, we measure monetary surprises as changes in 30-day bank bill interest rates from the close of the day prior to the announcement to the close on the day of the announcement (i.e. which defines the event window).

$$\Delta \tilde{r}_t^u = r_{30d,t} - r_{30d,(t-1)} \tag{4.1}$$

where $\Delta \tilde{r}_t^u$ is the unanticipated component of the change in the cash rate on the announcement day (at time t) and $r_{30d,t}$ and $r_{30d,(t-1)}$ are interest rates on the 30-day bank accepted bill on the announcement day and one day before the announcement, respectively. The yield on the day before the announcement reflects the market interest rate just before the announcement, which also includes the market expectation of the cash rate target change. The yield on the day of the announcement represents market

[10] The advantage of using 30-day bank bill rates is that the horizon of the instrument does not vary from one event to another (Kearns & Manners 2006).

interest rate that includes the actual cash rate change. Thus, the LHS in Equation (4.1) reflects the unanticipated component of the cash rate target change on the day of the announcement. The daily 30-day bank accepted bill rates are recorded at the close of business therefore, unanticipated changes in the cash rate reflect the surprise component of changes in monetary policy at the end of the day before the announcement.

The actual cash rate target change is the sum of the expected and unexpected change by definition. The expected change $\Delta\tilde{r}_t^e$ is then calculated as the difference between the actual change in the target cash rate $\Delta r_{crt,t}$ and the unexpected change $\Delta\tilde{r}_t^u$.[11]

$$\Delta\tilde{r}_t^e = \Delta r_{crt,t} - \Delta\tilde{r}_t^u \qquad (4.2)$$

From December 1998, all changes in monetary policy were announced one day after the board meeting (and not between meetings). Based upon the study of Rigobon and Sack (2004), we calculate the anticipated and unanticipated changes for every scheduled announcement (the inclusion of no-change announcements is also incorporated in some papers, such as Claus & Dungey 2012; Kearns & Manners 2006; Lu, In, & Kou 2009). Similar to other studies, we treat no-change announcements as zero changes of the cash rate, and the expected changes on the no-change announcement days are simply equal to the additive inverse of the anticipated changes. The advantage of the inclusion of no-change announcements is that our sample triples in size (from 42 to 147 observations). Values of the expected and unexpected changes and dates during the sample period are listed in Appendix 4.1.

[11] Lu, In, and Kou (2009) and Kearns and Manners (2006) focus only on the impact of the surprise component on the change in market interest rates and exchange rates. In this paper, we incorporate both expected and surprise components in the model to investigate how market participants respond to different parts of the monetary policy changes.

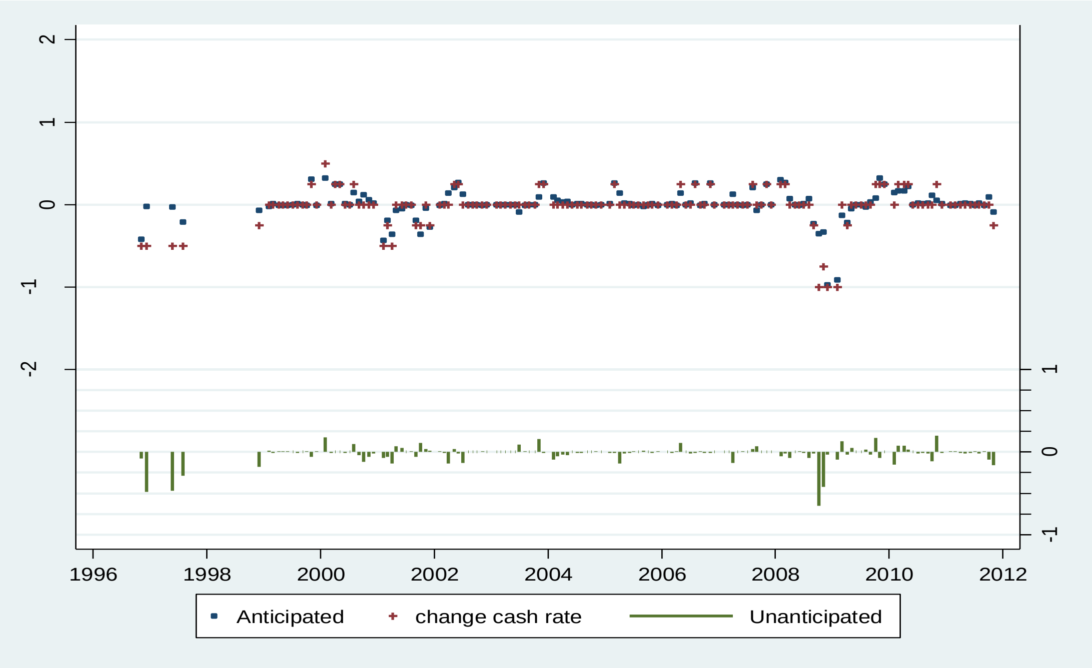
Table 4.3: Summary statistics of the forecast change in the cash rate

	Cash rate change	Anticipated change	Unanticipated change
Mean	10.20	9.21	5.02
Median	0.00	2.00	1.00
Maximum	100.00	97.00	65.00
Minimum	0.00	0.00	0.00
Std. Dev.	19.79	14.80	9.32
Skewness	2.55	3.02	3.76
Kurtosis	10.46	15.93	19.98
Observations	147	147	147

Note: This table reports summary statistics of absolute changes in the cash rate, anticipated, and unanticipated components of the changes during the period from January 1995 to December 2011. The summary statistics include mean, median, standard deviation, minimum, maximum (measured in basis points), skewness, and kurtosis.

Descriptive statistics for the absolute change in the cash rate as well as the anticipated and unanticipated changes are presented in Table 4.3. The absolute mean value of the unanticipated changes in the cash rate, including the no-change announcement, is 5.02 basis points with a standard deviation of 9.32 basis points. During the sample, market participants forecast more than 97% of the changes in the cash rate target. The absolute unanticipated change is much lower than the value reported by Romer and Romer (2004) in the US market during 1969-1996 period. However, it is similar to a recent study by Claus and Dungey (2012), who find an absolute value of monetary policy shock in the US to be about 2 basis points from 1994-2008.

Figure 4.3: Anticipated, unanticipated, and cash rate target changes



Note: This figure plots changes in the cash rate target (the red plus); the anticipated component (the blue square) on the left vertical and the unanticipated component (the green bar) on the right vertical. All these changes are measured in percent per year. The sample period is from January 1995 to December 2011.

Figure 4.3 plots the actual, anticipated, and unanticipated changes in the cash rate. Market participants could predict the direction of the change in the cash rate target correctly in all cases during the period. Figure 4.3 shows the low predictability of market participants during the global financial crises in 1997-1998 and 2008-2009, which are similar to the findings in the US market by Claus and Dungey (2012).

4.3 Response of interest rates across the maturity structure to monetary policy changes

4.3.1 Data

In this chapter, we investigate the response of interest rates across the term structure to the announcement of monetary policies. Specifically, these are the 90- and 180-day bank accepted bills and the 2-, 3-, 5-, and 10-year government bonds. Daily data for all these yields are obtained from the RBA. These yields are the midpoint of the predominant bid, and they offer quotations in each market at the close of business. The sample period is from January 1995 to December 2011. Table 4.4 presents statistics for these yields. Distribution of yields is characterized by the skewness and kurtosis measures, which indicate that the sampling distribution of yields can be considered non-normal. The volatility of Australian long-term Treasury bonds are more or less the same as those of short-term bank bills in the sample period.

Table 4.4: Summary statistics of yields on Australian Treasury bonds and bank bills

	m=3	**m=6**	**m=24**	**m=36**	**m=60**	**m=120**
Mean	5.582	5.643	5.533	5.658	5.836	6.057
Std. Dev.	1.138	1.176	1.185	1.170	1.164	1.175
Median	5.420	5.470	5.260	5.370	5.560	5.730
Skewness	0.378	0.471	0.906	1.072	1.301	1.584
Kurtosis	2.780	3.049	4.791	5.015	5.260	5.402
Max	8.640	9.430	10.350	10.440	10.480	10.560
Min	3.000	2.850	2.520	2.810	3.260	3.860

Note: This table reports summary statistics of yields at seven maturities in Australia. The summary statistics include mean, median, standard deviation, minimum, maximum (measured in percentages), skewness, and kurtosis. The sample period is from January 1995 to December 2011.

4.3.2 Impact of changes in monetary policy on the term structure of interest rates

To measure the impact of changes in monetary policy on the term structure of interest rates, we extend the regressions of Cook and Hahn (1989) in the manner of Kuttner (2001) by regressing the change in interest rates at different maturities on the expected and unexpected components of the cash rate changes

$$r_t^m - r_{t-1}^m = \alpha_m + \beta_{1m}\Delta\tilde{r}_t^e + \beta_{2m}\Delta\tilde{r}_t^u + \varepsilon_{tm}, \tag{4.3}$$

where r_t^m denotes the interest rate with m months to maturity at time t, and $\Delta\tilde{r}_t^e$ and $\Delta\tilde{r}_t^u$ are the expected and the unexpected change in the cash rate target at time t, respectively.

Regression results are reported in Table 4.5. Market interest rates at different maturities respond differently to expected and unexpected components. Responses to the unanticipated component are large and significant, while those to the anticipated component are small and insignificant. A 1% point unanticipated increase in the cash rate target raises the 90-day bank bill interest rate by 92.424 basis points. Table 4.5 also shows the smaller response of long rates compared to short rates to unanticipated changes in monetary policy. We apply the Wald test to examine the hypothesis of equal interest rate responses to the expected and unexpected component of the change $(H_0 : \beta_{1m} = \beta_{2m})$. The test rejects the hypothesis of an equal response at the 5% level of significance for all maturities. Our results are consistent with Lu, In, and Kou (2009), who investigated the effect of change in the cash rate target on Australian financial futures, and with Kuttner (2001) and Poole and Rasche (2000) in the US market (results where we do not do this decomposition are given in Appendix 4.2).

Table 4.5: Impact of a 1% point change in monetary policy surprise on the market of interest rates

This table reports the results of regressions of the formula

$$r_t^m - r_{t-1}^m = \alpha_m + \beta_{1m}\Delta\tilde{r}_t^e + \beta_{2m}\Delta\tilde{r}_t^u + \varepsilon_{tm}$$

where r_t^m denotes the interest rate with m months to maturity at time t, and $\Delta\tilde{r}_t^e$ and $\Delta\tilde{r}_t^u$ are the expected and unexpected change in cash rate target at time t.

	m=3	m=6	m=24	m=36	m=60	m=120
Anticipated (β_{1m})	-3.119	-2.765	-7.132	-7.968	-6.343	0.147
	(2.910)	(2.927)	(3.156)	(3.055)	(3.124)	(3.597)
Unanticipated (β_{2m})	92.424*	99.738*	76.702*	65.955*	52.733*	32.021*
	(3.927)	(9.896)	(5.819)	(4.037)	(3.667)	(3.456)
Constant (α_m)	0.693*	0.606	0.146	0.011	-0.176	-0.338
	(0.254)	(0.317)	(0.514)	(0.539)	(0.543)	(0.516)
Nob	147	147	147	147	147	147

Note: Regression with Newey-West standard errors with max lag = 13.
Standard errors are given in parentheses.
* denotes significance at the 1% level.

This table reports the reaction of market interest rates at different maturities to the expected and unexpected changes in the cash rate target. The cash rate changes are measured in percentages, and changes in market interest rates are measured in basis points. The anticipated and unanticipated changes in the cash rate are calculated by changes in the 30-day bank accepted bill rate (see text). The sample period is from January 1995 to December 2011.

Valadkhani and Anwar (2012) find an asymmetric relationship between monetary policy and the mortgage rate. More specifically, cash rate rises have a larger and more instantaneous impact on the mortgage rate than cash rate cuts. Table 4.6 reports responses of interest rates to positive and negative changes in the cash rate target. Cash rate target rises have a larger impact on interest rates than do cash rate cuts.

Table 4.6: Asymmetric response of interest rates to 1% point change in monetary policy surprises

This table reports the results of regressions of the formula

$$r_t^m - r_{t-1}^m = \alpha_m + \beta_{1m}\Delta\tilde{r}_t^e + \beta_{2m}\Delta\tilde{r}_t^u + \varepsilon_{tm}$$

where r_t^m denotes the interest rate with m months to maturity at time t, and $\Delta\tilde{r}_t^e$ and $\Delta\tilde{r}_t^u$ are expected and unexpected change in cash rate target at time t.

	m=3	**m=6**	**m=24**	**m=36**	**m=60**	**m=120**
Increase in the cash rate target						
Anticipated (β_{1m})	25.718*	37.966*	16.604	15.517	-4.982	-12.518
	(4.101)	(3.893)	(9.185)	(9.729)	(8.540)	(6.497)
Unanticipated (β_{2m})	111.890*	116.342*	102.895*	93.032*	55.385*	15.794*
	(2.327)	(4.005)	(10.083)	(10.734)	(9.523)	(6.036)
Constant (α_m)	-5.370*	-9.091*	-5.834*	-5.711*	-0.375	2.163
	(1.096)	(1.106)	(2.150)	(2.147)	(1.773)	(1.509)
Nob	24	24	24	24	24	24
Decrease in the cash rate target						
Anticipated (β_{1m})	-4.265	3.248	-1.104	-4.186	-5.300	0.252
	(6.324)	(8.469)	(7.331)	(6.719)	(7.609)	(10.021)
Unanticipated (β_{2m})	98.714*	114.088*	80.192*	65.361*	49.440*	28.510*
	(5.432)	(13.304)	(8.261)	(5.308)	(5.036)	(5.341)
Constant (α_m)	2.551	6.446	3.798	1.998	-0.315	-1.844
	(2.203)	(3.445)	(3.000)	(2.963)	(3.123)	(3.974)
Nob	18	18	18	18	18	18

Note: Regression with Newey-West standard errors with max lag = 13.
Standard errors are shown in parentheses.
* denotes significance at the 1% level.

This table reports the asymmetric reaction of market interest rates at different maturities to the expected and unexpected changes in the cash rate target. The cash rate changes are measured in percentages, and changes in market interest rates are measured in basis points. The anticipated and unanticipated changes in the cash rate are calculated by changes in the 30-day bank accepted bill rate (see text). The sample period is from January 1995 to December 2011.

The response of market interest rates to anticipated and unanticipated changes in monetary policy two days after the announcement are small and insignificant (see Appendix 4.3). These results are consistent with Battellino, Broadbent, and Lowe (1997), who report the adjustment of market interest rates to the change in monetary policy are practically complete on the day of the policy change.

