Nesting yield curve shifts and rotations in a model of monetary policy shocks[*]

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Abstract

In response to monetary policy shocks, the term structure generally shifts but sometimes rotates. This paper produces an empirically implementable model for nesting both responses. Estimates from data on the United States, Canada, Australia, and New Zealand, using latent factor models and identification through heteroskedasticity offer informational advantages over event studies. The results strongly support the hypothesis that differing term structure responses are reactions to different types of monetary policy shock, rather than differing reactions to the same policy shock. Model simulations produce results that closely resemble actual outcomes.

Keywords: Monetary policy, term structure, latent factor model.

JEL Classification: E44, E52, G12

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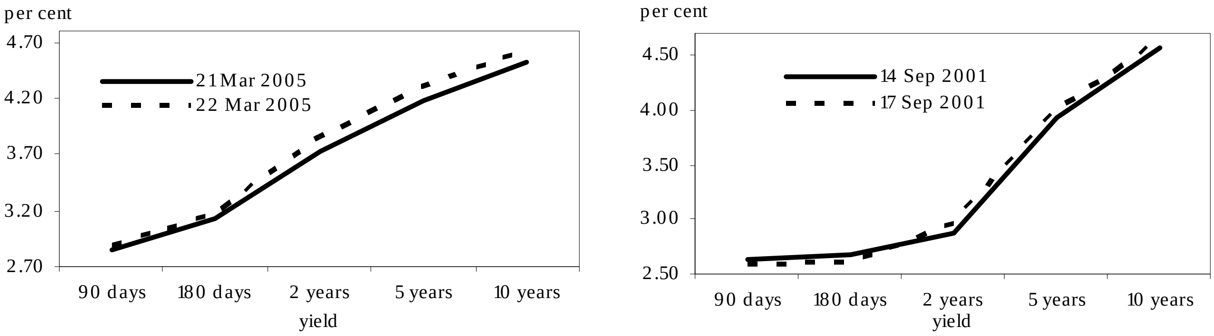
1 Motivation

Changes in monetary policy do not produce consistent effects on the yield curve. In most instances, in line with the expectations hypothesis of the term structure of interest rates, the yield curve shifts in response to a monetary policy change, as shown in Figure 1(a). In other instances the yield curve rotates following a change in monetary policy, when changes in inflationary expectations mean that decreased short term rates result in higher long term rates, as shown in Figure 1(b).[1]

Figure 1: Response of US yield curves to a change in monetary policy

(a) Before and after a 25 b.p. rise in the federal funds rate

(b) Before and after a 50 b.p fall in the federal funds rate



Despite this, the academic literature has so far focused on identifying at most two types of monetary policy move, anticipated and unanticipated moves. Such models allow for no more than two types of yield curve reaction: (i) no movement in the yield curve if the monetary policy move is fully anticipated by all market participants and (ii) either a shift or a rotation (but not both) determined by the data in response to an unanticipated monetary policy move, *i.e.*, a policy shock. The contribution of this paper is to allow for three types of move, anticipated monetary policy moves and two types of monetary policy shock, one type potentially causing a shift in the yield curve and the other potentially causing a rotation.

Motivations for monetary policy changes may not be homogenous. They may not only reflect economic developments but may also be a sign of changes in central bank preferences, objectives, or views about the structure of the economy; see Romer and Romer (1997). Ellingsen and Söderström (2001), for example, construct a theoretical model that produces shifts in the yield curve following monetary policy shocks in response to economic developments but yield curve rotations in response

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[1] All data used in this paper are sourced from the respective central bank websites. Market interest rates are assumed to be indicative of zero-coupon bond rates throughout.

to monetary policy shocks due to changes in central bank preferences. Romer and Romer (1989) identify six occasions between 1945 and 1989 when the US Federal Reserve (Fed) seems to have tightened policy not in response to real economic developments. Romer and Romer (2004) construct a new measure of monetary policy shocks for the United States by purging monetary policy changes from responses to economic developments (current and forecasts). They find that while the purged monetary policy shocks put downward pressure on inflation, those which were not purged displayed the common price puzzle effect. Rudebusch (2002) shows that estimated monetary policy rules in the United States between 1987 and 1999 are consistent with persistent special factors or shocks that cause the Fed to deviate from a Taylor type policy rule. Clarida, Galí and Gertler (2000) and Kim and Nelson (2006) also find differences in the conduct of monetary policy in the United States over the past thirty years or so.

Figures 2(a) to (d) provide an illustration that central bank preferences may not be static. Faced with similar (real time) information, four central banks, the Fed, the Bank of Canada (BoC), the Reserve Bank of Australia (RBA), and the Reserve Bank of New Zealand (RBNZ) do not always adjust monetary policy in a consistent manner. The four figures show the output and inflation gaps of the United Sates (Figure 2(a)), Canada (Figure 2(b)), Australia (Figure 2(c)), and New Zealand (Figure 2(d)) in quarters of changes in monetary policy.[2] A loosening is identified by a square and a tightening by a circle.[3] Observations in quadrant I (IV) indicate above (below) long run values for both inflation and output. In inflation targeting countries changes in policy in quadrant II (positive inflation gap and negative output gap) should mainly be tightenings. Similarly, changes in quadrant III (negative inflation gap and positive output gap) should mainly be loosenings in policy.

