Impacts of monetary policy shocks on inflation and output in New Zealand

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Abstract

We identify monetary policy shocks in New Zealand as one-day changes in the whole yield curve around monetary policy announcements. The impacts of these shocks on inflation and output are estimated using functional local projections. We find that the effects of monetary policy shocks are standard in the short run but might be different in the long run. Monetary policy shocks in a small open economy have similar effects as in a large economy, except that unconventional monetary policy announcements have limited impact on long-term interest rates. Accounting for forward guidance, used in New Zealand since 1997, is important.

1 Introduction

The identification of monetary policy shocks and their effects on output and inflation remain fundamental issues in macroeconomics. As small open economies have a number of differences compared to the well-studied large economies, monetary policy shocks might have different effects in these economies. We consider the case of New Zealand to provide new empirical evidence on the effects of monetary policy shocks on macroeconomic variables in a small open economy.

New Zealand provides an interesting example as it is a small open economy, and because the Reserve Bank of New Zealand (RBNZ) was the first central bank to publish interest rate projections as a tool for forward guidance of monetary policy, which it has done since 1997. The use of Forward Guidance means monetary policy operates on the whole yield curve, i.e. interest rates on government bonds at all maturities, so looking at just short-term rates would at best miss part of the picture, and at worst be

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biased and misleading. Existing studies of monetary policy shocks in small open economies in general, and New Zealand in particular, use changes in short-term rates. We apply the recently developed functional local projection method of Inoue and Rossi [2021], which allows us to define a monetary policy shock as a surprise change in the yield curve. Our measure of monetary policy shocks captures many shocks to the longer maturity end of the yield curve, illustrating the role played by Forward Guidance.

We find three important results. First, unconventional monetary policy announcements lead to smaller changes in long-term government yields in New Zealand compared to the U.S. Second, the RBNZ's monetary policy announcements result in more movements in the long end of the yield curve during conventional period. Third, we find that estimates based only on short-term rates - and so ignoring forward guidance - perform very poorly on many monetary policy announcement days with substantial forward guidance, and are even minorly biased on days where the only shocks are in short-term rates. These results are consistent with the facts that (i) New Zealand is a small open economy, and (ii) the RBNZ regularly provides forward guidance in conventional times.

How to understand these results? As New Zealand is a small open economy the RBNZ's unconventional monetary policy may have limited impact on long-term interest rates. There are several reasons for this. First, small open economies typically have limited financial markets in terms of market size and liquidity, which limits the monetary policy transmission to influence interest rates through open market operations or asset purchase programs. Second, small open economies are more exposed to external shocks, such as changes in global economic conditions, commodity prices, or geopolitical events, which can affect interest rates independently of their central banks' policy decisions. Third, global interest rate trends which are driven by major central banks like the Federal Reserve may also influence long-term interest rates in small open economies, regardless of their domestic monetary policy decisions. The government bonds of other small open economies, like Australia, may provide good substitutes.

Comparing our results with the results of Inoue and Rossi [2021], we suggest that the RBNZ's monetary policy in unconventional times has less impact on longer term interest rates compared to the Federal Reserve's. Our finding is consistent with Rios and Shamloo [2017] who study the effects of asset purchase programs in four countries including the United States, the United Kingdom, Sweden, and Switzerland. Rios and Shamloo [2017] find that monetary policy announcements lead to smaller changes in 10-year government yields in the three small open economies compared to the U.S.

Another important fact about New Zealand is the early implementation of forward guidance. Since the outbreak of the financial crisis, forward guidance has become an important instrument of unconventional monetary policy which aims at lowering longer term interest rates while leaving short-term rates unchanged. Forward guidance is defined as central banks' statements about the future path of interest rates. It has been used to guide interest rate expectations and provide extra monetary stimulus when the policy rate is restricted by the zero lower bound. Since 1997 the RBNZ has been publishing projections of the future 90-day rate to guide interest rate expectations up to three years in the future. The RBNZ can therefore be considered one of the first central banks to use forward guidance in a specific form. The RBNZ provides forward guidance on the path of future interest rates as a standard part of the Monetary Policy Statement issued with every monetary policy announcement. The use of forward guidance is thus present in both the conventional and unconventional periods.