4.3.3 Robustness check

Table 4.7: Impact of a 1% point change in monetary policy surprise on the market of interest rates-actual changes (sample excludes no-change announcement dates)

This table reports the results of regressions of the formula

$$r_t^m - r_{t-1}^m = \alpha_m + \beta_{1m}\Delta\tilde{r}_t^e + \beta_{2m}\Delta\tilde{r}_t^u + \varepsilon_{tm}$$

where r_t^m denotes the interest rate with m months to maturity at time t, and $\Delta\tilde{r}_t^e$ and $\Delta\tilde{r}_t^u$ are expected and unexpected change in cash rate target at time t.

	m=3	**m=6**	**m=24**	**m=36**	**m=60**	**m=120**
Anticipated (β_{1m})	-4.245	-3.772	-6.746	-7.11	-5.312	1.002
	(2.623)	(2.704)	(3.317)	(3.197)	(3.312)	(3.776)
Unanticipated (β_{2m})	96.438*	102.887*	76.575*	64.729*	50.459*	28.858*
	(4.029)	(11.067)	(6.281)	(3.849)	(3.337)	(2.798)
Constant (α_m)	1.997*	1.381	0.808	0.646	-0.125	-1.43
	(0.495)	(0.710)	(0.856)	(0.846)	(0.757)	(0.743)
Nob	42	42	42	42	42	42

Note: Regression with Newey-West standard errors with max lag = 13.
Standard errors are given in parentheses.
* denotes significance at the 1% level.

This table reports the reaction of market interest rates at different maturities to the expected and unexpected changes in the cash rate. The cash rate changes are measured in percentages, and change in market interest rates are measured in basis points. The anticipated and unanticipated changes in the cash rate are calculated by changes in the 30-day bank accepted bill rate (see text). The sample includes dates at which the RBA changes its cash rate target only. The sample period is from January 1995 to December 2011.

Our sample includes all scheduled announcements on which market participants thought there might be a change in the cash rate target regardless of whether the change actually occurred or not. Another sample would be one that consists of those days on which the RBA changes its cash rate target. As shown in Table 4.7, the exclusion of no-change announcement dates has no impact on the results.

4.4 Implications for the term structure of interest rates

By setting the cash rate target, the RBA influences the benchmark for lending and borrowing rates for the entire economy. Thus, yield curve modelling should take into account the monetary policy action by the central bank. For example, Piazzesi (2005) employs the timing of Federal Open Market Committee (FOMC) meetings to construct a continuous time model of the joint distribution of the bond yields and the interest rate target. Bauer (2011) proposes a dynamic term structure model to analyze the impact of monetary policy on the term structure of interest rates.

We now investigate the effect of monetary changes on the term structure of interest rates by looking at the changes in the volatility of interest rates at different maturities (measured by the standard deviation of yields). One straightforward way to analyze the effect of monetary policy on interest rate volatilities is to compare volatilities at different maturities for those days with an RBA monetary policy announcement and "normal" days[12]. The volatility curve is the sample standard deviation of daily yield changes as a function of maturity (Piazzesi 2001). Differences

[12] We define "normal" days as the days without any major macro news release or policy announcements. There are some differences between normal day and non-policy announcement days; however, here we use the two terms interchangeably.

in the level and the shape of the two curves will provide us with a clear picture of the effect of monetary changes on the term structure of interest rate volatilities.

Faust et al. (2007) and Balduzzi, Elton, and Green (2001) find macro news releases have significant impact on interest rates and their volatilities. Thus, to eliminate the effect of a macro news release on the term structure of interest rate volatilities on non-policy announcement days, we exclude those days with at least one of the most important macroeconomic releases in Australia: the Consumer Price Index (CPI), gross domestic product (GDP), unemployment rate (UE), and retail sales growth (RET). We chose these macro indicators because the literature has found them to have a significant impact on the fixed income market (Kim 1999; Dungey, McKenzie, & Smith 2009; Simpson & Ramchander 2004; Ramchander, Simpson, & Chaudhry 2005). These indicators are released by the Australian Bureau of Statistics (ABS) at 11:30 a.m.; the CPI and GDP are released quarterly, while the UE and RET are released every month. The release dates and times for each macroeconomic indicator are extracted from ABS media releases. Table 4.8 provides a summary of these key indicator announcements.

During the sample period, the ABS made 703 announcements regarding these indicators in 603 days. Most of the announcements occurred in the middle of the week; more specifically, 8.0% of all announcements occurred on Monday, 11.6% on Tuesday, 20.7% on Wednesday, 52.9% on Thursday, and 6.8% on Friday.

Table 4.8: Description of major macroeconomic indicators

	CPI	GDP	UE	RET	Total
ABS Cat No.	6401.0	5206.0	6202.0	8501.0	
Total announcements	88	88	264	263	703
Weekday					
- Monday	0	0	1	48	49
- Tuesday	6	9	0	62	77
- Wednesday	77	68	1	57	203
- Thursday	3	8	260	59	330
- Friday	2	3	2	37	44

Note: This table reports the description of schedule announcements of the key macroeconomic indicators by the ABS. The sample period is from January 1995 to December 2011.

Of the 147 cash rate announcements made by the RBA, 52 coincided with one or more macroeconomic announcements. To isolate the impact of a monetary policy announcement on interest rate volatilities, we construct a policy induced volatility curve for 95 days. On these days, the monetary policy announcement is the unique event that affects the term structure of interest rate volatilities. Our sample contains 4,745 days without any major announcements. The volatility curve estimated for those days reflects a "normal day" term structure of interest rate volatilities. Differences in the level and the shape of the two volatility curves (for "normal" and "policy" days) provide us with a clear picture of the effect of monetary policy changes on the term structure of interest rate volatilities.

Figure 4.4 plots the volatility curves on the days the RBA releases its cash rate target changes and on a non-policy announcement day corresponding to their 95% confidence intervals[13]. Figure 4.4A shows a hump shape of a "normal day" volatility

[13] The $100(1-\alpha)\%$ confidence intervals are given by $\frac{\sqrt{N-1}*s}{\sqrt{\chi^2_{\alpha/2,N-1}}} \leq \sigma \leq \frac{\sqrt{N-1}*s}{\sqrt{\chi^2_{1-\alpha/2,N-1}}}$ where N is the number of observation and $\chi^2_{\alpha/2,N-1}$ is the upper $\alpha/2$ critical value from the chi-square distribution with $N-1$ degree of freedom.

curve. The volatility starts at 4% for a 3-month maturity, increases to 7.8% for a 5-year maturity, and then decreases back to 7% for a 10-year maturity. Also, the volatility in the long run is much higher than it is in the short run. The monetary policy-induced volatility curve in Figure 4.4B behaves in a different way. It is high at the short end (at 14.8% for a 3-month maturity), drops to 8.4% at the 1-year maturity and then gradually decreases to 7% for the 10-year maturity. After comparing the two volatility curves, it is clear that the policy induces more volatility in the short term, while in the long term the effect is not strong. Specifically, on the day the RBA announces its target cash rate, the 90-day bank bill interest rate volatility is more than three times the volatility of that for a non-policy announcement day. In the long term, interest rate volatilities are more or less the same as those for a "normal day."

Figure 4.4: Term structure of Australian Treasury bond yield volatilities from 1995 to 2011

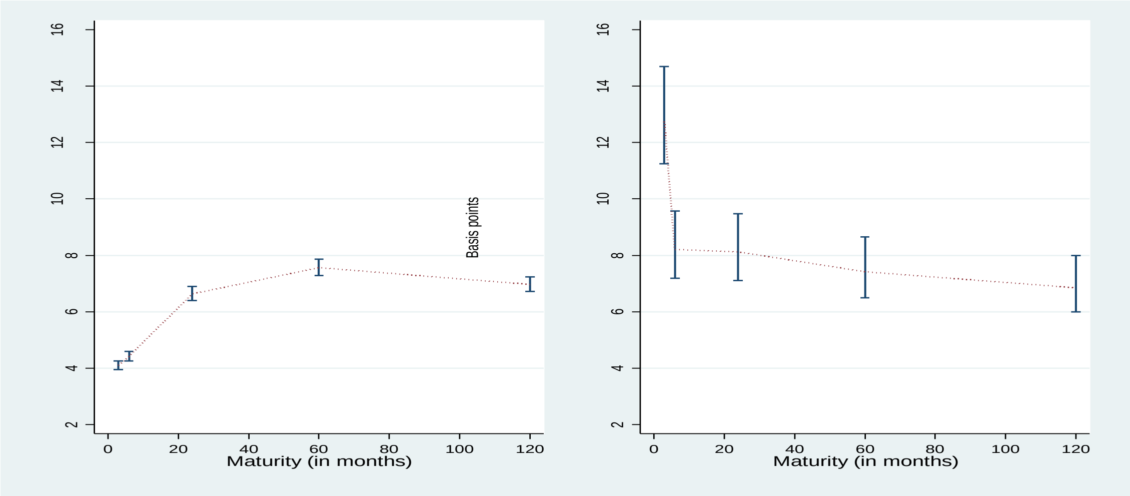


Figure 4.4A **Figure 4.4B**

This figure plots the term structure of Treasury bond yield volatilities. Volatilities are measured by the sample standard deviation. Upper and lower values are 95% confidence intervals. The sample period is from January 1996 to December 2011.

Our finding from the term structure of Australian Treasury bond yield volatilities is consistent with the market segmentation assumption. High volatility at the short end of the yield curve is consistent with the assumption that speculators play a more active role at the short end of the yield curve as compared with the long-end market. As a result, surprises in monetary policy generate more volatility in short-end maturity as speculators alter their investment portfolio. These findings support the conclusions suggested by Kuttner (2001) and Gürkaynak, Sack, and Swanson (2005) that the impact of monetary policy on the term structure of bond yields declines with maturity.

4.5 Conclusion

This chapter investigates the effect of anticipated and unanticipated changes in the cash rate on Australian term structure of interest rates. We find that unanticipated changes in the target cash rate significantly impact the entire term structure with the impact declining as the term to maturity becomes larger. By comparing interest rate volatility curves on policy and non-policy announcement days, we provide a clear picture of the effect of changes in monetary policy on the term structure of interest rates. We find the impact of the changes declines with maturity, which is consistent with the findings of Kuttner (2001) and Gürkaynak, Sack, and Swanson (2005) and supports the market segmentation theory.

I conclude by reflecting on the policy implications, if any, of our results. I found that the returns on Treasury Bonds adjust very quickly to news (i.e. the unanticipated component in a monetary policy announcement) and that the adjustment is complete within the day of the announcement. This suggests that financial market participants in the Australian bond market process unexpected information or news comprehensively and quickly, so that there is a very rapid adjustment in yields. This implies that the Australian financial market in Treasury Bonds is an efficient market and that, prima facie, there is no market failure that requires the design of appropriate government policy to ameliorate.

However, one may argue that our results may also reflect the impact of news other than just the monetary policy action on the monetary policy announcement day. With a higher frequency data set (i.e., intraday frequency rather than daily data), we can isolate the impact of other news from the analysis. We turn to this extension in the next chapter.