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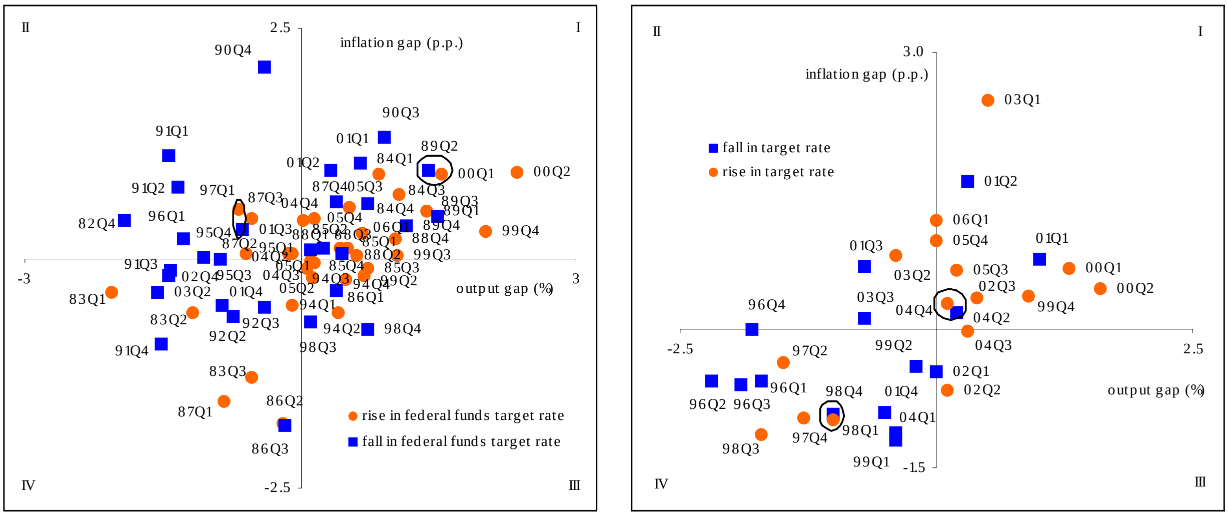
[2] The US output and inflation gaps were constructed applying an HP filter (smoothing parameter = 1,600) to real time CPI inflation and real output data published by the Federal Reserve Bank of Philadelphia. The Canadian output gap data are those published by the BoC. The Australian output gap was supplied by the RBA based on the methodology of Gruen, Robinson and Stone (2005) using real time data as described in Stone and Wardrop (2002). For New Zealand, the output gap was supplied by the RBNZ. Observations post 1997Q1 are RBNZ internal estimates of the output gap in real time. Observations prior to 1997Q1 are based on applying the filter that is currently used for output gap estimations to the real time data at each point in time; see Karagedikli and Plantier (2005) for a description of the method. For the inflation targeting periods, the inflation gap is the difference between actual CPI inflation and the mid point of the target range. The inflation target in New Zealand prior to 1993 are internal estimates supplied by the RBNZ.

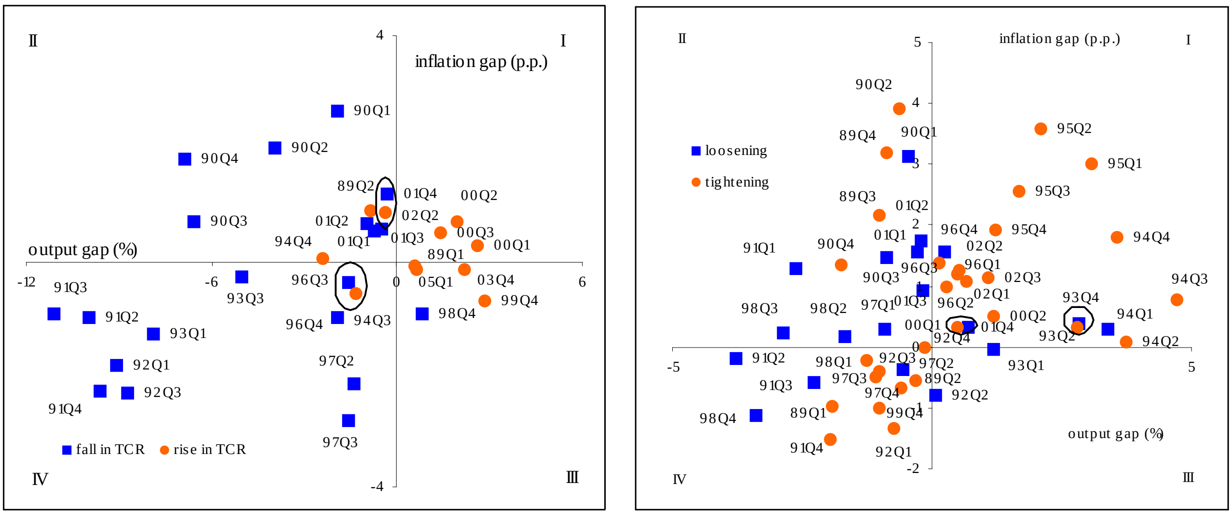
[3] For those quarters including more than one change in monetary policy the assignment was based on the majority of the moves. Canadian, New Zealand and US data all include quarters with an equal number of tightenings and loosenings in policy. In Canada 1998Q3 and in the United States 1989Q2 include an equal number of rises and falls in the central bank rates. For those quarters, the assignment was based on the relative magnitude of the changes. For the quarter as a whole, the target rate posted a rise of 75 basis points in Canada and an 18.75 basis points fall in the United States. Hence 1998Q3 was assigned a circle in Canada and a square in the US. In New Zealand, three quarters, 1996Q3, 1996Q4 and 1997Q4, contain an equal number of tightening and loosing statements, so judgement was applied, 1996Q4 was identified as a loosening, and the others as tightenings.

Figure 2: Monetary policy moves in three inflation targeting countries

(a) United States (b) Canada



(c) Australia (d) New Zealand



Although three of the four central banks are inflation targeting, the figures show that all have responded equally or more often to output gaps compared with inflation gaps. All four central banks have loosened (tightened) policy when the output gap was negative (positive) even though the inflation gap would have warranted the opposite policy action (quadrants II and III). Further, and even more interestingly for the present purpose, all four central banks have taken opposite policy actions when faced with similar inflation and output gaps. Examples of these instances are marked by circles in the figures. They are (97Q1;01Q3) and (89Q2;00Q1) for the United States, (98Q1;98Q4) and (04Q2;04Q4) for Canada, (94Q3;96Q3) and (01Q4;02Q2) for Australia, and (92Q4;01Q4) and (93Q2;93Q4) for New Zealand.

Perhaps the most surprising element of the figures is the departure from a Taylor-type rule by all central banks. This is particularly true for the United States, Canada, and New Zealand. All have tightened policy in periods of non-negligible negative inflation and output gaps (quadrant IV) and have loosened policy in times of non-negligible positive inflation and output gaps (quadrant I). The tightenings in the presence of negative inflation and output gaps in the late 1990s are likely to reflect actions by the central banks of Canada and New Zealand to halt or at least slow the depreciation of their domestic currencies.[4] Further, tightenings in New Zealand in the late 1980s and early 1990s likely reflect a more rapid decline in inflation than anticipated by the RBNZ following the introduction of inflation targeting. For Canada, the loosenings in policy in 2001 despite large positive gaps may reflect sustained higher levels of total CPI inflation compared to core CPI inflation, the BoC's operating target.

Figures 2 (a) to (d) only give a rough indication that monetary policy shocks may not all be the same. This means that actual policy shocks may cause varied reponses in the market yield curve. Modelling two types of policy shock is not easily implementable within the traditional empirical framework of event studies or VARs that are typically used to test asset price responses to monetary policy shocks in economics.[5] While pure monetary policy surprises may be separated from those in response to economic developments in these approaches, two types of pure shock cannot be easily identified.

The methodological innovations of this paper involve the use of latent factor models and identification through heteroskedasticity, building on recent work of Rigobon and Sack (2004) and Craine

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[4] Both countries relied on the monetary conditions index (MCI) – the weighted average of the 90-day bank bill rate and the exchange rate expresssed as a trade weighted index (TWI); the RBNZ explicitly and the BoC implicitly. This meant that in response to large depreciations in the wake of the Asian crisis both central banks increased interest rates.