The RBNZ's intensive use of forward guidance has important implications for the New Zealand economy. First, monetary policy shocks usually contain a nonnegligible unconventional part even in normal times. Looking at changes in the yield curve after every monetary policy announcement by the RBNZ during the conventional period, we notice more interest rate movements at long maturities which seems to be inconsistent with the theory that conventional monetary policy mainly affects short-term interest rates. However, forward guidance which refers to central bank public communication about the likely future path of interest rates is usually considered an unconventional monetary policy instrument and may affect interest rate expectations as well as long-term interest rates. Since the use of forward guidance is not limited to the unconventional period, every monetary policy announcement by the RBNZ in conventional times may contain forward guidance and may affect long-term interest rates as a result, which is consistent with our observation. Second, using changes in a particular short-term interest rate to identify monetary policy shocks will at best miss forward guidance and at worst be biased/misleading as a result. To support this argument, we re-estimate our model using a standard monetary policy shock which is one-day change in the three-month yield around monetary policy announcement. On monetary policy announcement days with substantial movements in long-term rates, we find that the standard monetary policy shock performs poorly in capturing the impulse responses of output and inflation. Even on days when the shift in the yield curve is almost entirely in short-term rates we find the traditional identification using just the change in short-term rates produces misleading point estimates for the impulse response of output, although it gets inflation right.

We contribute to the literature by providing the first estimates of functional monetary policy shocks in New Zealand. In doing so, we provide the estimates of yield curves in New Zealand using the Nelson-Siegel approach. The New Zealand yield curve is estimated in several papers but we are the first to make code and results publicly available. By estimating the impulse responses of inflation and output to the functional monetary policy shock, we provide new empirical evidence on effects of monetary policy shocks in a small open economy. We also provide a comparison between functional local projections - which estimate the impulse response functions to the functional shock - and standard local projections - which estimate the impulse response functions to a scalar shock, for example a change in the three-month interest rates, which is commonly used in the literature.

Related literature There are few studies on monetary policy shocks in New Zealand. Buckle et al. [2003] analyze the effect of monetary policy on the business cycles and inflation variability using an open economy structural VAR model with 13 variables. They identify monetary policy by including a forward-looking Taylor rule in the model and use the 90-day rate as a proxy for monetary policy stance. They find that monetary policy can reduce inflation variability and business cycles during the study period. With a different approach, Haug and Smith [2012] study the impulse responses of macroeconomic variables to structural shocks in New Zealand using local projections. The authors first estimate the shocks by fitting a VAR to the data and identify the shocks by using assumptions about contemporaneous relationships. By using the 90 day bank bill rate as a proxy for monetary policy stance, they find that interest rate shocks have a negative effect on prices in the medium run. Culling et al. [2019] examine the effect of a one-time 25 basis point cut in the OCR on inflation and output by comparing three modelling approaches including a DSGE model, a VAR with sign restrictions and a factor-augmented-VAR. They find that the effectiveness of unconventional monetary policy is different over time, but generally a cut in the OCR causes inflation and output to increase in the study period. Other studies examine the effects of monetary policy shocks on NZD exchange rate including Karagedikli et al. [2008] and Nguyen [2021]. Using high frequency data, Karagedikli et al. [2008] measure monetary policy surprises by using changes in the 90-day bank bill futures, weighted market expectations and changes in Overnight Indexed Swaps, while Nguyen [2021] identifies monetary policy shocks as unexpected changes in short-term interest rates.

The remainder of the paper proceeds as follows. Section 2 presents our estimation of monetary policy shocks in New Zealand. Section 3 presents the impacts of monetary policy shocks on inflation and output using functional local projections. Section 4 compares the estimated impulse responses by functional local projections and standard local projections. Section 5 concludes.

2 Estimation of monetary policy shocks in New Zealand

A monetary policy shock might be defined as non-systematic movements in monetary policy that are (1) predetermined or exogenous, (2) uncorrelated with each other, and (3) unpredictable. These properties make it possible for researchers to analyze the causal effects of the shock on other macroeconomic variables, but also make it difficult to accurately identify the shock. A common way to identify monetary policy shocks is to treat them as innovations to a Taylor rule, which ensures the three necessary characteristics of the shocks, but their economic meaning is somewhat difficult to interpret[1]. Using changes in the policy rate like New Zealand OCR is also not a good way to identify monetary policy shocks as these changes are not exogenous to economic conditions, and might be fully anticipated by economic entities.