Appendix 4.1: Changes in the cash rate target, expected, and unexpected change

	Date	(1)	(2)	(3)		Date	(1)	(2)	(3)		Date	(1)	(2)	(3)
1996	6-Nov	-0.50	-0.42	-0.08	**2003**	5-Feb	0.00	0.00	0.00	**2007**	4-Jul	0.00	0.00	0.00
	11-Dec	-0.50	-0.02	-0.48		5-Mar	0.00	0.00	0.00		8-Aug	0.25	0.21	0.04
1997	23-May	-0.50	-0.03	-0.47		2-Apr	0.00	0.00	0.00		5-Sep	0.00	-0.07	0.07
	30-Jul	-0.50	-0.21	-0.29		7-May	0.00	0.00	0.00		3-Oct	0.00	0.00	0.00
1998	2-Dec	-0.25	-0.07	-0.18		4-Jun	0.00	0.00	0.00		7-Nov	0.25	0.25	0.00
1999	3-Feb	0.00	-0.02	0.02		2-Jul	0.00	-0.09	0.09		5-Dec	0.00	0.00	0.00
	3-Mar	0.00	0.01	-0.01		6-Aug	0.00	-0.01	0.01	**2008**	5-Feb	0.25	0.30	-0.05
	7-Apr	0.00	-0.01	0.01		3-Sep	0.00	0.00	0.00		4-Mar	0.25	0.27	-0.02
	5-May	0.00	-0.01	0.01		8-Oct	0.00	0.00	0.00		1-Apr	0.00	0.07	-0.07
	2-Jun	0.00	-0.01	0.01		5-Nov	0.25	0.09	0.16		6-May	0.00	0.00	0.00
	7-Jul	0.00	0.00	0.00		3-Dec	0.25	0.26	-0.01		3-Jun	0.00	-0.01	0.01
	4-Aug	0.00	0.01	-0.01	**2004**	4-Feb	0.00	0.09	-0.09		1-Jul	0.00	0.01	-0.01
	8-Sep	0.00	0.00	0.00		3-Mar	0.00	0.05	-0.05		5-Aug	0.00	0.07	-0.07
	6-Oct	0.00	-0.01	0.01		7-Apr	0.00	0.03	-0.03		2-Sep	-0.25	-0.23	-0.02
	3-Nov	0.25	0.31	-0.06		5-May	0.00	0.04	-0.04		7-Oct	-1.00	-0.35	-0.65
	8-Dec	0.00	-0.01	0.01		2-Jun	0.00	0.00	0.00		4-Nov	-0.75	-0.33	-0.42
2000	2-Feb	0.50	0.32	0.18		7-Jul	0.00	0.01	-0.01		2-Dec	-1.00	-0.97	-0.03
	8-Mar	0.00	0.01	-0.01		4-Aug	0.00	0.01	-0.01	**2009**	3-Feb	-1.00	-0.91	-0.09
	5-Apr	0.25	0.25	0.00		8-Sep	0.00	0.00	0.00		3-Mar	0.00	-0.13	0.13
	3-May	0.25	0.25	0.00		6-Oct	0.00	0.00	0.00		7-Apr	-0.25	-0.22	-0.03
	7-Jun	0.00	0.01	-0.01		3-Nov	0.00	-0.01	0.01		5-May	0.00	-0.05	0.05
	5-Jul	0.00	0.00	0.00		8-Dec	0.00	0.00	0.00		2-Jun	0.00	0.00	0.00
	2-Aug	0.25	0.15	0.10	**2005**	2-Feb	0.00	0.01	-0.01		7-Jul	0.00	0.00	0.00
	6-Sep	0.00	0.04	-0.04		2-Mar	0.25	0.26	-0.01		4-Aug	0.00	-0.03	0.03
	4-Oct	0.00	0.12	-0.12		6-Apr	0.00	0.14	-0.14		1-Sep	0.00	0.03	-0.03
	8-Nov	0.00	0.06	-0.06		4-May	0.00	0.02	-0.02		6-Oct	0.25	0.08	0.17
	6-Dec	0.00	0.02	-0.02		8-Jun	0.00	0.01	-0.01		3-Nov	0.25	0.32	-0.07
2001	7-Feb	-0.50	-0.43	-0.07		6-Jul	0.00	-0.01	0.01		1-Dec	0.25	0.25	0.00
	7-Mar	-0.25	-0.19	-0.06		3-Aug	0.00	0.00	0.00	**2010**	2-Feb	0.00	0.15	-0.15
	4-Apr	-0.50	-0.36	-0.14		7-Sep	0.00	-0.02	0.02		2-Mar	0.25	0.17	0.08
	2-May	0.00	-0.07	0.07		5-Oct	0.00	0.00	0.00		6-Apr	0.25	0.17	0.08
	6-Jun	0.00	-0.05	0.05		2-Nov	0.00	0.01	-0.01		4-May	0.25	0.22	0.03
	4-Jul	0.00	0.00	0.00		7-Dec	0.00	-0.01	0.01		1-Jun	0.00	0.00	0.00
	8-Aug	0.00	-0.01	0.01	**2006**	8-Feb	0.00	0.00	0.00		6-Jul	0.00	0.02	-0.02
	5-Sep	-0.25	-0.19	-0.06		8-Mar	0.00	0.01	-0.01		3-Aug	0.00	0.01	-0.01
	3-Oct	-0.25	-0.36	0.11		5-Apr	0.00	-0.01	0.01		7-Sep	0.00	0.02	-0.02
	7-Nov	0.00	-0.04	0.04		3-May	0.25	0.14	0.11		5-Oct	0.00	0.11	-0.11
	5-Dec	-0.25	-0.27	0.02		7-Jun	0.00	0.00	0.00		2-Nov	0.25	0.05	0.20
2002	6-Feb	0.00	-0.01	0.01		5-Jul	0.00	0.02	-0.02		7-Dec	0.00	0.01	-0.01
	6-Mar	0.00	0.01	-0.01		2-Aug	0.25	0.26	-0.01	**2011**	1-Feb	0.00	-0.01	0.01
	3-Apr	0.00	0.14	-0.14		6-Sep	0.00	-0.01	0.01		1-Mar	0.00	-0.01	0.01
	8-May	0.25	0.21	0.04		4-Oct	0.00	0.01	-0.01		5-Apr	0.00	0.01	-0.01
	5-Jun	0.25	0.27	-0.02		8-Nov	0.25	0.26	-0.01		3-May	0.00	0.02	-0.02
	3-Jul	0.00	0.13	-0.13		6-Dec	0.00	0.00	0.00		7-Jun	0.00	0.01	-0.01
	7-Aug	0.00	0.00	0.00	**2007**	7-Feb	0.00	0.00	0.00		5-Jul	0.00	-0.01	0.01
	4-Sep	0.00	0.00	0.00		7-Mar	0.00	0.00	0.00		2-Aug	0.00	0.02	-0.02
	2-Oct	0.00	0.00	0.00		4-Apr	0.00	0.13	-0.13		6-Sep	0.00	-0.01	0.01
	6-Nov	0.00	-0.01	0.01		2-May	0.00	0.00	0.00		4-Oct	0.00	0.09	-0.09
	4-Dec	0.00	0.00	0.00		6-Jun	0.00	-0.01	0.01		1-Nov	-0.25	-0.09	-0.16

Note: (1) change cash rate target, (2) expected change, and (3) unexpected change

This table lists the actual change in the target cash rate and the expected and unexpected changes in cash rate target on the announcement days. The unexpected change is measured as changes in 30-day bank bill interest rates from the close of the day prior to the announcement to the close of the day of the announcement (see text for details).

Appendix 4.2: Response of interest rates to a 1% point change in cash rate target

This table reports the results of regressions of the formula

$$r_t^m - r_{t-1}^m = \alpha_m + \beta_m \Delta r_{crt,t} + \varepsilon_{mt}$$

where r_t^m denotes the interest rate with m months to maturity at time t, and $\Delta r_{crt,t}$ is the change in cash the rate target at time t.

	m=3	**m=6**	**m=24**	**m=36**	**m=60**	**m=120**
Change cash rate (β_m)	25.622*	28.069	18.086	14.269	11.428	9.735
	(9.529)	(11.104)	(8.036)	(6.555)	(5.447)	(3.963)
Constant (α_m)	-0.898	-1.101	-1.250	-1.220	-1.159	-0.868
	(0.661)	(0.752)	(0.765)	(0.743)	(0.680)	(0.562)
Nob	147	147	147	147	147	147

Note: Regression with Newey-West standard errors with max lag = 13.
Standard errors are shown in parentheses.
* denotes significance at the 1% level.

This table reports the reaction of market interest rates at different maturities to changes in the cash rate target. Cash rate changes are measured in percentages, and changes in market interest rates are measured in basis points. The sample period is from January 1995 to December 2011.

Appendix 4.3: Impact of a 1% point monetary policy surprise on the market of interest rates from one to two days after the announcement

This table reports the results of regressions of the formula

$$r_{t+1}^{m} - r_{t}^{m} = \alpha_m + \beta_{1m}\Delta\tilde{r}_t^{e} + \beta_{2m}\Delta\tilde{r}_t^{u} + \varepsilon_{t+1,m}$$

where r_t^m denotes interest rate with m months to maturity at time t, and $\Delta\tilde{r}_t^{e}$ and $\Delta\tilde{r}_t^{u}$ are the expected and the unexpected change in cash rate target at time t.

	m=3	**m=6**	**m=24**	**m=36**	**m=60**	**m=120**
Anticipated (β_{1m})	-1.852	-3.086	-5.924	-6.888	-6.606	-4.343
	(2.174)	(2.254)	(2.404)	(2.643)	(2.852)	(3.115)
Unanticipated (β_{2m})	5.344	9.455	8.452	6.394	3.629	-1.322
	(4.205)	(7.291)	(8.757)	(7.985)	(8.472)	(8.529)
Constant (α_m)	0.527	0.499	0.600	0.533	0.342	0.291
	(0.262)	(0.324)	(0.535)	(0.587)	(0.590)	(0.586)
Nob	147	147	147	147	147	147

Note: Regression with Newey-West standard errors with max lag = 13.
Standard errors are shown in parentheses.
* denotes significance at the 1% level.

This table reports the reaction of market interest rates at different maturities to the anticipated and unanticipated component of cash rate target changes from one to two days after the announcement. The cash rate changes are measured in percentages, and changes in market interest rates are shown in basis points. The sample period is from January 1995 to December 2011.

Chapter 5 : The impact of changes in monetary policy on the Australian term structure of interest rates: Evidence from intraday data

5.1 Introduction

How interest rates at different maturities react to the change in monetary policy is still a matter of debate. Many recent studies have investigated the effect of monetary policy changes on the term structure of interest rates using daily (Kuttner 2001; Poole, Rasche, & Thornton 2002; Hamilton 2008) or monthly (Francis, Ghysels, & Owyang 2011) data. These studies are based on an assumption that monetary policy change is a unique event that takes place on a given day. However, in reality, some days have more than one major news event, and the change in interest rates may also be influenced by this other news.

This chapter examines the impact of Australian monetary policy announcements on the term structure of interest rates using intra-day data provided by the Securities Industry Research Centre of Asia-Pacific (SIRCA). By selecting narrow windows around monetary policy announcements, we are able to mitigate the effect of other news on market interest rates on the announcement days. It is unlikely that there are other news releases or major events within 30 or 60 minutes after the monetary policy announcement. As a result, we are able to measure the effect of monetary policy announcements on the term structure of interest rates more precisely.

This chapter has a number of features. First, until recently, Lu, In, and Kou (2009) is the only research in this field using intra-day data. They examine the effect of monetary policy surprise on the 3- and 10-year Australian futures. This chapter differentiates itself from Lu, In, and Kou (2009) by including both the expected and unexpected components of monetary policy in the model. The inclusion of the expected component allows us to check the validity of the method to break monetary policy change down into expected and surprise components. In this chapter, we investigate the effect of monetary policy announcements on Australian Treasury bonds, which allows us to compare our results with the international literature using daily data. Second, to our knowledge, this paper is the first to investigate the effect of monetary policy announcements on Australian Treasury bonds that are traded in the over-the-counter (OTC) market. The existing literature investigates the effect on US Treasury bonds that are traded on the official markets, which are much more liquid and transparent than OTC markets.

The chapter reaches three main findings. First, the surprise component of monetary policy announcements has a significant impact on the change in yields across the term structure of Australian Treasury bonds. In addition, this effect decreases as the maturity of the bond increases, which is consistent with the findings of Chapter 4 and other studies using low frequency data. Second, the Treasury bond yields almost completely adjust to the change in monetary policy within 30 minutes after the announcement. Third, short-term realized volatility is significantly increased when the RBA announces its cash rate target, while the effect on longer maturities is insignificant.

The rest of this chapter is organized as follows. In section 5.2, we summarize the data used in the analysis. Section 5.3 contains our model and empirical results, whereas Section 5.4 discusses the implications for the term structure of interest rate volatilities. Finally, we provide some concluding remarks in Section 5.5.

5.2 Data

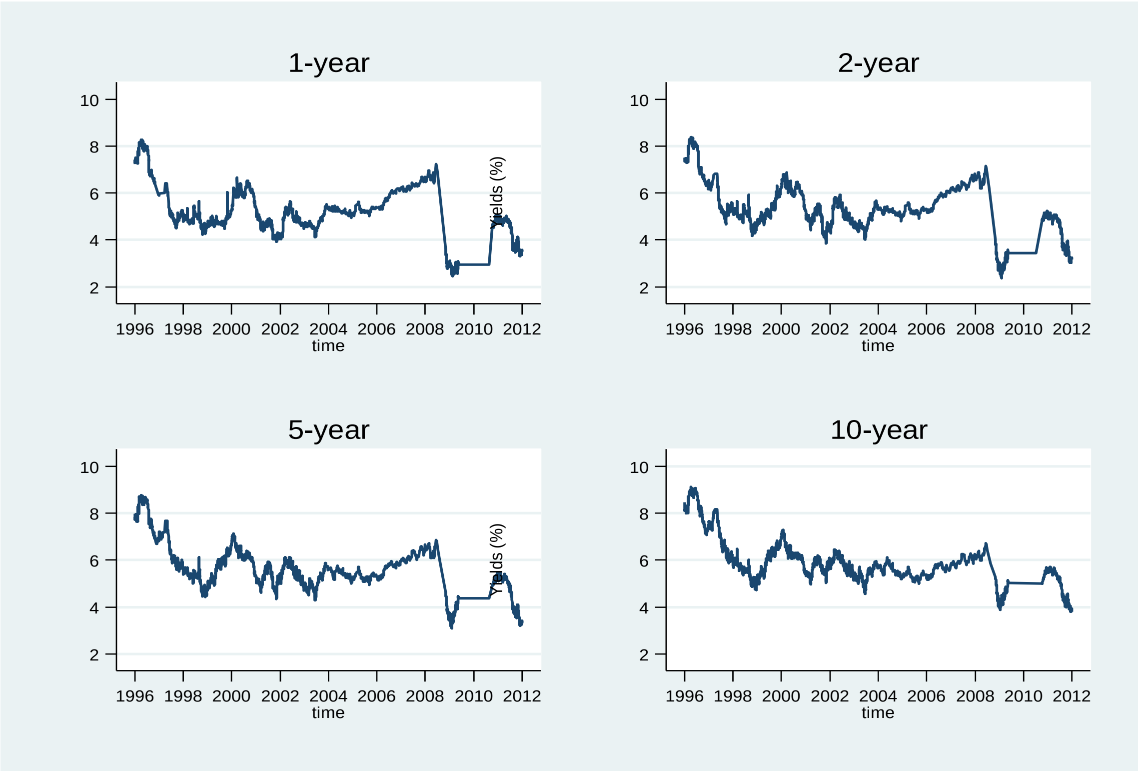
5.2.1 Interest rate data

To measure the impact of the RBA announcement on the term structure of Treasury bond yields, we collect intra-day data on yields around the announcement time. The data is provided by the SIRCA. For each of the Australian Treasury bonds, the database contains the times to the nearest millisecond corresponding to the bid/ask yield quotations. After removing national public holidays and days with less than 10 quotes, our sample includes 3,410 trading days, providing over 700,000 yield values for the Australian bonds at 1-, 2-, 5-, and 10-year maturities in the 60-minute window[14]. Figure 5.1 plots the average bid/ask yields at 9:30 a.m. in the sample period[15]. Casual observation of these plots suggests high correlations between bond yields with different maturities.

[14] There were very few transactions during the June 2009 - September 2010 period. Thus, we exclude this period from our sample.

[15] Beginning in February 2008, yields are recorded at 2:30:00 p.m.

Figure 5.1: Australian Treasury bond yields by maturity from 1996-2011



Note: This figure plots Australian Treasury bond yields at different maturities. Yields are recorded daily at 9:30 a.m. until February 2008 and thereafter at 2:30 p.m. The sample period is from January 1996 to December 2011.

Summary statistics of yields at maturities from 1 to 10 years in the sample period are presented in Table 5.1. A treasury bond with a larger maturity has a higher mean value of yield and a lower standard deviation. Distributions of the yields are characterized by the skewness and the kurtosis measures, which show that the distribution of yields can be considered as non-normal.

We sample data around the announcement of cash rate target change beginning with the first observation available on 2 January 1996 to 30 December 2011. We collect the bid and ask yields for 1-, 2-, 5-, and 10-year Australian Treasury bonds from 15 minutes before to 60 minutes after the RBA announcement. More specifically, we sample the yields at 15 minutes before and 30 seconds, 1, 5, 10, 30, and 60 minutes after the announcement. If there is no yield at these exact times, the last non-missing value is taken.

Table 5.1: Summary statistics of Treasury bond yields

	1-year	**2-year**	**5-year**	**10-year**
Mean	3.981	4.089	4.654	5.083
Standard deviation	1.271	1.335	1.209	0.957
Min	2.430	2.383	3.010	3.740
Max	8.320	8.840	9.230	9.155
Skewness	0.714	0.556	0.578	1.126
Kurtosis	2.603	2.257	2.531	4.733

Note: This table reports summary statistics of Australian Treasury bond yields at maturities from 1 to 10 years. Yields are measured by the average bid/ask yields. The summary statistics include mean, standard deviation, minimum, maximum (measured in percentages), skewness, and kurtosis. The sample period is from January 1996 to December 2011.