[5] Prominent examples of the event study approach are Cook and Hahn (1989), Kuttner (2001), and Cochrane and Piazzesi (2002) while those of VARs are Sims (1992), Cushman and Zha (1997) and Bernanke and Mihov (1998).

and Martin (2007) who show that these models have an informational advantage over event studies. Applications of the model on daily data from the United States, Canada, Australia, and New Zealand produce strong results corroborating the existence of two alternative types of monetary policy shock which map directly into shift and rotation outcomes in the observed data. Simulations generated from the models strongly support the consistency of a model which is able to nest the two types of responses in the yield curve to monetary policy shocks.

The paper proceeds as follows. Section 2 outlines an empirically implementable specification for estimating the effects of changes in monetary policy on the yield curve. Section 3 discusses the data and Section 4 gives the estimation results. Section 5 offers some concluding remarks.

2 An Empirically Implementable Specification

The effects of monetary policy moves on the yield curve have been investigated via event studies such as Cook and Hahn (1989) and more recently Hardy (1998) and Thornton (1998, 2004). In event studies, infrequent monetary policy event days are extracted from the higher frequency yield curve observations. A weakness of this approach is that it does not generally distinguish between the expected and unexpected component of the policy changes and can therefore not be construed as a 'pure' policy shock. One means of focussing on the unanticipated nature of monetary policy shocks has been to represent them as the residuals from VAR models, for example Sims (1992), Edelberg and Marshall (1996), Bagliano and Favero (1998), Evans and Marshall (1998) and Peersman (2002), although this has been the subject of heated debate between Sims (1998) and Rudebusch (1998). Another alternative is to use futures data to account for unexpected changes in monetary policy; see, for example, Kuttner (2001), Faust, Swanson and Wright (2004), and Gürkaynak, Sack and Swanson (2005).

Romer and Romer (1989, 1994, and 2004) follow a narrative approach and examine historical Federal Reserve Board documents to isolate changes in US monetary policy that were in response to changed economic conditions from those that were in response to changes in the Fed's preferences. In spirit similar to Romer and Romer, but relying on more formal quantitative analysis, Owyang and Ramey (2004) build a regime switching model to separate US monetary policy changes in response to changed economic activity from those in response to changed central bank preferences.

There are several draw-backs in using any of the above methods to test for the presence of differing monetary policy shocks. VAR models incorporating economic variables are generally low frequency, while interest rate data typically respond to shocks expeditiously. It may be difficult to extract from quarterly or monthly data the reaction of interest rates to an event occurring on a specific day. The potential to apply the Romer and Romer (2004) or Owyang and Ramey (2004) method augmented with futures market data is limited outside the United States due to a lack of central bank documents and futures data. Further, an integrated model that identifies the shocks and estimates their effects on various market interest rate is preferable to a two step approach of first identifying the shocks and then estimating their effects on market interest rates.

Nesting both the identification and estimation of the impact of monetary policy shocks can be done in a latent factor framework. In the finance literature, returns are often modelled as a function of one or more latent factors. A model of the change in a given interest rate can be expressed as[6]

$$r_{j,t} = \gamma_j a_t + \delta_j d_{j,t}, \tag{1}$$

where $r_{j,t}$ is the demeaned first difference of the interest rate at maturity j at time t, a_t is a shock common to all maturities at time t, and $d_{j,t}$ represents the idiosyncratic shocks to $r_{j,t}$; see the key study of Cox, Ingersoll and Ross (1985). The parameters γ_j and δ_j are the factor loadings. The common shock a_t to all maturities may be, but does not necessarily represent, macroeconomic shocks; see Ramchander, Simpson and Chaudhry (2005). This simple factor model is often extended to include more than one common shock, as for example in Knez, Litterman and Scheinkman (1994) and Dai and Singleton (2000). Multiple factors are included to represent different movements in the yield curve, such as changes in the level, the slope or the curvature of the yield curve; Diebold, Rudebusch and Aruoba (2006) and Craine and Martin (2007).

Two curvature factors are added to equation (2), one which distinguishes the shorter end of the yield curve, and another which distinguishes the longer end. Augmenting equation (1) with these two additional common factors leads to

$$r_{j,t} = \gamma_j a_t + \kappa_j I_\kappa b_t + \tau_j I_\tau c_t + \delta_j d_{j,t}, \tag{2}$$

where b_t and c_t are common factors representing changes in curvature and

$$I_\kappa = \begin{cases} 1 & for \quad j < j^* \\ 0 & otherwise \end{cases}$$

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[6] As in many cases with interest rates, the data are found to be highly persistent and have near unit root properties. Thus the model is presented in terms of changes.

$$I_\tau = \begin{cases} 1 & for \quad j \geqslant j^* \\ 0 & otherwise \end{cases} .$$

The value of j^* represents the maturity at which the long and short ends are distinguished. Though j^* was chosen exogenously in the estimations below, the sensitivity of this choice was checked by varying the value of j^*.[7]

The process in equation (2) applies to the interest rates on all days. In addition to these four shocks, the yield curve is presumed to respond to changes in monetary policy so that additional factors apply on monetary policy days. The focus of this paper is to investigate the existence of two different types of monetary policy shock possibly causing different reactions in market yields, as shown in Figures 1(a) and 1(b). To allow for these potentially differing responses, all interest rates respond to two types of monetary policy shock that apply only on monetary policy days. Including two monetary policy shocks in equation (2) gives the final model,

$$r_{j,t} = \alpha_j m_t + \beta_j n_t + \gamma_j a_t + \kappa_j I_\kappa b_t + \tau_j I_\tau c_t + \delta_j d_{j,t}, \tag{3}$$

where m_t and n_t represent the two monetary policy shocks with factor loadings α_j and β_j which occur only on monetary policy days. These two sets of factor loadings are the parameters of interest here while all other factor loadings are nuisance parameters. By assumption all factors are independent and identically distributed with zero means and unit variances.

2.1 Identification

While initially equation (3) seems unidentified, there are identifying features. Monetary policy shocks (m_t and n_t) occur only on exogenously identified monetary policy days and can be separated from the common shock, a_t. The common shocks b_t and c_t can be separated from each other and from a_t because they do not all apply to the same maturities. To separate the two monetary policy shocks, a restriction is imposed such that the effect of a given size of monetary policy movement at the short end of the yield curve is the same in each type of shock so that $\alpha_1 = \beta_1$ where $r_{1,t}$ represents the short term interest rate which is most closely related to changes in the central bank rate. This identifying restriction is motivated by the fact that, barring exceptional circumstances, changes in the central bank rate are generally in the order of 25 basis points. The contentious issue of the effects of monetary policy shocks relates to the long end of the yield curve. General

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[7] The results from this sensitivity analysis are not presented here but are available from the authors.

agreement exists that short yields move in line with changes in the central bank rate irrespective of the response of long yields. Central banks typically implement monetary policy by influencing short term interest rates. $\alpha_1 = \beta_1$ translates into assuming that the central bank's influence over short term interest rates is stable over the sample period.