Numerous approaches have been proposed to solve the identification problem of monetary policy shocks[2]. One approach is high-frequency identification which proposes using high-frequency data on financial variables - such as bond yields or interest rate futures - around monetary policy announcements to identify unexpected monetary policy changes. Examples of studies using the high-frequency identification are Gürkaynak et al. [2005], Gertler and Karadi [2015], and Nakamura and Steinsson [2018] which identify monetary policy shocks as changes in a short-term interest rate (for example, federal funds or other interest rate futures) in very tight windows of time (typically 30 minutes) around FOMC meetings. While the high-frequency identification is a promising approach, the use of changes in short-term interest rates to identify monetary policy shocks is a major limitation because monetary policy might affect interest rates at various maturities. While conventional monetary policy mainly affects short-term interest rates, unconventional monetary policy mainly affects longer term interest rates. By using information on only short-term interest rates the unconventional part of monetary policy shocks is likely to be ignored.

To address the misidentification problem, we follow Inoue and Rossi [2021] to identify monetary policy shocks as changes in the entire yield curve around monetary policy announcements. We first estimate yield curves using zero-coupon yields at daily frequency and then measure monetary policy shocks as differences in the estimated yield curves in a one-day window of time around monetary policy announcements. By including changes in yields across the entire maturity the estimated monetary policy shocks are capable to capture both conventional and unconventional monetary policy movements.

[1] McKay and Wolf [2023] interpret a shock to the central bank's policy rule as contemporaneous policy shock and deviation from the policy rule ("news" shock).

[2] For readers unfamiliar with monetary policy shocks and identification methods, we recommend the summary of Ramey [2016].

2.1 The estimation of New Zealand yield curves

To estimate the New Zealand yield curve, we apply the Nelson and Siegel [1987]/Diebold and Li [2006] approach and model yields as a function of their maturity

$$y_t(\tau) = \beta^{\tau}_{1,t} + \beta^{\tau}_{2,t}\Big(\frac{1 - e^{-\lambda\tau}}{\lambda\tau}\Big) + \beta^{\tau}_{3,t}\Big(\frac{1 - e^{-\lambda\tau}}{\lambda\tau} - e^{-\lambda\tau}\Big) \quad (1)$$

where t is the date; τ is the time to maturity; $y_t(\tau)$ is the yield to maturity; $\beta_1, \beta_2, \beta_3$ are coefficients capturing the level, slope and curvature of the yield curve, respectively. For readers unfamiliar with yield curves and their use in Macroeconomics we recommend the great summary of Gürkaynak and Wright [2012].

The parameter λ determines the exponential decay rate of the yield curve model. With small values of λ, the model has slow decay rate and can better fit the curve at long maturities. With large values of λ, the model has a fast decay rate and can better fit the curve at short maturities. Following Diebold and Li [2006], we set λ at 0.0609 to maximize the loading on $\beta^{\tau}_{3,t}$ at 30 months[3].