Table 5.2 contains the descriptive statistics of the changes in yields of the Australian Treasury bonds at different time horizons after the announcement of the change in the cash rate. Except for the positive of the average change of 5-year bond yields for a 5-minute window, the mean value of the changes are negative, showing that on average, Treasury bond yields decrease after the announcement. Additionally, high values of the kurtosis measure at all maturities and window sizes show that the distribution of interest rate changes has a leptokurtic distribution with the values concentrated around the mean.

Table 5.2: Descriptive statistics of interest rates changes after changes in the cash rate target

		30-second	1-minute	5-minute	10-minute	30-minute	60-minute
1-year							
	Mean	-0.11	-0.24	-0.06	-0.11	-0.42	-0.23
	Std. Dev.	5.35	5.46	5.36	5.33	5.54	5.54
	Min	-39.00	-39.00	-39.00	-39.00	-39.00	-39.00
	Max	19.00	19.00	19.00	18.00	18.00	19.00
	Skewness	-2.17	-2.04	-2.22	-2.35	-2.04	-2.01
	Kurtosis	25.45	23.48	25.31	25.48	21.60	22.07
2-year							
	Mean	-0.10	-0.23	-0.04	-0.38	-0.61	-0.43
	Std. Dev.	4.64	4.78	4.67	5.60	5.74	5.70
	Min	-30.00	-30.00	-30.00	-36.00	-36.00	-34.00
	Max	18.00	18.00	18.00	18.00	18.00	19.00
	Skewness	-1.11	-1.06	-1.19	-2.58	-2.37	-2.07
	Kurtosis	18.79	16.75	18.07	21.03	18.75	17.49
5-year							
	Mean	-0.15	-0.20	0.04	-0.13	-0.32	-0.28
	Std. Dev.	4.13	4.18	4.25	4.83	4.89	4.91
	Min	-20.00	-20.00	-20.00	-27.00	-27.00	-25.00
	Max	19.00	19.00	19.00	18.00	18.00	18.00
	Skewness	0.21	0.18	0.26	-1.14	-1.17	-0.82
	Kurtosis	11.65	11.18	10.90	13.52	12.44	10.74
10-year							
	Mean	-0.02	-0.11	-0.04	-0.04	-0.12	-0.04
	Std. Dev.	3.76	3.84	3.76	3.76	3.84	3.80
	Min	-12.00	-12.00	-12.00	-12.00	-12.00	-12.00
	Max	14.00	14.00	13.50	13.50	12.50	11.00
	Skewness	-0.09	-0.07	-0.12	-0.06	-0.02	-0.08
	Kurtosis	7.18	6.74	7.08	6.89	6.24	5.98

Note: This table reports summary statistics of the changes in yields of Australian Treasury bonds at maturity from 1 to 10 years at different window sizes (from 30 seconds to 60 minutes) after the RBA announcement of cash rate targets. The summary statistics include mean, standard deviation, minimum, maximum (measured in basis points), skewness, and kurtosis. The sample period is from January 1996 to December 2011.

5.2.2 Monetary policy data

To measure the effect of monetary policy announcements on the term structure of interest rates, we collect information on the timing of the monetary policy announcements. The RBA began announcing its monetary stance to the public in January 1990 at 9:30 a.m. Australian EST on the day at which the change took effect. Since December 1998, the bank routinely announces its cash rate at 9:30 a.m. on the day after the board meetings. A one-line, no-change statement was also released at 9:30 a.m. on that day when the decision was unchanged[16] (see Valadkhani & Anwar 2012; Dungey & Hayward 2000; Battellino, Broadbent, & Lowe 1997).

Following Kearns and Manners (2006), we utilize the 30-day bank bill rates to isolate the expected and unexpected components in cash rate target change. More specifically, we measure monetary surprises as changes in 30-day bank bill interest rates from the day prior to the announcement to the day of the announcement[17]. The expected component is then calculated as the difference between the actual change in the target cash rate and the surprise. In this chapter, we include all scheduled announcements in our sample. No-change announcements are also incorporated in other papers, such as Rigobon and Sack (2004), Kearns and Manners (2006), Lu, In, and Kou (2009), and Claus and Dungey (2012). We treat no-change announcements as zero changes of the cash rate, and the expected changes on the no-change announcement days are simply equal to the additive inverse of the anticipated changes (i.e., if the expected cash rate

[16] Beginning in February 2008, the RBA releases its decision at 2:30 p.m. on the day of the board meeting.

[17] Daily 30-day bank bill rates are the midpoint of the predominant bid and ask quotations in each market at the close of business; thus, the surprise components are the unexpected changes in cash rate targets at the close of business on the day before the announcements. The use of intra-day rates to measure the surprise part of cash rate target change before the announcements would be more accurate, but the number of 30-day bank bill trades per day is too small to apply this approach.

change was 25 basis points, the unexpected change would be -25 basis points on a no-change announcement day). Values and timing of the expected and unexpected components in the sample period can be found in Appendix 4.1.

5.3 Impact of changes in monetary policy on the term structure of interest rates

5.3.1 Impact of monetary policy changes on the term structure of Treasury bond yields

To measure how market interest rates respond to the RBA announcements with respect to changes in the cash rate target at different windows, we follow Kuttner (2001), who extends Cook and Hahn's (1989) regression equation and regresses the change in interest rates at different maturities on the expected and unexpected components of the cash rate changes.

$$r_{t+w}^{m} - r_{t}^{m} = \alpha_{mw} + \beta_{1mw}\Delta\tilde{r}_{t}^{e} + \beta_{2mw}\Delta\tilde{r}_{t}^{u} + \varepsilon_{tmw}, \tag{5.1}$$

where r_{t+w}^{m} denotes yield on Treasury bond with m years to maturity (m varies from 1 to 10 years) at w minutes after the announcement of the cash rate target (w varies from 30 seconds (0.5 minutes) to 60 minutes); r_{t}^{m} is the yield at 15 minutes before the announcement. Since investors in the market may or may not know of the change at the exact time of the announcement, we select the yields at 15 minutes before the RBA announcements to avoid any impact of the announcement on the market participants; $\Delta\tilde{r}_{t}^{e}$, $\Delta\tilde{r}_{t}^{u}$ are the expected and surprise components of monetary policy changes, respectively[18].

[18] The residuals test will display heteroscedasticity (ARCH/GARCH effects) and non-normality just by virtue of the fact that high frequency interest rate data is being used in the analysis. The usual caveat

Table 5.3 reports the effect of the expected and surprise components of monetary policy changes on Treasury bonds at different windows. As expected, bond yields respond differently to expected and surprise components of monetary policy. The response to the anticipated part is small and insignificant, while the response to the surprise part is large and highly significant[19]. Although monetary surprises have a strong effect on Treasury bonds at all maturities, the size of the effect decreases with maturity. At the 30-minute window, the responses to a 1-percentage-point increase in the cash rate surprise are 20.83 basis points for 1-year bond yields, 27.95 basis points for 2-year bond yields, 20.24 basis points for 5-year bond yields, and 11.80 basis points for 10-year bond yields. The effect of policy surprises decreases as maturity increases at windows of 30 seconds to 5 minutes. However, at longer windows (10, 30, and 60 minutes), the response of the 2-year yield is somewhat stronger than the response in the 1-year yield. Apart from this, the effect decreases with maturity here as well. These results are similar to the findings of Lu, In, and Kou (2009), who investigate the high-frequency responses of Australian financial futures to the surprise component of the cash rate announcement.

would then apply, namely, that the results of statistical influence need to be interpreted with some caution.

[19] The coefficient on the unanticipated component is in the order of 10 to 20 times larger than the coefficient on the anticipated component in each case in Table 5.3. Given this huge difference in the point estimates and the fact that they are precisely estimated (shown by the high t-statistics), a test of the hypothesis that the unanticipated and anticipated components are equal will be emphatically rejected. Thus, the data supports asymmetry.

Table 5.3: Impact of a 1% point change in monetary policy on interest rates

This table reports the results of regressions of the formula

$$r^m_{t+w} - r^m_t = \alpha_{m,w} + \beta_{1,m,w}\Delta\tilde{r}^e_t + \beta_{2,m,w}\Delta\tilde{r}^u_t + \varepsilon_{t,m,w},$$

where r^m_{t+w} denotes the yield on Treasury bond with m years to maturity at w minutes after the announcement of the cash rate, r^m_t is the yield at 15 minutes before the announcement, and $\Delta\tilde{r}^e_t$, $\Delta\tilde{r}^u_t$ are the expected and surprise components of monetary policy changes, respectively.

		30-sec	1-min	5-min	10-min	30-min	60-min
1-year	Anticipated ($\beta_{1,1,w}$)	1.712	3.566	1.278	1.355	2.341	1.047
		(2.475)	(2.496)	(2.483)	(2.444)	(2.557)	(2.537)
	Unanticipated ($\beta_{2,1,w}$)	20.850*	20.286*	20.868*	21.345*	20.825*	22.683*
		(4.132)	(4.167)	(4.144)	(4.080)	(4.268)	(4.234)
	$F_{(\beta_{1,1,w}=\beta_{2,1,w}=0)}$	14.521	15.247	14.138	15.296	14.070	15.757
2-year	Anticipated ($\beta_{1,2,w}$)	1.826	3.974	1.910	0.720	0.899	0.475
		(2.162)	(2.193)	(2.189)	(2.392)	(2.496)	(2.464)
	Unanticipated ($\beta_{2,2,w}$)	17.078*	16.313*	16.921*	28.534*	27.954*	28.396*
		(3.608)	(3.661)	(3.655)	(3.993)	(4.166)	(4.114)
	$F_{(\beta_{1,2,w}=\beta_{2,2,w}=0)}$	13.153	14.143	12.678	27.496	24.390	25.469
5-year	Anticipated ($\beta_{1,5,w}$)	1.405	3.155	1.171	-0.087	-0.282	0.008
		(2.001)	(2.002)	(2.062)	(2.187)	(2.254)	(2.250)
	Unanticipated ($\beta_{2,5,w}$)	11.238*	10.782*	11.721*	21.042*	20.238*	20.305*
		(3.340)	(3.342)	(3.442)	(3.651)	(3.763)	(3.755)
	$F_{(\beta_{1,5,w}=\beta_{2,5,w}=0)}$	6.798	8.022	6.749	17.468	15.101	15.423
10-year	Anticipated ($\beta_{1,10,w}$)	-0.020	1.249	-0.118	-0.273	0.281	0.663
		(1.802)	(1.831)	(1.799)	(1.788)	(1.859)	(1.837)
	Unanticipated ($\beta_{2,10,w}$)	12.232*	11.801*	12.031*	11.753*	11.799*	11.480*
		(3.008)	(3.057)	(3.004)	(2.985)	(3.103)	(3.067)
	$F_{(\beta_{1,10,w}=\beta_{2,10,w}=0)}$	8.711	8.739	8.401	8.044	7.777	7.781

Note: Standard errors in parentheses

* is significant at the 5% level.

F represents the test statistics under the null hypothesis $H_0 : \beta_{1,m,w} = \beta_{2,m,w} = 0$.

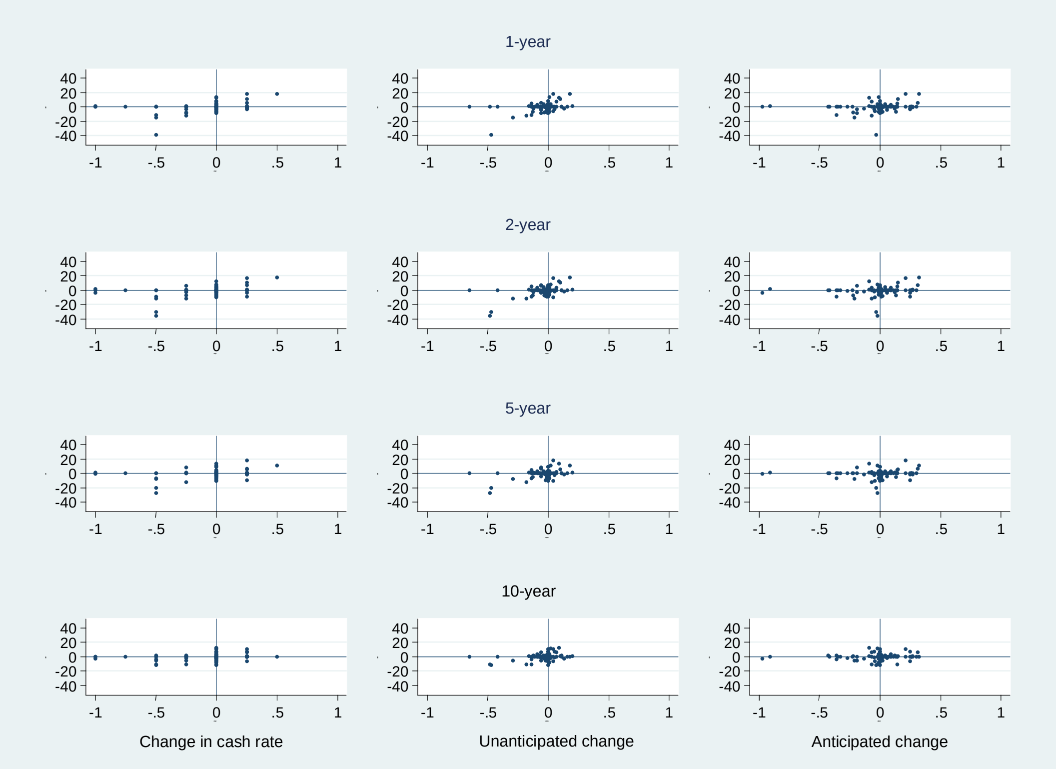
Estimates of constant terms are omitted.

This table reports the reaction of Treasury bond yields at different maturities to expected and unexpected changes in the cash rate. Cash rate changes are measured in percentages, and the change in market interest rates is measured in basis points. The sample period is from November 1996 to December 2011.

Table 5.3 also shows that the yields on Treasury bonds are quick to respond to the announcements of monetary policy; the unanticipated coefficients at the 30-minute window are similar to those at the 60-minute window. We also investigate the results from the sample, which includes only days on which the RBA changes its cash rate target (i.e., we exclude announcement days of no cash rate target change) as a robustness check. Results from this smaller sample presented in Appendix 5.2 produce similar results, which confirm the validity of the model.