The practical separation of the shocks means that empirical identification can be achieved through the covariance matrix of the changes in interest rates across maturities. Using the independence assumption, on non monetary policy days, when $m_t = n_t = 0$, the covariance matrix, Ω_X of a system of k maturities with $2 < j^* < k$ for the curvature shocks, is given by

$$\Omega_X = \begin{bmatrix} \gamma_1^2 + \kappa_1^2 + \delta_1^2 & & & \\ \gamma_2\gamma_1 + \kappa_2\kappa_1 & \gamma_2^2 + \kappa_2^2 + \delta_2^2 & & \\ ... & ... & ... & \\ ... & ... & ... & \\ \gamma_k\gamma_1 + \tau_k\tau_1 & \gamma_k\gamma_2 + \tau_k\tau_2 & ... & \gamma_k^2 + \tau_k^2 + \delta_k^2 \end{bmatrix}. \tag{4}$$

On monetary policy days, when $m_t, n_t \neq 0$, the covariance matrix, Ω_M is given by

$$\Omega_M =$$

$$\begin{bmatrix} \alpha_1^2 + \beta_1^2 + \gamma_1^2 + \kappa_1^2 + \delta_1^2 & ... & ... \\ \alpha_2\alpha_1 + \beta_2\beta_1 + \gamma_2\gamma_1 + \kappa_2\kappa_1 & ... & ... \\ ... & ... & ... \\ \alpha_{k-1}\alpha_1 + \beta_{k-1}\beta_1 + \gamma_{k-1}\gamma_1 + \tau_{k-1}\tau_1 & ... & \alpha_{k-1}\alpha_k + \beta_{k-1}\beta_k + \gamma_{k-1}\gamma_k + \tau_{k-1}\tau_k \\ \alpha_k\alpha_1 + \beta_k\beta_1 + \gamma_k\gamma_1 + \tau_k\tau_1 & ... & \alpha_k^2 + \beta_k^2 + \gamma_k^2 + \tau_k^2 + \delta_k^2 \end{bmatrix}. \tag{5}$$

In line with the indentifying restriction that a given monetary policy shock has the same effect at the short end irrespective of the reaction of the long end of the yield curve, α_1^2 is set equal to β_1^2 in the estimations below.

The model is estimated using GMM techniques, based on the second moments as specified in equations (4) and (5). In the case of an overidentified model, which occurs when there are four or more interest rates, the Hansen (1982) method for combining the generated moment conditions with the number of parameter estimates is implemented, using a Newey-West weighting scheme to determine the truncation for the autocovariance matrix.

3 Data

The latent factor model is applied to daily interest rate data of the United States, Canada, Australia and New Zealand. The choice of these four countries was guided by a number factors. Most importantly, changes in monetary policy can be identified in all four countries. The United States is an obvious benchmark as the most important global bond market. Canada, Australia and New Zealand are a natural choice as these three are early adopters of inflation targeting and have therefore been experiencing a stable goal for monetary policy, a particular inflation rate that can be checked against a firmly established target and good histories of monetary policy announcements.

In the United States changes in the federal funds rates since January 1971 are available from the Board of Governors of the Federal Reserve System website. New Zealand was the first country to implement a specific inflation target for monetary policy, announced in 1989 and Canada was the second in 1991. Australia followed a few years later, with the formal announcement of inflation targeting occurring in 1993. In practice both Canada and Australia may have begun some years earlier (see Ragan (2005), de Brouwer and Gilbert (2003)). All three central banks are explicitly announcing and explaining changes in monetary policy, the RBA since 1990 and, formally the RBNZ since 1999. For Canada, a chronology of changes in monetary policy is publicly available from the BoC since 1935 while changes in policy have been explained by press releases since 1994 (see Lafrance (2000)).

United States

The sample period for the United States is 28 September 1982 to 5 April 2006 and policy changes are identified by changes in the federal funds rate.[8] In those 24 years, the Fed adjusted policy 141 times, reflecting 71 increases and 70 decreases in the federal funds rate. Policy is decided by the Federal Open Market Committee (FOMC) and since February 1994 policy actions are announced on the day of the FOMC meeting. The FOMC meets on eight scheduled days during the year and holds other meetings as needed such as those on 13 and 17 September 2001. The sample period contains 63 scheduled meeting days on which monetary policy remained unchanged and two unscheduled meetings days on which policy also remained unchanged.

Canada

The sample period for Canada is 22 February 1996 to 5 April 2006[9] and policy changes are

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[8] Thornton (2006) shows that the FOMC has been effectively targeting the federal funds rates since 1982. There is some controversy whether all changes in the federal funds rate represent changes in monetary policy. Romer and Romer (2004) show that the federal funds rate may vary for reasons other than changes in monetary policy. We acknowledge this but assume that these instances are few and should hence not bias the empirical results.

[9] Although the BoC website provides a chronology of changes in the bank rate since the founding of the BoC in 1935,

identified by changes in the target for the overnight rate. Over that 10 year period, monetary policy changed 50 times, reflecting 22 increases and 28 decreases in the target rate. Two changes in the bank rate are excluded as the target for the overnight rate did not change on those dates. These are 22 February 1996 and 16 October 1996 when the bank rate increased 9 and decreased 25 basis points while the target rate remained unchanged at 5.19 and 3.75 percent.

In November 2000, the BoC introduced eight fixed announcement days per year on which it communicates whether the target for the overnight rate is adjusted or remains unchanged. The target rate may however change in addition to these fixed dates as on 17 September 2001 when the BoC decreased the target rate 25 basis points in response to the terrorist attacks in the United States on 11 September 2001.

Australia

The sample period for Australia is 4 January 1989 and 5 April 2006. Policy changes from January 1990 are from RBA press releases. Prior to this data are available in Dungey and Hayward (2000) from 1985 to 1989. There is evidence of a shift in volatility of Australian interest rates in 1988, hence the investigation here begins in 1989. Since July 1997, the RBA has announced changes to the target cash rate (TCR) on the day following its 11 monthly Board meetings - on the first Tuesday of each month except January - so that all changes since then have occurred on the Wednesday mornings following the first Tuesday of the month.[10]

In total, there are 43 days on which monetary policy changed between 4 January 1989 and 5 April 2006. In those 17 years, the RBA decreased the TCR 27 times and increased the rate 16 times. In addition, there are 79 Wednesdays following the first Tuesday of the month since July 1997 on which the TCR did not change.