For each yield with maturity τ, there are three factors: $[\beta^{\tau}_{1,t}, \beta^{\tau}_{2,t}, \beta^{\tau}_{3,t}]$, and the factor loadings are: $[1, (\frac{1-e^{-\lambda\tau}}{\lambda\tau}), (\frac{1-e^{-\lambda\tau}}{\lambda\tau} - e^{-\lambda\tau})]$. The loading on $\beta^{\tau}_{1,t}$ is 1, a constant that does not vanish as τ approaches infinity; hence $\beta^{\tau}_{1,t}$ may be viewed as a long-term factor or level factor, since it equally increases all yields independently of their maturity, thereby changing the level of the yield curve. The loading on $\beta^{\tau}_{2,t}$ is $(\frac{1-e^{-\lambda\tau}}{\lambda\tau})$, which equals 1 at $\tau = 0$, and then quickly decays to zero as τ increases; hence $\beta^{\tau}_{2,t}$ may be viewed as factor that is important in the short-term. Furthermore, the yield curve slope is defined as $y_t(\infty) - y_t(0)$, which is exactly equal to $-\beta^{\tau}_{2,t}$; hence $\beta^{\tau}_{2,t}$ can also be interpreted as the slope factor of the yield curve. Another reason for this interpretation is that an increase in $\beta^{\tau}_{2,t}$ increases short-term yields more than long-term yields, because the short rates load on $\beta^{\tau}_{2,t}$ more heavily, thereby changing the slope of the yield curve. The loading on $\beta^{\tau}_{3,t}$ is $(\frac{1-e^{-\lambda\tau}}{\lambda\tau} - e^{-\lambda\tau})$, which equals 0 at $\tau = 0$ (and thus is not short-term), increases, and then decays to zero (and thus is not long-term); hence $\beta^{\tau}_{3,t}$ may be viewed as a medium-term factor. Alternatively, an increase in $\beta^{\tau}_{3,t}$ has little effect on very short-term or very long-term yields, but can increase medium-term yields, thereby changing the curvature of the yield curve, and

[3] Han et al. [2021] and Koeda and Sekine [2022] estimate the decay factor in several countries and suggest that the decay factor has decreased over time. However, we are not aware of any studies on whether a different value should be used for New Zealand. We instead estimate our model using different values of λ and find that changes in results are minor. Therefore, we report the result using $\lambda = 0.0609$ to be comparable to Inoue and Rossi [2021]'s results. Results using different values of λ are provided in Online Appendix (Figure 9 and 10).

$\beta^{\tau}_{3,t}$ can also be viewed as the curvature factor. Figure 1 plots the factor loadings as functions of maturity τ with $\lambda = 0.0609$.

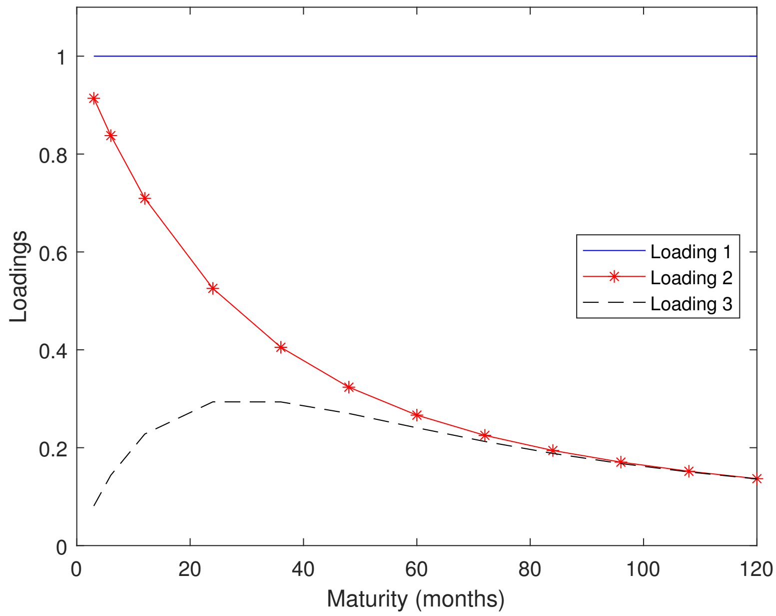

Figure 1: Factor loadings with $\lambda = 0.0609$. *Notes.* The loading 1 is 1; the loading 2 is $(\frac{1-e^{-\lambda\tau}}{\lambda\tau})$; the loading 3 is $(\frac{1-e^{-\lambda\tau}}{\lambda\tau} - e^{-\lambda\tau})$. While the loading 1 is a constant, the loading 2 and 3 decay to zero at the exponential rate of λ. The higher λ, the faster decay rate of the yield curve model.

Data and model The model is fitted to New Zealand zero-coupon yields observed daily (closing prices), covering from 03/01/2012 to 31/12/2021, and observed at maturities $\tau \in [3, 6, 12, 24, 36, 48, 60, 72, 84, 96, 108, 120]$ months. The data are from Refinitiv [2022][4] and the covering period reflects the data availability[5]. With $\lambda = 0.0609$, the three factors $[\beta^{\tau}_{1,t}, \beta^{\tau}_{2,t}, \beta^{\tau}_{3,t}]$ in equation (1) can be estimated using OLS given data on zero-coupon yields $y_t(\tau)$ and maturity τ.