In addition, the scatter plots in Figure 5.2 reveal that cash rate target change and anticipated component have little or no relation to changes in Treasury bond yields (the average correlation coefficients between changes in yields within 30 minutes after the announcement and the actual and anticipated cash rate target changes are 0.29 and 0.12, respectively, which are close to zero). In contrast, changes in Treasury bond yields line up with the unanticipated component of cash rate target change (the average correlation coefficients is 0.89, which is positive and quite large). Our results provide similar patterns when compared with other empirical works that use daily data such as Kuttner (2001), Poole and Rasche (2000), and Hamilton (2008).

Figure 5.2: Response of Australian Treasury bond yields to cash rate target changes



Note: This figure plots the relationship between changes in Treasury bond yields (measured in basis points) 30 minutes after the announcement and cash rate target changes (measured in percentages). Anticipated and unanticipated changes in the cash rate are measured by changes in the 30-day bank accepted bill rate (see text). The sample period is from November 1996 to December 2011.

5.3.2 Speed of the change in Treasury bonds after monetary policy announcement

To measure the speed with which Treasury bond yields adjust to the monetary policy surprise, we compare the change in Treasury bond yields within 30 minutes after the announcement with the change in yields from 30 to 60 minutes after the announcement.

Table 5.4: Speed of a 1% point change in monetary policy on interest rates

This table reports the results of regressions of the formulas

$$r_{t+30}^{m} - r_{t}^{m} = \alpha_m + \beta_{1,m}\Delta\tilde{r}_t^{e} + \beta_{2,m}\Delta\tilde{r}_t^{u} + \varepsilon_{t,m}$$

$$r_{t+60}^{m} - r_{t+30}^{m} = \alpha_m + \beta_{1,m}\Delta\tilde{r}_t^{e} + \beta_{2,m}\Delta\tilde{r}_t^{u} + \varepsilon_{t,m}$$

where r_{t+w}^{m} denotes the yield of the Treasury bond with m years to maturity at w minutes after the announcement of the cash rate, r_t^m is the yield at 15 minutes before the announcement (see text for details), and $\Delta\tilde{r}_t^{e}$, $\Delta\tilde{r}_t^{u}$ are the expected and surprise components of monetary policy changes, respectively.

		Interval 1 **9:30 – 10:00**	**Interval 2** **10:00 - 10:30**
1-year	Anticipated $(\beta_{1,1})$	2.156	-1.288*
		(2.556)	(0.622)
	Unanticipated $(\beta_{2,1})$	20.761*	1.799
		(4.267)	(1.037)
	$F_{(\beta_{1,1}=\beta_{2,1}=0)}$	13.849	2.988
2-year	Anticipated $(\beta_{1,2})$	1.107	-0.656
		(2.488)	(0.540)
	Unanticipated $(\beta_{2,2})$	27.775*	0.455
		(4.153)	(0.902)
	$F_{(\beta_{1,2}=\beta_{2,2}=0)}$	24.406	0.764
5-year	Anticipated $(\beta_{1,5})$	-0.320	0.115
		(2.238)	(0.341)
	Unanticipated $(\beta_{2,5})$	20.136*	0.134
		(3.736)	(0.570)
	$F_{(\beta_{1,5}=\beta_{2,5}=0)}$	15.142	0.109
10-year	Anticipated $(\beta_{1,10})$	0.193	-0.024
		(1.845)	(0.478)
	Unanticipated $(\beta_{2,10})$	11.865*	-0.422
		(3.079)	(0.797)
	$F_{(\beta_{1,10}=\beta_{2,10}=0)}$	7.934	0.156

Note: Standard errors are shown in parentheses.

* indicates significance at the 5% level.

F is the test statistics under the null hypothesis $H_0 : \beta_{1,m} = \beta_{2,m} = 0$.

This table reports the reaction speed of Treasury bond yields at different maturities to expected and unexpected changes in the cash rate. Cash rate changes are measured in percentages, and change in market interest rates is measured in basis points. The sample period is from November 1996 to December 2011.

Table 5.4 reports the reaction speed of market participants to a 1% change in the target cash rate. Estimates of surprise coefficients within the first 30 minutes are large and highly significant. Meanwhile, in the next 30 minute interval, the coefficients are small and insignificant, revealing that Treasury bond yields adjustments to the change in monetary policy have almost finished 30 minutes after the announcement.

5.4 Monetary policy announcement and the term structure of realized volatilities

Following the procedures of Barndorff-Nielsen and Shephard (2002) and Andersen, Bollerslev, and Diebold (2007), we define daily realized volatilities as the daily sum of 5-minute square returns (see Chapter 6 for a detailed explanation of the measurement of Australian Treasury bond return volatilities). Table 5.5 reports the effect of monetary policy announcements on the term structure of realized volatilities.

Evidence from Table 5.5 suggests that the realized volatility of Treasury bonds is higher on the monetary policy announcement days. For 1-year Treasury bonds, the average daily realized volatilities are 2.886 and 4.097 on normal days and on the monetary policy announcement day, respectively. This difference is significant at the 10% level for 1- and 2-year Treasury bonds. The variation of realized volatility, measured by the standard error, shows the realized volatilities for the normal days are considerably less dispersed than those for the announcement days.

Table 5.5: Changes in the term structure of realized volatilities of Treasury bond returns due to releases of monetary policy

YTM	Groups	Nob	Mean	Std. Err	[95% conf.	Interval]
1-year						
	Normal days (0)	1610	2.886	0.115	2.660	3.111
	Announcement days (1)	29	4.097	1.222	1.595	6.600
	Difference [(0)-(1)]		-1.212*	0.873	-2.924	0.500
2-year						
	Normal days (0)	1723	3.245	0.159	2.932	3.557
	Announcement days (1)	35	5.327	1.966	1.332	9.322
	Difference [(0)-(1)]		-2.083*	1.152	-4.343	0.178
5-year						
	Normal days (0)	1727	2.534	0.120	2.299	2.770
	Announcement days (1)	34	3.113	0.773	1.540	4.686
	Difference [(0)-(1)]		-0.579	0.863	-2.272	1.115
10-year						
	Normal days (0)	1855	1.909	0.090	1.733	2.085
	Announcement days (1)	39	2.105	0.695	0.698	3.511
	Difference [(0)-(1)]		-0.196	0.628	-1.427	1.036

Note: * denotes significance at the 10% level under H_0: Difference = 0 and H_1 Difference < 0

This table reports the effect of monetary policy announcements on the term structure of Australian Treasury bond return volatilities. Volatility is defined as the sum of 5-minute square returns. The sample period is from January 1996 to December 2011. Since we removed all inactive days from the sample for each Treasury bond, the number of observations of Treasury bonds at different maturities may not be equal (see Chapter 6 for details).

To further investigate the relationship between monetary policy announcements and Treasury bond return volatilities, we propose a model incorporating a dummy variable that represents the monetary policy announcement event in the Heterogeneous Autoregressive model of Realized Volatility (HAR-RV) developed by Corsi (2009), resulting in a new HAR-RV-A model:

$$RV_{t+1}^{m} = \beta_{0,m} + \beta_{D,m} RV_{t}^{m} + \beta_{W,m} RV_{W}^{m} + \beta_{M,m} RV_{M}^{m} + \beta_{A,m} D_{A} + \varepsilon_{t+1,m}, \quad (5.2)$$

where RV_{t+1}^{m} denotes the realized volatility of a Treasury bond of maturity m at day $t+1$; RV_{W}^{m} and RV_{M}^{m} are the weekly and monthly realized volatilities at time t, respectively. Weekly and monthly volatilities are the simple average of daily volatilities of the previous 5 and 22 days (including day t). D_A is a dummy variable that takes the value of one when there is a monetary policy announcement at day $t+1$ and is zero otherwise.

Table 5.6 reports the estimates of Australian Treasury bond return volatilities. Estimates of the HAR-RV in the first column show the model can explain the movement of the Australian Treasury bond return volatilities well, which is consistent with Corsi (2009), Andersen, Bollerslev, and Diebold (2007), and Corsi, Pirino, and Renò (2010). Estimates of the monetary policy announcement coefficients, which are presented in the second column, show the realized volatility of the 1-year Treasury bond is significantly increased when the RBA announces its cash rate target. On average, return volatility in monetary policy announcement days is 1.931 higher than on days without an announcement or other major news releases. However, at longer maturities, the coefficient on the announcement dummy becomes smaller and is statistically not significant. Thus, we are unable to observe any significant effect of monetary policy announcement on Treasury return volatilities. The smaller effect of monetary policy announcements on the Australian term structure of interest rates as maturity increases is also found in Chapter 4 and in Lu, In, and Kou (2009).

Table 5.6: HAR-RV and HAR-RV-A estimation

This table reports the results of regressions of the formulas

$$RV_{t+1}^{m} = \beta_{0,m} + \beta_{D,m} RV_{t}^{m} + \beta_{W,m} RV_{W}^{m} + \beta_{M,m} RV_{M}^{m} + \varepsilon_{t+1,m},$$

$$RV_{t+1}^{m} = \beta_{0,m} + \beta_{D,m} RV_{t}^{m} + \beta_{W,m} RV_{W}^{m} + \beta_{M,m} RV_{M}^{m} + \beta_{A,m} D_{A} + \varepsilon_{t+1,m},$$

where RV_{t+1}^{m} denotes the realized volatility of a Treasury bond of maturity m at day $t+1$, RV_{W}^{m} and RV_{M}^{m} are weekly and monthly realized volatilities, and D_A is a dummy variable that takes a value of 1 when there is a monetary policy announcement at day $t+1$ and is zero otherwise.

Bond	**Estimate of**	**HAR-RV**	**HAR-RV-A**
1-year	$\beta_{0,1}$	0.291*	0.254
		-0.131	-0.131
	$\beta_{D,1}$	0.124***	0.124***
		-0.035	-0.035
	$\beta_{W,1}$	0.072***	0.074***
		-0.013	-0.013
	$\beta_{M,1}$	0.019***	0.018***
		-0.003	-0.003
	$\beta_{A,1}$		1.931**
			-0.615
2-year	$\beta_{0,2}$	0.457**	0.433**
		-0.154	-0.155
	$\beta_{D,2}$	0.251***	0.254***
		-0.031	-0.031
	$\beta_{W,2}$	0.054***	0.054***
		-0.011	-0.011
	$\beta_{M,2}$	0.014***	0.014***
		-0.002	-0.002
	$\beta_{A,2}$		1.221
			-0.863
5-year	$\beta_{0,5}$	0.514***	0.496***
		-0.131	-0.131
	$\beta_{D,5}$	0.125***	0.126***
		-0.031	-0.031
	$\beta_{W,5}$	0.044***	0.045***
		-0.012	-0.012
	$\beta_{M,5}$	0.019***	0.019***
		-0.003	-0.003
	$\beta_{A,5}$		0.852
			-0.67
10-year	$\beta_{0,10}$	0.337***	0.323***
		-0.091	-0.091
	$\beta_{D,10}$	0.195***	0.195***
		-0.029	-0.029
	$\beta_{W,10}$	-0.001	0
		-0.012	-0.012
	$\beta_{M,10}$	0.027***	0.027***
		-0.003	-0.003
	$\beta_{A,10}$		0.668
			-0.479

Note: Standard errors are given in parentheses.

*, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively.

This table reports the OLS estimate of the realized volatility of returns on Australian Treasury bonds. The sample period is from November 1996 to December 2011.

5.5 Conclusion

This chapter investigates the effect of changes in monetary policy on Treasury bond yields and return volatilities using high-frequency tick data. By selecting narrow windows around the monetary policy announcement, we are able to isolate the impact of the announcement from other relevant news in the market. Our results show the RBA announcements have a significant impact on Treasury bond yields for all maturities and these impacts decrease with maturity. The adjustment of Treasury bond yields to the release of monetary policy announcement is almost finished within 30 minutes following the announcement. Furthermore, we extend the HAR-RV realized volatility model by incorporating a dummy variable for the monetary policy announcement. The augmented HAR-RV model reveals that the realized volatility of the 1-year Treasury bond is significantly increased when the RBA announces its cash rate target. The effect becomes progressively smaller as the term to maturity increases, and past one year, the effect is statistically insignificant.

This chapter confirms the results from the current literature using low-frequency data. In addition, our results support the liquidity preference hypothesis that argues that news in the market generates more volatility at the short end than it does for longer end maturities since speculators may prefer short-term maturities.

Appendix 5.1: Expected and unexpected changes in Treasury bond yields

		30-second	1-minute	5-minute	10-minute	30-minute	60-minute
1-year							
	Expected	25	26	25	27	29	32
	Unexpected	15	14	16	16	17	19
2-year							
	Expected	24	25	26	26	28	31
	Unexpected	17	15	15	17	18	22
5-year							
	Expected	24	25	26	26	28	31
	Unexpected	17	15	15	17	18	22
10-year							
	Expected	27	29	27	26	30	35
	Unexpected	19	17	20	19	23	20

Note: This table reports the number of expected and unexpected changes in yields after 30 seconds and 1, 5, 10, 30, and 60 minutes after the announcement of cash rate changes by the RBA. Market interest rates are expected to move in the same direction as the surprise component of cash rate target changes. The sample period is from December 1996 to November 2011.

Appendix 5.2: Impact of a 1% change in monetary policy on interest rates (the sample excludes no-change in target cash rate announcement days)

This table reports the results of regressions of the formula

$$r_{t+w}^{m} - r_{t}^{m} = \alpha_{m,w} + \beta_{1,m,w}\Delta\tilde{r}_{t}^{e} + \beta_{2,m,w}\Delta\tilde{r}_{t}^{u} + \varepsilon_{t,m,w},$$

where r_{t+w}^{m} denotes the yield of a Treasury bond with m years to maturity at w minutes after the announcement of the cash rate, r_{t}^{m} is the yield at 15 minutes before the announcement, and $\Delta\tilde{r}_{t}^{e}$, $\Delta\tilde{r}_{t}^{u}$ are the expected and surprise components of monetary policy changes, respectively.