New Zealand

The sample period for New Zealand is 26 January 1989 and 5 April 2006. Starting from 17 March 1999, policy changes are identified by changes in the official cash rate (OCR). Prior to March 1999 the RBNZ operated more informally, implementing monetary policy through public announcements, so called open mouth operations. The dates for monetary policy changes prior to March 1997 are from the chronology of open mouth operations in Guthrie and Wright (2000) (covering January 1989 to September 1997) and Claus (2006) (September 1997 to March 1999).

Canada's central bank rate and its operation have experienced a number of changes over the past 70 years. The sample here covers the most recent means of operation since February 1996. The 22 February starting point is in line with the starting point of the current key interest rate period determined by the BoC; see *A history of the key interest rate* (http://www.bankofcanada.ca/en/policy/bankrate_history.html)

[10] The Dungey and Hayward date of 20 May 1989 was corrected to 19 May 1989. From February 2008 monetary policy announcements in Australia will occur on the Tuesday afternoon of the Board meetings.

Between 26 January 1989 and 5 April 2006, the RBNZ changed monetary policy 167 times. Policy was tightened 101 times and was loosened 66 times. With the 26 May 1998 *Monetary Policy Statement*, the RBNZ announced that, barring any exceptional circumstances, announcements or cash target changes would be made at 9.00 a.m. on Wednesdays and it would remain silent on these days if it was broadly satisfied with the way conditions had evolved. The sample period contains 31 Wednesday Morning Window (WMW) days on which policy remained unchanged. Between March 1999 and April 2006, the RBNZ issued 58 statements. In these 58 statements, the RBNZ announced 29 rate changes, 10 decreases and 19 increase in the OCR.[11]

Table 1 presents sample statistics for the four data sets. Columns 2, and 6 show the sample standard deviations of changes in US, Canadian, Australian, and New Zealand interest rates on days monetary policy changed. The same statistics for the days on which monetary policy did not change are presented in the remaining columns. These no change days can be devided into pre-determined policy announcement days on which no policy change occured (columns 4 and 8 in Table 1) and all other days (columns 5 and 9). Columns 3 and 7 give the statistics for the union of the two sets of no change days (the number of days in columns 4 and 5 and in 8 and 9 sum to those in columns 3 and 7). The standard deviations are normalized with respect to the 90-day rate on monetary policy days.

All interest rate changes are demeaned and are daily observations at annual rates measured in basis points. The US, Canadian, and Australian rates are 90-day and 180-day bank bill / t-bill rates and 2-year, 5-year and 10-year (Commonwealth) Treasury / Government of Canada bond rates. The New Zealand rates are 90-day bank bill rates and 1-year, 2-year, 5-year and 10-year Government bond rates. The 100 basis point tightening on 27 August 1998 in Canada is excluded as an outlier reducing the number of monetary policy days in Canada to 49. Further, the period around the 19 October 1987 stock market crash is excluded from the US sample.[12]

An important data issue in examining the monetary policy suprises is whether to include pre-determined announcement days on which no change occurs, on the basis that the lack of change may have been a surprise. Table 1 strongly suggests that pre-determined announcement days with no change (columns 4 and 8) more closely resemble all other days (columns 5 and 9) than days of monetary policy change (columns 2 and 6). This is true across the maturity structure. The pre-determined announcement days with no change are consequently considered to generally not

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[11] The complete chronology of changes in monetary policy in New Zealand between 1989 and 2006 is available from the authors.

[12] The excluded dates are 12 to 20 October 1987.

be consistent with monetary policy surprise days and are here classified as no change days, with the sample statistics shown in columns 3 and 7.

Table 1: Normalized sample standard deviations

Bill/ bond rate	Change	No change			Change	No change		
		announce + no announce	announce	no announce		announce + no announce	announce	no announce
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	United States				Canada			
90-day	1	0.602	0.769	0.599	1	0.303	0.372	0.302
180-day	1.107	0.623	0.698	0.622	0.892	0.381	0.443	0.381
2-year	1.128	0.668	0.853	0.666	0.785	0.586	0.490	0.586
5-year	1.101	0.680	0.715	0.679	0.725	0.528	0.504	0.528
10-year	0.973	0.648	0.524	0.650	0.489	0.468	0.417	0.468
Days	141	5989	65	5924	49	2591	17	2574
	Australia				New Zealand			
90-day	1	0.200	0.149	0.201	1	0.450	0.767	0.443
180-day	0.938	0.235	0.188	0.236	0.858			
1-year						0.417	0.477	0.416
2-year	0.777	0.371	0.290	0.341	0.690	0.396	0.477	0.394
5-year	0.551	0.340	0.298	0.372	0.513	0.355	0.347	0.355
10-year	0.442	0.342	0.281	0.343	0.441	0.345	0.333	0.345
Days	43	4458	79	4379	167	4318	64	4254

sample United States: 28 September 1982 to 5 April 2006
sample Canada : 22 February 1996 to 5 April 2006
sample Australia: 4 January 1989 to 5 April 2006
sample New Zealand: 26 January 1989 to 5 April 2006

The table shows that all interest rates experience greater variation on monetary policy change days compared to non policy days but the gap narrows with increasing maturity. An interesting point is that the variation on non-policy days rises with maturity in the United States, Canada, and Australia but falls with maturity in New Zealand. The different behavior of New Zealand interest rates may reflect the frequent changes in policy in New Zealand prior to the OCR period. Shortening the sample to post 1999 produces a rise in variation with rising maturity on non-policy days.

4 Empirical results

Tables 4 to 2 show the estimation results from applying the latent factor model in equation (3) to US, Canadian, Australian, and New Zealand data. The tables are divided into two panels. The upper panel of each table shows the baseline estimation for each country and the lower panel gives the results from imposing a rotation point at the 5-year bond rate for one of the two types of monetary policy shock. The factor loadings are normalized so that a 1 percent monetary policy shock causes a 1 percent change in the 90-day rate. The degrees of freedom for computing the p-value for each coefficient reported in the tables are based on the number of monetary policy days for the two types of monetary policy shock and on the number of all other days for the common, the curvature and the idiosyncratic factors. The models are estimated using the OPTMUM procedure in Gauss 6.0.[13]

The parameters of interest in assessing the presence of shifts and rotations are the estimates of α_j and β_j shown in columns 1 and 2 of Tables 2 to 5. In the United States, Canada, and Australia two different yield curve responses to monetary policy shocks are evident, one being a shift in the curve and the other a rotation. In each of the three countries the factor loadings for one of the monetary policy shocks all have the same sign $\alpha_j > 0, \forall\, j = 1, ...5$, while the factor loadings for the second monetary policy shock type switch signs. In all three cases the factor loadings are positive for lower maturities and negative for the 10-year rate, $\beta_j > 0,\ for\ j = 1, ...4$ and $\beta_5 < 0$. The New Zealand results, however, in Table 5 clearly identify two shocks both causing shifts in the yield curve, with $\alpha_j, \beta_j > 0, \forall\, j = 1, ...5$.

The results indicate that the yield curves in all four countries are fully explained by four factors, this is evident in the results by the zero factor loadings on the 90-day rate for the idiosyncratic factor in all four countries. Additionally, the loadings for the 5-year maturities idiosyncratic factors (δ_j) are found to be zero indicating that the 5-year rate may provide the benchmark behavior for the other maturities.

To further examine the results a rotation point is imposed in the second monetary policy shock by setting the factor loading on the 5-year maturity to zero, $\beta_4 = 0$ in each country. The 5-year rate was chosen because of its low level of significance in the unrestricted estimation. The results of the restricted estimations are shown in the bottom panel of each of the tables. In general the results shown in the bottom panel are little changed from the top panel, and the restriction is not rejected at the 10 per cent significance level in any case using the statistic 2 times the difference between

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[13] Preliminary investigation indicates similar results using the Maxlik procedure.

Table 2: Latent factor model parameter estimates for the United States

The results are those for equation (3). The table shows the normalized factor loadings and p-values are in parenthesis.

Bill/bond rate	**Monetary policy shocks**		**Non monetary policy shocks**			
			Common	**Curvature**		**Idiosyn.**
	$\boldsymbol{\alpha_j}$	$\boldsymbol{\beta_j}$	$\boldsymbol{\gamma_j}$	$\boldsymbol{\kappa_j}$	$\boldsymbol{\tau_j}$	$\boldsymbol{\delta_j}$
(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**
Baseline model						
90-day	1	1	0.574	0.827	0	0
	(0.000)	(0.000)	(0.000)	(0.000)		
180-day	1.101	0.979	0.824	0.405	0	-0.542
	(0.000)	(0.000)	(0.000)	(0.000)		(0.000)
2-year	0.927	0.702	1.035	0	0.360	-0.331
	(0.000)	(0.000)	(0.000)		(0.001)	(0.000)
5-year	1.028	0.270	0.974	0	0.700	0
	(0.000)	(0.115)	(0.000)		(0.000)	
10-year	0.921	-0.010	0.864	0	0.669	-0.369
	(0.000)	(0.481)	(0.000)		(0.000)	(0.000)
Value of objective function						30.233
Overidentifying restriction test p-value						0.000
Imposing a rotation point at the 5-year rate						
90-day	1	1	0.610	0.873	0	0
	(0.000)	(0.000)	(0.000)	(0.000)		
180-day	1.164	0.904	0.873	0.428	0	-0.572
	(0.000)	(0.000)	(0.000)	(0.000)		(0.000)
2-year	1.075	0.506	1.095	0	0.378	-0.349
	(0.000)	(0.000)	(0.000)		(0.001)	(0.000)
5-year	1.154	0	1.029	0	0.738	0
	(0.000)		(0.000)		(0.000)	
10-year	1.014	-0.272	0.912	0	0.705	-0.390
	(0.000)	(0.000)	(0.000)		(0.000)	(0.000)
Value of objective function						31.614
Overidentifying restriction test p-value						0.000

sample: 28 September 1982 to 5 April 2006

Table 3: Latent factor model parameter estimates for Canada

The results are those for equation (3). The table shows the normalized factor loadings and p-values are in parenthesis.

Bill/bond rate	**Monetary policy shocks**		**Non monetary policy shocks**			
			Common	**Curvature**		**Idiosyn.**
	$\boldsymbol{\alpha_j}$	$\boldsymbol{\beta_j}$	$\boldsymbol{\gamma_j}$	$\boldsymbol{\kappa_j}$	$\boldsymbol{\tau_j}$	$\boldsymbol{\delta_j}$
(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**
Baseline model						
90-day	1	1	0.243	-0.318	0	0
	(0.000)	(0.000)	(0.000)	(0.000)		
180-day	1.791	0.880	0.388	-0.185	0	-0.270
	(0.000)	(0.000)	(0.000)	(0.000)		(0.000)
2-year	0.499	0.772	0.699	0	-0.188	0.219
	(0.000)	(0.000)	(0.000)		(0.000)	(0.000)
5-year	0.408	0.210	0.588	0	-0.386	0
	(0.001)	(0.040)	(0.000)		(0.000)	
10-year	0.339	-0.178	0.453	0	-0.387	-0.189
	(0.001)	(0.091)	(0.000)		(0.000)	(0.000)
Value of objective function						19.5111
Overidentifying restriction test p-value						0.012
Imposing a rotation point at the 5-year rate						
90-day	1	1	0.265	0.347	0	0
	(0.000)	(0.000)	(0.000)	(0.000)		
180-day	0.773	0.826	0.423	0.203	0	0.296
	(0.000)	(0.000)	(0.000)	(0.000)		(0.000)
2-year	0.475	0.671	0.765	0	0.204	-0.240
	(0.002)	(0.000)	(0.000)		(0.001)	(0.000)
5-year	0.404	0	0.642	0	0.421	0
	(0.004)		(0.000)		(0.000)	
10-year	0.314	-0.383	0.494	0	0.422	0.206
	(0.011)	(0.000)	(0.000)		(0.000)	(0.000)
Value of objective function						22.234
Overidentifying restriction test p-value						0.008

sample: 22 February 1996 to 5 April 2006

Table 4: Latent factor model parameter estimates for Australia

The results are those for equation (3). The table shows the normalized factor loadings and p-values are in parenthesis.