		½	1	5	10	30	60
1-year	Anticipated $(\beta_{1,1,w})$	1.126	3.194	0.710	0.789	1.648	0.275
		(4.240)	(4.301)	(4.270)	(4.229)	(4.355)	(4.357)
	Unanticipated $(\beta_{2,1,w})$	23.078*	21.541*	23.176*	23.508*	22.745*	25.588*
		(7.588)	(7.696)	(7.641)	(7.568)	(7.793)	(7.797)
	$F_{(\beta_{1,1,w}=\beta_{2,1,w}=0)}$	5.405	5.315	5.252	5.528	5.140	6.004
2-year	Anticipated $(\beta_{1,2,w})$	1.531	3.868	1.653	-0.682	-0.646	-0.966
		(3.727)	(3.819)	(3.752)	(4.215)	(4.364)	(4.257)
	Unanticipated $(\beta_{2,2,w})$	18.552*	16.838*	18.300*	32.068*	31.986*	32.591*
		(6.669)	(6.835)	(6.714)	(7.542)	(7.809)	(7.618)
	$F_{(\beta_{1,2,w}=\beta_{2,2,w}=0)}$	4.738	4.744	4.600	9.744	9.052	9.787
5-year	Anticipated $(\beta_{1,5,w})$	1.035	3.047	0.969	-1.044	-1.443	-1.050
		(2.963)	(2.993)	(2.991)	(3.324)	(3.456)	(3.443)
	Unanticipated $(\beta_{2,5,w})$	12.835*	11.504*	12.697*	23.412*	23.720*	23.590*
		(5.303)	(5.355)	(5.351)	(5.949)	(6.185)	(6.162)
	$F_{(\beta_{1,5,w}=\beta_{2,5,w}=0)}$	3.577	3.845	3.416	8.172	7.661	7.734
10-year	Anticipated $(\beta_{1,10,w})$	0.550	1.943	0.421	0.176	0.557	1.158
		(2.080)	(2.131)	(2.093)	(2.077)	(2.122)	(2.214)
	Unanticipated $(\beta_{2,10,w})$	10.685*	9.621*	10.619*	10.626*	10.929*	10.393*
		(3.721)	(3.814)	(3.746)	(3.716)	(3.797)	(3.962)
	$F_{(\beta_{1,10,w}=\beta_{2,10,w}=0)}$	4.834	4.734	4.640	4.590	4.856	4.400

Note: Standard errors are given in parentheses.

* denotes significance at the 5% level.

F is the test statistics under the null hypothesis $H_0 : \beta_{1,m,w} = \beta_{2,m,w} = 0$.

This table reports the reaction of market interest rates on Treasury bonds at different maturities to the expected and unexpected changes in the cash rate target. The sample period is from November 1996 to December 2011 excluding no-change announcement days.

Chapter 6 : Monetary policy announcements and jumps in the term structure of Australian Treasury bond yields

6.1 Introduction

How the term structure of Treasury bond yields react to the announcement of monetary policy is of fundamental importance to monetary policymakers. It shows how well market participants anticipate the decision in addition to how they adjust their views about future monetary policy, output growth, and inflation.

The purpose of this chapter is to detect and characterize jumps in the Australian term structure of Treasury bond yields. We employ the method developed by Barndorff-Nielsen and Shephard (2004, 2006) and Andersen, Bollerslev, and Diebold (2007) to identify and measure jumps in Australian Treasury bond yields and then set out to investigate the effect of the RBA announcement on the occurrence of jumps across the term structure of Australian Treasury bond yields. The 'news' announcement literature suggests that the release of news in the market may be responsible for generating jumps in high-frequency bond price dynamics (see Andersen, Bollerslev, Diebold, & Vega 2007; Dungey, McKenzie, & Smith 2009; Piazzesi 2005; Andersson 2010). This chapter is related to that of Dungey, McKenzie, and Smith (2009), who find a significant effect of scheduled macroeconomic news announcements on the occurrence of jumps in the US term structure of Treasury bond yields. Andersson (2010) examines how monetary policy decisions in the US and Euro area affect bond and stock market volatilities and finds a strong increase in intraday volatility at the time of the release of the monetary policy decisions by the two central banks.

The chapter has a number of features. First, to the best of our knowledge, this is the first study to examine the effect of monetary policy announcements on jumps in the term structure of Treasury bond yields. Second, we use intraday data on trading of the Australian Treasury bonds through the Over-the-Counter (OTC) market which is different to current literature on jumps in the term structure of interest rates that, instead, employs data on intraday transactions prices traded on the official markets (see Andersen, Bollerslev, & Diebold 2007; Dungey, McKenzie, & Smith 2009; Andersson 2010).

This chapter reaches two main findings. First, the number of jumps in the yields on Treasury bonds strongly increases on the days when the RBA announces its cash rate target compared with days without any important news releases. This finding confirms the fact that the RBA's regular announcements have a significant impact on the prices of Treasury bonds and the policy changes are not well anticipated by market participants (see Chapters 4 and 5 and Lu, In, & Kou 2009). Second, we find that the effect of monetary policy announcements on jumps is particularly pronounced when market participants underestimate the new cash rate target. An asymmetric response to the announcements is also found in the study of Valadkhani and Anwar (2012), who argue that the cash rate increases have a larger and more instantaneous impact on the mortgage rate than rate cuts.

The remainder of this chapter is structured as follows. Section 6.2 provides a theoretical review of the realized volatility, the bi-power variation method, and the jump test that are employed in the empirical analysis. Section 6.3 introduces and summarizes the data. Section 6.4 reports the empirical application of the jump test to the Treasury bond yields and investigates the link between the monetary policy announcements and the occurrence of a jump. Finally, Section 6.5 concludes.

6.2 Identifying and measuring jumps in the term structure of Treasury bond yields

To identify and measure jumps in the Australian term structure of Treasury bond yields, we follow the bi-power variation method developed by Barndorff-Nielsen and Shephard (2004, 2006), Huang and Tauchen (2005), and Andersen et al. (2007a).

In this chapter, we sample the Australian Treasury bonds trading day into 5-minute intervals. Since the day session of Australian Treasury bonds is from 8:30 a.m. to 4:30 p.m., the number of 5-minute intervals in an 8-hour daily transaction period is 97. Without a loss of generality, we normalize the daily time interval to unity. The discretely sampled 5-minute returns at day t and order i of the intraday returns $(r_{t,i})$ is the difference between the natural logarithm of asset prices at times corresponding to order i and $i-1$ on day t. That is,

$$r_{t,i} \equiv p_{t,i} - p_{t,(i-1)} \tag{6.1}$$

where $p_{t,i}$ is the log price of the bond on day t at order i. The daily realized volatility of Treasury bond yields is the sum of the corresponding 96 high frequency intraday squared returns:

$$RV_{t+1} = \sum_{i=2}^{97} r_{t,i}^2 \tag{6.2}$$

Huang and Tauchen (2005) and Barndorff-Nielsen and Shephard (2006) propose the use of the staggered bi-power variation to separate the jumps as follows:

$$BV_{t+1} \equiv \mu_1^{-2}(1-2/97)^{-1}\sum_{i=3}^{97}\left|r_{t,i}\right|\left|r_{t,(i-2)}\right|, \tag{6.3}$$

where $\mu_1 = \sqrt{2/\pi} \equiv E(|Z|)$ is the mean of the absolute value of a standard, normally distributed random variable. The difference between the realized variance and bi-power variation provides a consistent estimate of the contribution to the variance due to jumps in the underlying price process. Furthermore, following Barndorff-Nielsen and Shephard (2004), we truncate the jumps at zero to avoid negative values.

$$J_{t+1} \equiv \max[RV_{t+1} - BV_{t+1}, 0], \tag{6.4}$$

In order to detect significant jumps, the test statistic for significant jumps component under the null hypothesis of no jump is defined as follows:

$$JS_{t+1} = 97^{1/2} \times \frac{[RV_{t+1} - BV_{t+1}]RV_{t+1}^{-1}}{\sqrt{\left(\mu_1^{-4} + 2\mu_1^{-2} - 5\right)\max\left\{1, TQ_{t+1}BV_{t+1}^{-2}\right\}}}. \tag{6.5}$$

where TQ_{t+1} denotes the staggered realized tri-power quarticity[20]

The test statistic in Equation (6.5) is corrected for the size distortion and the market microstructure noise component in the observed price process, and it follows a standard normal distribution. Finally, we identify the significant jumps by comparing the test statistic against some critical values: Φ_α which is the critical value of the standard normal distribution corresponding to the α level of significance.

6.3 Data

6.3.1 Interest rate data

In this chapter, we sample the data from Thomson Reuters Tick History provided by SIRCA beginning with the first available observation on 9 January 1996. The dataset

[20] $TQ_{1,t+1}\left(\frac{1}{97}\right) \equiv 97\mu_{4/3}^{-3}(1-\frac{4}{97})^{-1}\sum_{i=5}^{97}|r_{t,i}|^{4/3}|r_{t,(i-2)}|^{4/3}|r_{t,(i-4)}|^{4/3}$, where $\mu_{4/3} \equiv 2^{2/3} \cdot \Gamma(7/6) \cdot \Gamma(1/2)^{-1}$.

covers 1-, 2-, 5-, and 10-year Treasury bonds. The chain (RIC 0#AUTSY) provides all actual Treasury bonds intraday times, bid/ask prices, and bid/ask yields.

The Australian Treasury bonds are traded on the over-the-counter (OTC) market via phone between financial market participants, which are mostly banks, as well as fund managers, Commonwealth and State Governments and Central Borrowing Authorities, foreign Central Banks, OECD foreign government sponsored authorities and instrumentalities, and other counterparties (AFMA 2012). Theoretically, the OTC market is open 24 hours a day; however, trading typically occurs when the Australian 3- and 1-year Treasury bond futures market is open and is significantly more active during the day session rather than the night session. Hence, we define our Treasury bond trading day as starting at 8:30 a.m. and finishing at 4:30 p.m. (all time references refer to Australian Eastern Standard Time**)**. We divide each trading day into 5-minute intervals, giving 97 intervals per day. If there is no bid/ask yields at that exact time, the missing observation is filled with its last non-missing value. We measure the continuous returns as the difference between the average natural logarithm of prices at each consecutive sampling interval. Following Andersen, Bollerslev, and Diebold (2007), we remove all Australian national public holidays and days with 40 consecutive 5-minute intervals of no new bid/ask quotes. After removing all public holiday and inactive days, our sample contains 2,570 trading days, which equals 249,266 observations on prices and yields for each of the Treasury bonds. Figure 6.1 presents the average bid/ask yields for each maturity at the opening of the day session in the sample period.

Figure 6.1: Average bid/ask yields of Australian Treasury bonds by maturity from 1996-2012

Note: This figure shows yields (measured by average bid/ask yields and in percentages) at different maturities. These yields are recorded daily at 8:30 a.m. The sample period is from January 1996 to December 2012.

6.3.2 Monetary policy and macroeconomic data

In order to investigate the effect of monetary policy announcements on jumps in the term structure of Treasury bond yields, we employ information on the timing and expectation of the RBA's monetary policy announcements in Chapter 4. The surprise in monetary announcement is the difference between the actual cash rate change and the market expectation of the change. A positive (negative) surprise is defined as the market participants' underestimate (overestimate) of the change. Dungey, McKenzie, and Smith (2009), Faust et al. (2007), and Balduzzi, Elton, and Green (2001) find macroeconomic news releases have a significant impact on interest rate volatilities.

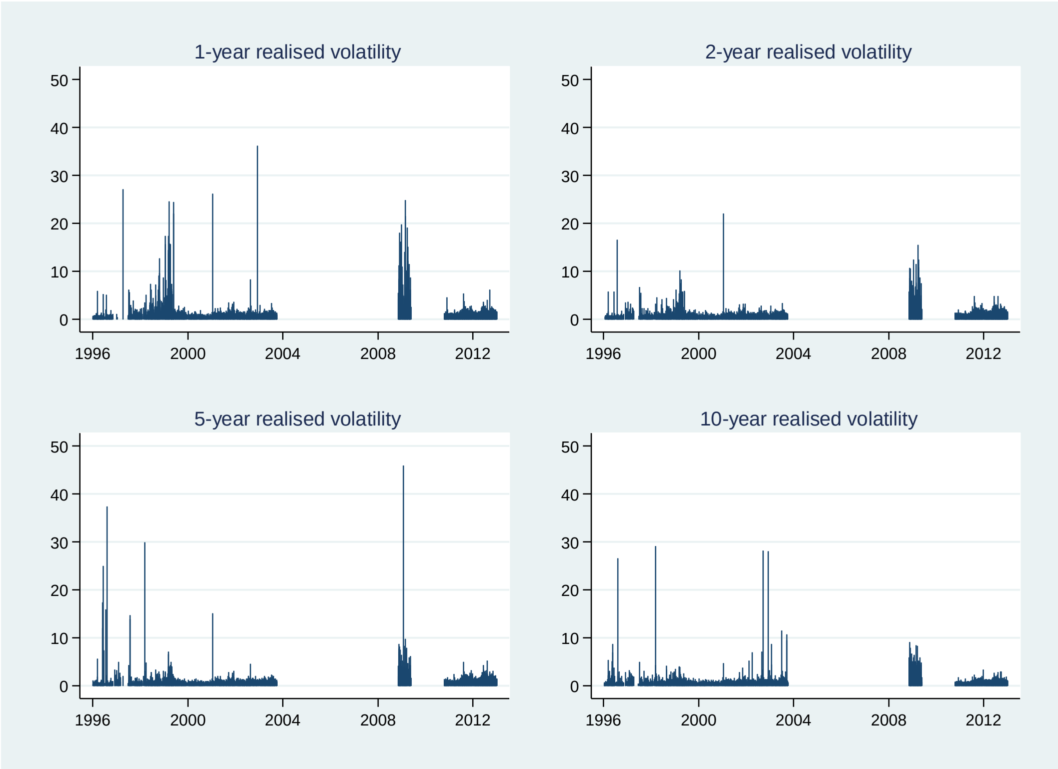
Thus, to mitigate the effect of macro news releases on the appearance of jumps, we omit those days with at least one of the most important macroeconomic releases in Australia: the Consumer Price Index (CPI), gross domestic product (GDP), unemployment rate (UE), and retail sales growth (RET). These macro indicators are chosen because the literature has found them to have a significant impact on the fixed income market (Kim 1999; Dungey, McKenzie, & Smith 2009; Simpson & Ramchander 2004; Ramchander, Simpson, & Chaudhry 2005). These indices are released by the Australian Bureau of Statistics (ABS) at 11:30 a.m.; the CPI and GDP are released quarterly, and the UE and RET are released monthly. The release date and time for each macroeconomic indicator are extracted from ABS media releases.

6.4 Empirical results

6.4.1 Jumps in the term structure of Australian Treasury bond yields

Figure 6.2 plots the daily realized volatility in standard deviation form ($RV_t^{1/2}$) of the Australian Treasury bond yields in the sample period. We remove two periods from our sample as there are almost no transactions on any day in the periods: from November 2003 to October 2008 and from May 2009 to October 2010. Casual observation of these plots suggests that return volatilities of Treasury bonds at different maturities follow a similar pattern. In addition, they exhibit a high degree of serial correlation with themselves, which is confirmed by the Ljung-Box statistics for up to a tenth-order serial correlation presented in Table 6.1 in the $RV_t^{1/2}$ column; the correlations are 1,010, 1,315, 130, and 144 for 1-, 2-, 5-, and 10-year bonds, respectively, and they are statistically significant at the 5% level.

Figure 6.2: Realized volatility of Australian Treasury bond yields



Note: This figure graphs the realized volatilities in standard deviation form, and the $RV^{1/2}$ of yields on Australian Treasury bonds. The sample period is from January 1996 to December 2012 and has been filtered to remove all Australian national public holidays and inactive days (see text for details).

Table 6.1 reports summary statistics for daily realized volatility and jumps of Australian Treasury bond yields. Comparing volatilities across the term structure, the 1-year Treasury bond is the most volatile, followed by 5-year and 2-year bonds. The results in Table 6.1 show the natural logarithm of the realized volatility series as having a distribution that is much closer to normal than the raw realized volatility, a finding that is consistent with Andersen et al. (2001), Deo, Hurvich, and Lu (2006), and Andersen, Bollerslev, and Diebold (2007). Alternatively, the jumps are of equal importance for bonds at different maturities, with the mean of the J_t series (see Equation (6.4)) accounting for 0.521, 0.496, 0.528, and 0.536 of the mean of RV_t for 1-, 2-, 5-, and 10-year Treasury bond markets, respectively (these proportions are J_t / RV_t from Table 6.1). These data illustrate one of the characteristics of the return volatility series of the Australian Treasury bonds that the jumps (J_t) and the continuous price movement component contribute equally to the volatility movement. These values are much higher than that of 0.126 in the US Treasury bond market from 1990-2002 (considered in Andersen, Bollerslev, & Diebold 2007).

Table 6.1: Summary statistics for daily realized volatilities and jumps

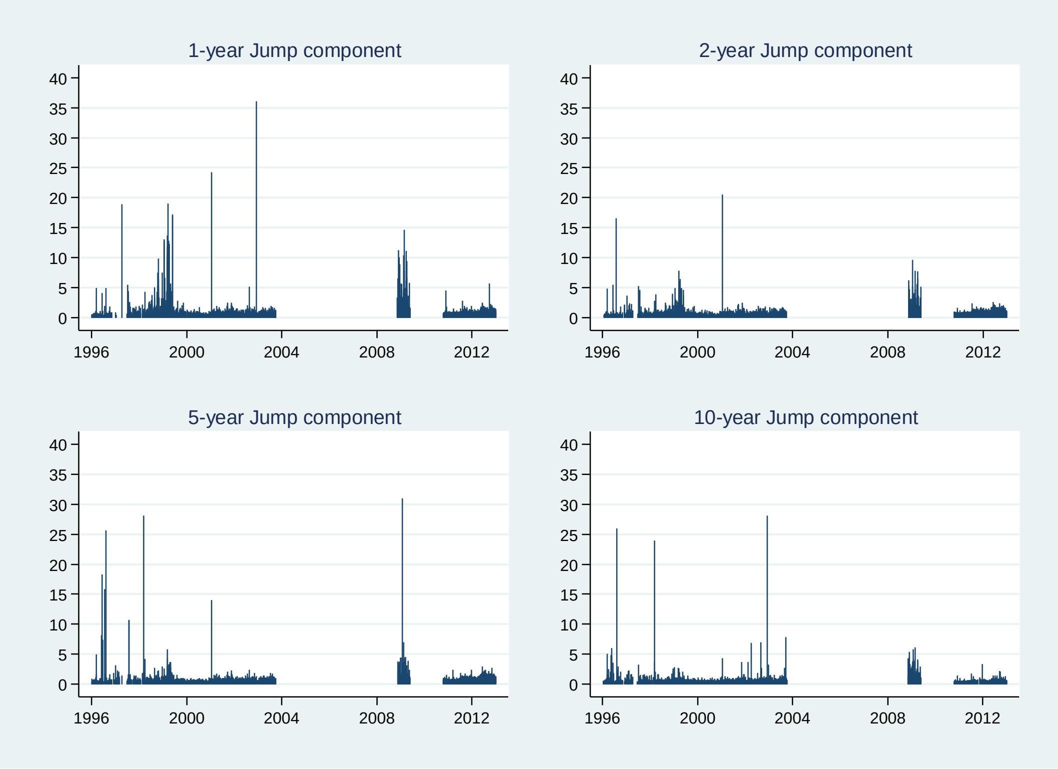
	RV_t	$RV_t^{1/2}$	$\log(RV_t)$	J_t	$J_t^{1/2}$	$\log(J_t+1)$
1-year bond						
Mean	11.004	1.936	0.632	5.738	1.377	0.870
Std. dev.	56.982	2.695	1.408	40.514	1.960	0.870
Skewness	12.347	5.586	1.233	22.168	7.521	2.915
Kurtosis	207.418	44.505	5.473	639.171	89.091	13.278
Min.	0.064	0.253	-2.747	0.000	0.000	0.000
Max.	1301.503	36.076	7.171	1301.212	36.072	7.172
LB_{10}	179.705*	1010.638*	1769.97*	40.412*	604.228*	1295.462*
Nob.	1,734	1,734	1,734	1,734	1,734	1,734
2-year bond						
Mean	4.571	1.541	0.407	2.266	1.088	0.722
Std. dev.	17.999	1.482	1.231	12.857	1.041	0.636
Skewness	15.440	4.984	0.800	24.660	7.651	2.766
Kurtosis	336.879	43.078	4.313	722.023	105.719	13.839
Min.	0.081	0.285	-2.512	0.000	0.000	0.000
Max.	483.549	21.990	6.181	417.521	20.433	6.037
LB_{10}	217.842*	1315.81*	1864.294*	15.484	537.976*	1189.341*
Nob.	1,784	1,784	1,784	1,784	1,784	1,784
5-year bond						
Mean	6.334	1.462	0.267	3.346	1.041	0.656
Std. dev.	66.464	2.049	1.211	35.463	1.505	0.625
Skewness	24.670	12.359	0.969	21.213	12.770	4.050
Kurtosis	686.926	214.401	6.120	494.283	209.183	29.389
Min.	0.023	0.151	-3.787	0.000	0.000	0.000
Max.	2105.814	45.889	7.652	954.993	30.903	6.863
LB_{10}	1.555	130.803*	1281.991*	2.263	48.629*	425.123*
Nob.	1,786	1,786	1,786	1,786	1,786	1,786
10-year bond						
Mean	4.061	1.251	0.018	2.175	0.823	0.479
Std. dev.	36.406	1.580	1.108	27.343	1.224	0.559
Skewness	20.687	11.172	1.330	24.739	14.877	4.579
Kurtosis	446.479	175.729	7.162	637.701	292.511	34.077
Min.	0.063	0.250	-2.772	0.000	0.000	0.000
Max.	846.583	29.096	6.741	785.879	28.034	6.668
LB_{10}	0.602	144.220*	950.863*	0.141	45.460*	378.842*
Nob.	1,922	1,922	1,922	1,922	1,922	1,922

Note: * indicates significance at the 5% level.

This table reports summary statistics of the realized volatility and jumps in the Australian term structure of Treasury bond yields at maturities from 1 to 10 years. The summary statistics include mean, standard deviation, skewness, kurtosis, minimum, maximum, Ljung-Box test statistic with up to 10 lags (LB_{10}), and the number of observations (Nob). Daily realized volatilities and jumps are based on 5-minute returns (see text for details). The sample period is from January 1996 to December 2012.

Figure 6.3 graphs the significant square root of jumps $(J_t^{1/2})$ for each of the maturities for 5-minute sampling intervals corresponding to $\alpha = 0.995$. The plot shows a high degree of coincidence of jumps across maturities, which is similar to Dungey, McKenzie, and Smith (2009), who report a high frequency of co-exceedances of jumps across the term structure of the US Treasury bond yields.

Figure 6.3: Significant jumps in the term structure of Australian Treasury bond yields



Note: This figure plots the significant square roots of jumps corresponding to $\alpha = 0.995$ or $J_{0.995}^{1/2}$ for the Australian term structure of Treasury bond yields. The jumps are detected using 5-minute returns. The sample period is from January 1996 to December 2012.

Table 6.2 reports a high frequency of jumps corresponding to α =0.995 for all Australian Treasury bonds. Jumps are found in the 1-year bond series on 1,462 days over 1,734 days and account for 84% of the time. A high percentage of jumps in Treasury bonds is also found in the literature (Dungey, McKenzie, & Smith 2009; Andersen, Bollerslev, & Diebold 2007). In addition, Table 6.2 shows evidence that jumps may exhibit daily seasonality. The percentage of jumps in the 10-year series on each day of the week is 84%, 74%, 76%, 73%, and 74% from Monday through Friday, respectively. Jumps are more likely occur on Mondays than on other days of the week for all maturities.

Table 6.2: Appearance of jumps by weekdays in the term structure of Treasury bond yields

		1-year	2-year	5-year	10-year
MON	No. of days	329	340	338	386
	No. of jump days	282	291	295	323
	Percentage of jump	(0.86)	(0.86)	(0.87)	(0.84)
TUE	No. of days	386	390	392	426
	No. of jump days	328	320	322	317
	Percentage of jump	(0.85)	(0.82)	(0.82)	(0.74)
WED	No. of days	341	354	354	383
	No. of jump days	287	286	289	290
	Percentage of jump	(0.84)	(0.81)	(0.82)	(0.76)
THU	No. of days	306	308	317	324
	No. of jump days	260	249	260	237
	Percentage of jump	(0.85)	(0.81)	(0.82)	(0.73)
FRI	No. of days	372	392	385	403
	No. of jump days	305	315	306	300
	Percentage of jump	(0.82)	(0.8)	(0.79)	(0.74)
TOTAL	No. of days	1734	1784	1786	1922
	No. of jump days	1462	1461	1472	1467
	Percentage of jump	(0.84)	(0.82)	(0.82)	(0.76)

Note: This table reports the appearances of jumps in the term structure of Australian Treasury bond yields. The data have been filtered to remove all Australian national public holidays, inactive days, and days with at least one of the macroeconomic news releases. Since inactive days, which are defined as those days with 40 consecutive 5-minute intervals of no new bid/ask quotes, are removed from the sample, the numbers of days are not the same among Treasury bonds. We select a significance level of 0.005 to limit the number of jumps. The sample period is from January 1996 to December 2012.

6.4.2 Jumps and monetary policy announcements

Table 6.3 summarizes the link between RBA announcements and the appearance of jumps in Treasury bonds (jumps are detected at the 0.005 level of significance). The proportion of jumps on the normal days are equal to those in Table 6.2 as the number of monetary policy announcement days accounts for a small proportion of days in the sample. The proportions of monetary policy announcement days with jumps are higher than those of normal days at all maturities; these differences range from 1% for 1-year bonds to 12% for 10-year bonds. In addition, Table 6.3 shows a number of jumps recorded in the days without major news releases (see the Normal days row). Dungey, McKenzie, and Smith (2009) explain that bond prices are influenced by the news events in the market as well as major macroeconomic announcements. The surprise component of news releases is more important than the announcement itself in determining the number of jump days (Lu, In, & Kou 2009; Dungey, McKenzie, & Smith 2009).

Similar to findings in Chapters 4 and 5, we classify the RBA announcements into positive, negative, and no surprise categories. Surprise in monetary policy announcements is described as positive (negative) when the market participants underestimate (overestimate) the change in the cash rate target. Positive surprises are most likely to coincide with jumps, and negative surprises are least likely. Percentages of jumps on positive surprise days are 93%, 88%, 88%, and 94% for 1, 2, 5, and 10-year bonds, respectively. Asymmetric responses of market interest rates due to RBA announcements of the cash rate target are also found in Chapters 4 and 5 and in Valadkhani and Anwar (2012), showing an asymmetric relationship between cash rate target and market interest rates. Specifically, the cash rate increases have larger, instantaneous impacts on the market rates than do cash rate cuts.

Table 6.3: Summary of RBA announcements and the occurrence of jumps

		1-year	2-year	5-year	10-year
Announcement	No. of days	40	44	42	48
	No. of jump days	34	37	36	42
	Percentage of jump	(0.85)	(0.84)	(0.86)	(0.88)
Positive surprise	No. of days	15	16	16	18
	No. of jump days	14	14	14	17
	Percentage of jump	(0.93)	(0.88)	(0.88)	(0.94)
Negative surprise	No. of days	18	21	19	21
	No. of jump days	14	17	15	17
	Percentage of jump	(0.78)	(0.81)	(0.79)	(0.81)
No surprise	No. of days	7	7	7	9
	No. of jump days	6	6	7	8
	Percentage of jump	(0.86)	(0.86)	(1.00)	(0.89)
Normal days	No. of days	1694	1740	1744	1874
	No. of jump days	1428	1424	1436	1425
	Percentage of jump	(0.84)	(0.82)	(0.82)	(0.76)

Note: This table summarizes the relationship between the RBA announcement and jumps in the term structure of Treasury bond yields. The data have been filtered to remove all Australian national public holidays, inactive days, and days with at least one of the macroeconomic news releases. We select the significance level of 0.005 to limit the number of jumps. The sample period is from January 1996 to December 2012.

Evidence in Table 6.3 shows jumps tend to occur in the term structure of Australian Treasury bond yields when the RBA announces its cash rate target change. To further investigate the link between the RBA announcement and the occurrence of jumps, we follow Dungey, McKenzie, and Smith (2009) to employ the random intercept logistic model to measure the impact of the RBA announcement on the probability of a jump as follows:

$$\text{logit}\left\{\Pr(j_{mt}=1)\right\} = \beta_0 + \sum_{k=1}^{4}\beta_k D_{kt} + \beta_5 D_{ANNt} + \zeta_i + \varepsilon_{mt} \qquad (6.6)$$

$$\text{logit}\left\{\Pr(j_{mt}=1)\right\} \equiv \ln\left\{\frac{\Pr(j_{mt}=1)}{1-\Pr(j_{mt}=1)}\right\} \qquad (6.7)$$

where $\Pr(j_{mt}=1)$ denotes the probability that a jump occurs for a Treasury bond with maturity i on trading day t; D_k $(k=1 \text{ to } 4)$ are dummy variables for weekdays Monday through Thursday; D_{ANNt} is a dummy variable that captures the release of the announcement to the market for day t; $\zeta_i \sim N(0,\psi)$ are Treasury bond-specific random intercepts that are assumed to be independent and identically distributed across the Treasury with a maturity m and independent of D_{kt} and D_{ANNt}; and ε_{mt} are the error terms that have a standard logistic distribution and are assumed to be independent of all explanatory variables. Equation (6.7) represents the logit link function for a binary response. The fraction in the parentheses is the expected number of successes per failure.