Bill/bond rate	**Monetary policy shocks**		**Non monetary policy shocks**			
			Common	**Curvature**		**Idiosyn.**
	$\boldsymbol{\alpha_j}$	$\boldsymbol{\beta_j}$	$\boldsymbol{\gamma_j}$	$\boldsymbol{\kappa_j}$	$\boldsymbol{\tau_j}$	$\boldsymbol{\delta_j}$
(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**
Baseline model						
90-day	1	1	-0.168	-0.279	0	0
	(0.000)	(0.000)	(0.000)	(0.000)		
180-day	1.125	0.622	-0.236	-0.232	0	-0.198
	(0.000)	(0.000)	(0.000)	(0.000)		(0.000)
2-year	1.108	0.409	-0.531	0	0.135	0.103
	(0.000)	(0.009)	(0.000)		(0.004)	(0.009)
5-year	0.763	0.131	-0.486	0	0.290	0
	(0.000)	(0.177)	(0.000)		(0.000)	
10-year	0.433	-0.144	-0.406	0	0.348	0.182
	(0.002)	(0.156)	(0.000)		(0.000)	(0.000)
Value of objective function						17.287
Overidentifying restriction test p-value						0.027
Imposing a rotation point at the 5-year rate						
90-day	1	1	-0.155	-0.246	0	0
	(0.000)	(0.000)	(0.000)	(0.000)		
180-day	1.117	0.666	-0.217	-0.201	0	-0.175
	(0.000)	(0.000)	(0.000)	(0.000)		(0.000)
2-year	0.666	0.178	-0.460	0	-0.150	-0.115
	(0.000)	(0.002)	(0.000)		(0.001)	(0.000)
5-year	0.460	0	-0.422	0	-0.282	0
	(0.000)		(0.000)		(0.000)	
10-year	0.362	-0.094	-0.351	0	-0.314	0.178
	(0.000)	(0.037)	(0.000)		(0.000)	(0.000)
Value of objective function						18.072
Overidentifying restriction test p-value						0.034

sample: 4 January 1989 to 5 April 2006

Table 5: Latent factor model parameter estimates for New Zealand

The results are those for equation (3). The table shows the normalized factor loadings and p-values are in parenthesis.

Bill/bond rate	**Monetary policy shocks**		**Non monetary policy shocks**			
			Common	**Curvature**		**Idiosyn.**
	$\boldsymbol{\alpha_j}$	$\boldsymbol{\beta_j}$	$\boldsymbol{\gamma_j}$	$\boldsymbol{\kappa_j}$	$\boldsymbol{\tau_j}$	$\boldsymbol{\delta_j}$
(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**
Baseline model						
90-day	1	1	0.622	0.526	0	0
	(0.000)	(0.000)	(0.000)	(0.000)		
1-year	1.093	0.742	0.656	0	-0.073	-0.393
	(0.000)	(0.000)	(0.000)		(0.012)	(0.000)
2-year	0.872	0.539	0.561	0	-0.286	-0.366
	(0.000)	(0.000)	(0.000)		(0.000)	(0.000)
5-year	0.537	0.378	0.400	0	-0.516	0
	(0.000)	(0.004)	(0.000)		(0.000)	
10-year	0.268	0.386	0.326	0	-0.496	-0.229
	(0.003)	(0.001)	(0.000)		(0.000)	(0.000)
Value of objective function						10.395
Overidentifying restriction test p-value						0.238
Imposing a rotation point at the 5-year rate						
90-day	1	1	-0.538	-0.455	0	0
	(0.000)	(0.000)	(0.000)	(0.000)		
1-year	1.017	0.386	-0.573	0	0.061	0.318
	(0.000)	(0.000)	(0.000)		(0.016)	(0.000)
2-year	0.769	0.158	-0.488	0	0.246	-0.315
	(0.000)	(0.000)	(0.000)		(0.000)	(0.000)
5-year	0.477	0	-0.349	0	0.446	0
	(0.000)		(0.000)		(0.000)	
10-year	0.277	0.061	-0.286	0	0.429	0.200
	(0.001)	(0.002)	(0.000)		(0.000)	(0.000)
Value of objective function						12.045
Overidentifying restriction test p-value						0.211

sample: 26 January 1989 to 5 April 2006

the restricted and unrestricted objective functions distributed $\chi^2(1)$ in the United States, Canada, and New Zealand and at the 21 percent level in Australia. In the US, Canadian, and Australian cases the imposed rotation point leads to the coefficient on the 10-year rate, β_5, gaining statistical significance. In the Canadian and US cases the rotation becomes more pronounced than previously with a larger absolute coefficient on the 10-year rate. In the New Zealand case the rotation point forces the weight on the 10-year maturity down, but without resulting in a switch in sign.

Figures 3(a) to (h) are graphical representations of the estimation results. The figures show the actual yield curve on the calendar day prior to a change in monetary policy (the solid line in each figure), the yield curve predicted by the estimation results (the dashed line), and the actual yield curve on the end of day of the monetary policy change (the dotted line).[14] The predicted yield curves in Figures 3(a), (c), (e), and (g) are those of column 2 in the bottom panel of Tables 4 to 2. The predicted yield curves in Figures 3(b), (d), (f), and (h) are those of column 3 in the bottom panel of Tables 4 to 2. For the purpose of illustration the predicted yield curve abstracts from all shocks other than monetary policy shocks.

The actual and predicted yield curve responses are strikingly similar in the United States, Canada, and Australia for both types of monetary policy shock. The simulated shift is virtually the same compared with the actual yield curve response for Canada (Figure 3(c)) and for yields greater than 180-days in the case of Australia (Figure 3(e)). While the magnitude of the predicted response is larger than the actual response, their shapes are very close in the United States (Figure 3(a)). The remarkable feature of the simulated rotation in the yield curve is that although the model overpredicts the magnitude of the response at the short end, the predicted outcome closely aligns with the actual outcomes for the United States, Canada, and Australia at the long end of the yield curve (Figures 3(b), (d), and (f)).

The results for New Zealand are less encouraging as the simulated and actual yield curves display less similarity than those of the other three countries. It is not surprising that the results for New Zealand are somewhat different from the other three countries. This most likely represents the peculiarity of the implementation of policy during the end of the open mouth operations period. There are instances when policy changed frequently with inconsistent directions of change.[15] It would be useful to compare the open mouth operations period with that since the introduction of

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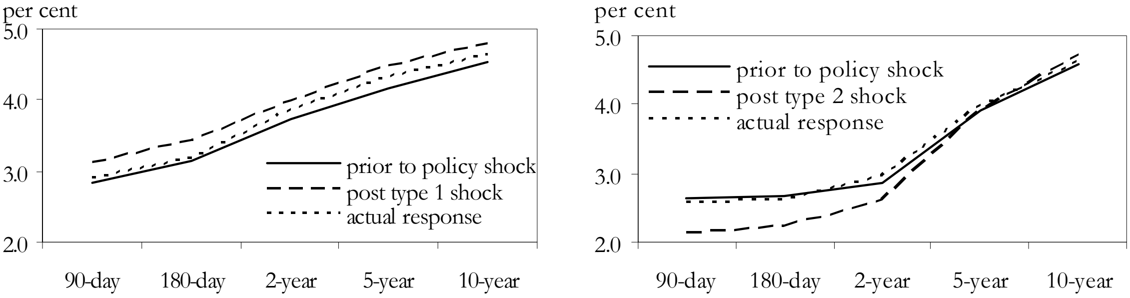
[14] For the purpose of illustration we conditioned on our prior knoweldge of the type of reaction in the data, that is a shift or rotation. We have no way of *a priori* establishing which type will occur in advance.