Dungey, McKenzie, and Smith (2009) argue that it is difficult to find the correct specification of the D_{ANNt} dummy. Following studies previously published in the literature, we utilize various proxies for the D_{ANNt} dummy as robustness checks. A dummy variable is generated that takes the value of unity on days with an announcement (including scheduled no-change announcements) and is zero otherwise $\left(D^1_{ANNt}\right)$. The surprise component of cash rate target change is associated with price discontinuities in Australian Treasury bond yields (see Chapters 4 and 5 and Lu, In, & Kou 2009). As a result, how market participants respond to monetary surprise is the main source of jumps in the yields on Treasury bonds. To identify this possibility, we generate one dummy variable that takes the value of unity when the monetary policy surprise is positive relative to the prior estimate and is zero otherwise (denoted by $\left(D^2_{ANNt}\right)$) and another dummy variable that takes the value of unity when the surprise is negative and is zero otherwise is denoted $\left(D^3_{ANNt}\right)$.

Table 6.4 presents exponential regression coefficients, which are interpreted as a conditional odds ratio. The first row corresponds to a model in which the news variable is specified as D^{1}_{ANNt}. The announcement dummy variable is higher than unity and significant, indicating that the announcement of the cash rate target change has a positive effect on the possibility of having jumps in the term structure of Treasury bond yields. Specifically, the odds of having jumps in the term structure of Australian Treasury bond yields on the day of the RBA announcements is 48.4% higher than it is on those days without any announcements or major macroeconomic news releases when controlling for the day of the week. The effect is more pronounced for positive surprise announcements for which the odds of having jumps are 143.8% higher than normal days. The coefficient of the negative surprise announcement variable, which is reported on the third line, is less than unity and insignificant, confirming the asymmetric response of market interest rates to RBA announcements of the cash rate target. A positive surprise announcement has a larger instantaneous impact on the market rates than a negative surprise announcement. The Monday dummy variable is higher than unity and significant in all models, showing a higher probability of observed jumps on Monday. The Monday effect is also found in other studies. For example, Dungey, McKenzie, and Smith (2009) report a higher possibility of jumps in the term structure of the US Treasury bond yields on Mondays during the 2002-2006 period.

The estimated variance of the random intercept ψ is 0.033, implying that there is a small variability in the propensity for the occurrence of a jump across the term structure of Treasury bond yields. The conditional intraclass correlation ρ represents the ratio of the variance of the random effect to the total variance, and it can be interpreted as the proportion of variance explained by clustering. The conditional intraclass correlation is 0.01, showing low dependence among the binary responses for the unobservable individual Treasury bond characteristics. Specifically, unobservable Treasury bond characteristics account for only 1% of the propensity to have a jump in a specific day.

Table 6.4: Impact of monetary policy announcements on jumps in the term structure of Treasury bond yields

This table reports the results of regressions of the formula

$$\text{logit}\left\{\Pr(j_{mt}=1)\right\} = \beta_0 + \sum_{k=1}^{4}\beta_k D_{kt} + \beta_5 D_{ANNt} + \zeta_m + \varepsilon_{mt}$$

where $\Pr(j_{mt}=1)$ denotes the probability that a jump occurs for a Treasury bond with a maturity m on trading day t, D_k, $(k=1 \text{ to } 4)$ are dummy variables for the days of the week, D_{ANNt} is a dummy variable that captures the release of the announcement to the market, $\zeta_m \sim N(0,\psi)$ are Treasury bond-specific random intercepts, and ε_{mt} are the error terms.

Fixed part					Random part		log likelihood	D_{ANNt} Specification
D_{ANNt}	D_{MON}	D_{TUE}	D_{WED}	D_{THU}	ψ	ρ		
1.484*	1.582*	1.104	1.066	1.073	0.033	0.01	-3471.662	1
(0.33)	(0.156)	(0.099)	(0.099)	(0.102)				
2.438*	1.582*	1.109	1.075	1.073	0.033	0.01	-3470.685	2
(1.054)	(0.156)	(0.099)	(0.099)	(0.102)				
0.949	1.582*	1.119	1.100	1.073	0.033	0.01	-3473.35	3
(0.27)	(0.156)	(0.1)	(0.101)	(0.102)				

Note: Standard errors are given in parentheses.

* denotes significance at the 5% level.

D_{ANNt} Specification = 1 (release of monetary policy announcement); = 2 (positive surprise in announcement); =3 (negative surprise in announcement)

This table reports the effect of monetary policy announcements on the occurrence of a jump in the term structure of Australian Treasury bond yields. The jumps in Treasury bond yields are based on five-minute returns. The sample period is from January 1996 to December 2012.

As a robustness check, we measure the impact of monetary policy announcements on jumps in the term structure of Treasury bond yields using the Generalized Estimating

Equations (GEE) method. The GEE method is based on the assumption that the expectation of occurring jumps follows a Bernoulli distribution so that Equation (6.7) is replaced with the following:

$$\Pr(j_{mt} = 1) \sim Bernoulli$$

Estimates using the GEE method are presented in Appendix 6.1. The size and significance of the coefficients of D_{ANNt} under the GEE methods are close to those reported in Table 6.4, confirming the robustness of our regression results. The other coefficients of the dummy variables are also similar, and the day of the week effects from Monday to Wednesday are statistically significant.

6.4.3 Speed of Treasury bond price adjustment to a monetary policy surprise

To investigate the effect of a monetary policy announcement on the term structure of Australian Treasury bond yield volatilities, we follow Balduzzi, Elton, and Green (2001) to regress the return at different time horizons around the release time on the size of the surprise component as follows:

$$r_{\tau mt} = \alpha_{\tau m} + \beta_{\tau m} S_t + e_{\tau mt}, \qquad (6.8)$$

where $r_{\tau mt}$ denotes the return from τ minutes after the announcement on a Treasury bond of maturity m at time t. S_t is the surprise component in the monetary policy announcement at time t (measured as a percentage). To assess the speed of response of Treasury bond returns to the monetary policy announcement, we select three different time horizons for Equation (6.8) from -15 (15 minutes before the release) to +10 (10 minutes after the announcement). The endpoint to calculate the return is kept constant at 30 minutes after the announcement. The 30-minute endpoint is selected as it is enough time for market prices to fully adjust to news surprises (Balduzzi, Elton, & Green 2001; Lu, In, & Kou 2009; Dungey, McKenzie, & Smith 2009).

Table 6.5 reports how quickly Treasury bond returns react to monetary policy surprises. The constant terms $\alpha_{\tau m}$ (not reported in the table) are all small and insignificant. At a -15 minutes time horizon (return from 15 minutes prior to 30 minutes after the release), the surprise coefficients are positive and significant, showing that the surprise component may generate an upsurge in bond returns. A one-percentage point surprise causes an 8.435%, 8.417%, 5.448%, and 2.723% increase in the return on Treasury bonds of 1-, 2-, 5-, and 10-year maturities, respectively. In addition, at a 5-minute horizon, the surprise coefficients are only significant on 2- and 5-year bonds, revealing that 1- and 10-years bond prices have already been fully adjusted to the news within 5 minutes of the releases. Finally, at a 10-minute horizon, all surprise coefficients are statistically insignificant, showing that all Treasury bonds prices are fully adjusted within 10 minutes of the announcement.

Table 6.5: Speed of adjustment to monetary policy surprises

This table reports the results of regressions of the formula

$$r_{\tau mt} = \alpha_{\tau m} + \beta_{\tau m} S_t + e_{\tau mt},$$

where $r_{\tau mt}$ denotes the return from τ minutes after the announcement on a Treasury bond of maturity m at time t and S_t is the surprise component in the monetary policy announcement at time t.

		Time horizons		
		-15	5	10
1-year	Surprise $(\beta_{\tau 1})$	8.435*	0.961	0.290
		(2.465)	(1.370)	(1.241)
	R-square	0.236	0.013	0.001
2-year	Surprise $(\beta_{\tau 2})$	8.417*	5.144*	-0.389
		(1.562)	(1.234)	(0.727)
	R-square	0.409	0.293	0.007
5-year	Surprise $(\beta_{\tau 5})$	5.448*	3.849*	-0.367
		(1.519)	(0.898)	(0.563)
	R-square	0.243	0.315	0.01
10-year	Surprise $(\beta_{\tau 10})$	2.723*	0.103	0.240
		(1.159)	(0.275)	(0.256)
	R-square	0.107	0.003	0.019

Note: Standard errors are shown in parentheses.
* denotes significance at the 5% level.
Constant terms are omitted.

6.5 Conclusion

This chapter sheds light on the link between RBA announcements of the cash rate target and the occurrence of jumps in the term structure of Australian Treasury bond yields. Using long-time intraday data in the OTC market of Australian Treasury bonds, we document the volatility pattern of the return on Treasury bonds on announcement days. We find the probabilities of having jumps on monetary policy announcement days are significantly higher than the probabilities for days without any major news releases at all maturities.

Specifically, we estimate the probability of jumps in the term structure of Australian Treasury bond yields in response to monetary policy announcements of the target cash rate. The logit with random effects model shows the odds of having jumps in the term structure of Australian Treasury bond yields is higher on the days of the RBA announcements and is more pronounced for the positive surprise announcements days.

Appendix 6.1: Impact of monetary policy announcements on jumps in the term structure of Treasury bond yields using the generalized estimating equations (GEE) method

This table reports the results of regressions of the formulas

$$\text{logit}\left\{\Pr(j_{mt} = 1)\right\} = \beta_0 + \sum_{k=1}^{4} \beta_k D_{kt} + \beta_5 D_{ANNt} + \varepsilon_{mt}$$

$$\Pr(j_{mt} = 1) \sim \textit{Bernoulli}$$

where $\Pr(j_{mt} = 1)$ denotes the probability that a jump occurs for a Treasury bond with maturity m on trading day t, D_k, $(k = 1 \text{ to } 4)$ are dummy variables for days of the week, D_{ANNt} is a dummy variable that captures the release of the announcement to the market, and ε_{it} are the error terms.

D_{ANNt}	D_{MON}	D_{TUE}	D_{WED}	D_{THU}	D_{ANNt} Specification
1.483*	1.58*	1.104*	1.066*	1.073	1
(0.289)	(0.114)	(0.062)	(0.038)	(0.071)	
2.439*	1.58*	1.108*	1.074*	1.073	2
(0.773)	(0.114)	(0.059)	(0.032)	(0.071)	
0.949	1.58*	1.119*	1.099*	1.073	3
(0.165)	(0.114)	(0.062)	(0.035)	(0.071)	

Note: Standard errors are given in parentheses.

* denotes significant at the 5% level.

D_{ANNt} Specification = 1 (release of monetary policy announcement); = 2 (positive surprise in announcement); =3 (negative surprise in announcement).

Chapter 7 : Conclusions

The main implications of this thesis are as follows:

Consistent with the existing literature, Chapter 2 found that the UIP condition did not hold even when we used a more sophisticated estimation method (GMM) to account for omitted variable bias. The results under GMM methods improved with the coefficient on the interest rate differential in the UIP regression and now had the correct (positive) sign. However, the evidence for UIP for the USD/AUD exchange rate remains weak as the joint hypothesis that the intercept is zero and the slope coefficient is one was rejected at the 1% level. An explanation for the failure of the UIP relation is that it considers only some information in the term structure of Australia and US yields, namely the difference in the two countries' interest rates (i.e., the relative level factor). There was no reference to the slopes (or curvatures) of the two countries' yield curves, which may contain valuable information for USD/AUD exchange rate prediction.

In Chapter 3, we investigated the information in the entire yield curves of Australia and the US, which are summarized by three factors: level, slope and curvature for explaining the fluctuation in the USD/AUD exchange rate. We found that the relative level factor had no predictive power for movements in the USD/AUD exchange rate. The level factor is similar to the interest rate differential; they both capture the same information. This result was not unexpected given our findings in Chapter 2. However, the relative slope and curvature factors did have predictive power for the USD/AUD exchange rate changes for the period up to the global financial crisis (GFC). This trend demonstrated the need to exploit all the information in relative yield curves in exchange rate forecasting and not just the information contained in interest rate differentials (i.e., relative level factor). However, when the sample was extended to include the GFC period, the predictive power of the relative slope and curvature factors broke down. This result was not surprising given the dramatic effects of the crisis on world economic activity and in particular on the conduct of monetary policy.

We then turned to an investigation of the effect of monetary policy announcements on the term structure of interest rates in Australia. Chapter 4 examined this issue using daily data. We found that the unexpected component of the monetary policy announcement (i.e., the change in the announced target cash rate that caught private agents by surprise or was unanticipated) had significant impacts on the entire Australian term structure of interest rates. These impacts became less pronounced as the term to maturity became longer.

A potential shortcoming of the analysis of Chapter 4 is that there may have been other economic news on the same day as the monetary policy announcement, which may have also influenced the term structure of yields and their volatility, thus contaminating our results to some extent. To account for this possibility, Chapter 5 investigated the effects of monetary policy announcements concerning the target cash rate on the Australian term structure of interest rates using intra-day data. This method allowed us to specify a narrow time interval (a window) around the time of the monetary policy announcement, thereby isolating the announcement from other economic news of the day. Consistent with the results in Chapter 4, we found that unanticipated changes in the announced target rate had a significant impact on the entire term structure of interest rates with the impact less pronounced as the term to maturity increased. We also discovered that the realized volatility on 1-year Treasury bond significantly increased on the days when the RBA announced its cash rate target. We concluded that private agents did not fully anticipate movements in the announced cash rate target and that the unanticipated or unexpected movement in the cash target rate had a significant impact on the term structure of interest rates and the volatility of yields.

In Chapter 6, we documented jumps in the term structure of interest rates and modeled the probability of having a jump on a given day. We controlled for a monetary policy announcement day by incorporating a dummy variable into the model. We found that the probability of having a jump in the term structure of interest rates on monetary policy announcement days was significantly higher than the probabilities on days without any major news releases at all maturities. Moreover, the probability was higher when there was a positive surprise (i.e., the announced target cash rate was higher than expected).

Overall, we had two major conclusions. First, exchange rate movements in the USD/AUD are difficult to predict, but the use of relative factors has had some success in prediction and is an improvement on relying solely on the UIP relation. Second, unanticipated movements in the target cash rate ripple through the entire term structure of interest rates. Unanticipated monetary policy has significant interest rate effects.

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