[15] An example of this frequent change in policy is the period December 1997 to March 1998 when monetary policy was tightened on 5 December 1997, loosened on 16 December, tightened on 23 February 1998, loosened on 18 March and tightened on 27 March.

Figure 3: Yield curve responses to monetary policy shocks

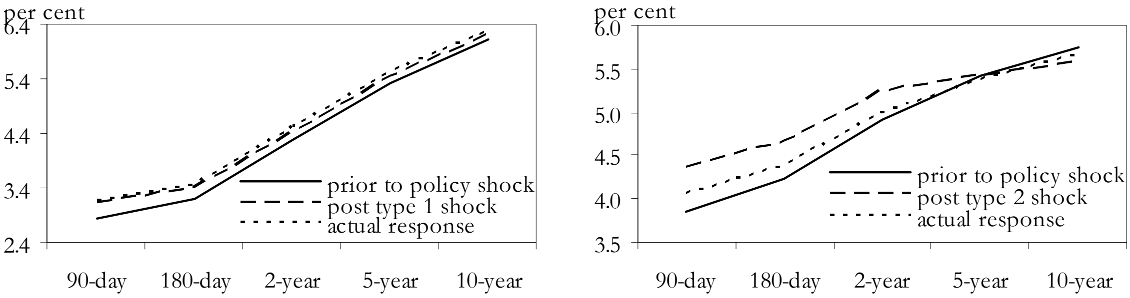
(a) United States
25 b.p. rise on 22 March 2005

(b) United States
50 b. p. fall on 17 Sep 2001



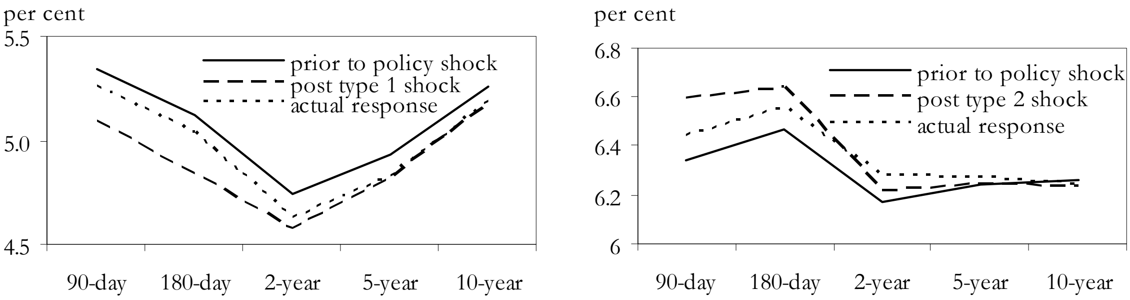
(c) Canada
25 b.p. rise on 26 June 1997

(d) Canada
50 b.p. rise on 12 December 1997



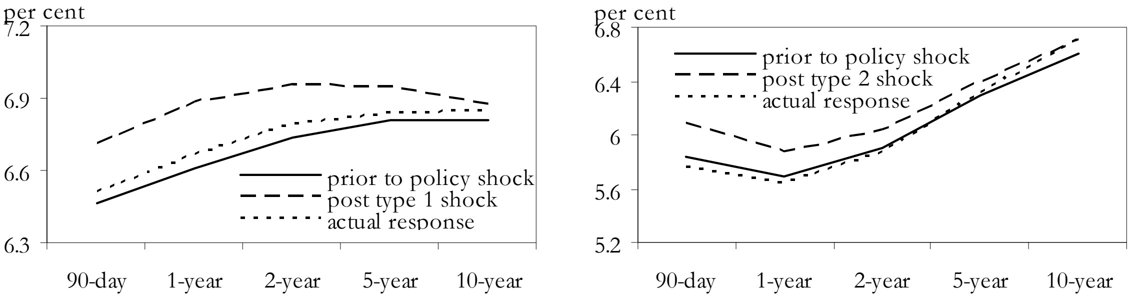
(e) Australia
25 b.p. fall on 7 March 2001

(f) Australia
25 b.p. rise on 2 August 2000



(g) New Zealand
25 b.p. rise on 19 April 2000

(h) New Zealand
25 b.p. rise on 16 May 2001



the OCR. This is subject to further investigation once the OCR period is long enough to allow for sensible estimation.

The finding of shifts and rotations is interesting against the background of inflation targeting. One may expect the presence of inflation targeting to have an impact on finding two types of reponse. Our results do not support this view but suggest that an inflation targeting framework provides scope for central banks to change policy in response to developments other than economic shocks and that central banks indeed make use of this opportunity. The Fed is not a formal inflation targeter and about a quarter of the Australian sample represents non inflation targeting years. However, inflation targeting was well established over the entire Canadian sample.

The 17 September 2001 50 b.p. rise in the federal funds rate shown in Figure 3(b) is particularly interesting in the context of this paper as it provides a natural experiment of the ideas developed here. The Fed kept the federal funds rate unchanged on its unscheduled meeting on 13 September 2001, but loosened policy after another unscheduled meeting on 17 September 2001. The loosening in policy on that day was not in response to economic developments but to 'supply unusually large volumes of liquidity to the financial markets, [...], until more normal market function is restored' (see Federal Reserve Press Release, September 17, 2001). Figure 3(h) not only shows a rotation in the actual yield curve following this move but it also shows a striking accuracy at the 10-year rate between the actual and the predicted rotation in the yield curve.

5 Concluding Remarks

This paper takes a closer look at the effects of changes in monetary policy on the yield curve based on the observation that the yield curve generally shifts but sometimes rotates in response to monetary policy shocks. The paper proposes a latent factor model to investigate if these different responses can be distinguished empirically. The empirical model is applied to US, Canadian, Australian, and New Zealand daily interest rates.

The latent factor model successfully nests the seemingly inconsistent responses of market interest rates to monetary policy shocks. Our estimations identify two types of response to unanticipated monetary policy changes, a shift and a rotation in the yield curve for the United States, Canada and Australia and two shifts for New Zealand. An inflation targeting regime does not seem to affect the presence of shifts and rotations in the yield curve in response to policy shocks. Simulations generated from the models produce yield curve responses that compare closely to actual outcomes. For example, the US model is able to reproduce the upward shift in the yield curve following the

22 March 2005 tightening in policy and is also able to reproduce the yield curve rotation following the loosening in policy on 17 September 2001 which was clearly a special case.

The empirical results have important implications. Observed yield curve responses are no longer inconsistent but reveal a regularity that can be extracted empirically. This means that it may be desirable to model monetary policy in a flexible way that allows for different types of monetary policy move.

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