Figure 2 plots the movements of daily zero-coupon bond yields from January 2012 to December 2021 in New Zealand showing an overall decreasing trend. In the last two years of the study period the yields experienced several remarkable changes. First, the short-term yields occasionally went slightly

[4]RIC codes: NZGOV3MZ=R, NZGOV6MZ=R, NZGOV1YZ=R, NZGOV2YZ=R, NZGOV3YZ=R, NZGOV4YZ=R, NZGOV5YZ=R, NZGOV6YZ=R, NZGOV7YZ=R, NZGOV8YZ=R, NZGOV9YZ=R, NZGOV10YZ=R.

[5]The 3-month zero-coupon yields are available from 14/10/2010 and 6-month zero-coupon yields are available from 3/1/2012. The 1-year and longer zero-coupon yields are available starting from 5/1/1999 and this longer sample, without 3-month and 6-month maturities, is used for various robustness exercises.

below zero. Second, the short end of the yield curve was inverted with 3-year and 4-year yields were lower than 3-month or 6-month yields. These changes might have resulted from unconventional measures of the RBNZ when facing the COVID 19 pandemic. Using the same data as Figure 2, Figure 3 plots the term structure of daily zero-coupon yields as a function of time and maturity, and shows significant changes over time in terms of level, slope, and curvature of yield curves.

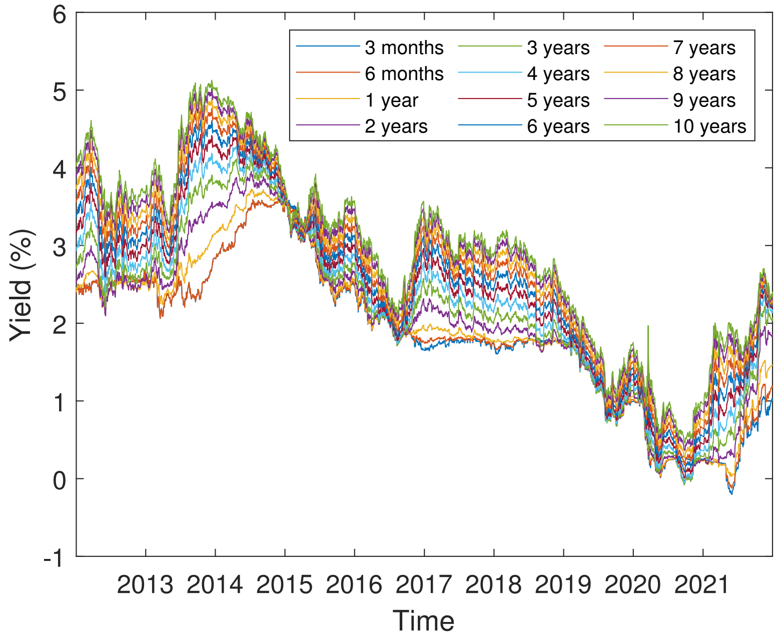

Figure 2: New Zealand yields over time.

Results By applying OLS to equation (1), we obtain a series of the three factors over time[6]. The New Zealand yield curve is estimated in several papers (for example Krippner [2006]), but we are the first to make code and results publicly available[7]. The code is based on Nyholm [2020].

The values of $[\beta^{\tau}_{1,t}, \beta^{\tau}_{2,t}, \beta^{\tau}_{3,t}]$ at a particular date t can then be plugged in equation (1) which gives us a function of the yield curve on that day. To illustrate the result, Figure 4 shows the New Zealand yield curves on 13/3/2014, 7/8/2019, and 24/11/2021. The solid lines are fitted yield curves, while the asterisk points are actual yields from the data. It can be seen that yield curves can take on several different shapes, for example positive, inverted, or humped shapes.

[6]The R^2 of the estimates for the yield curves are very high and can be found in Table 1 in Online Appendix.

[7]Code and results on the estimated factors are available at https://github.com/huongngocvu/Yield-curve-estimation.

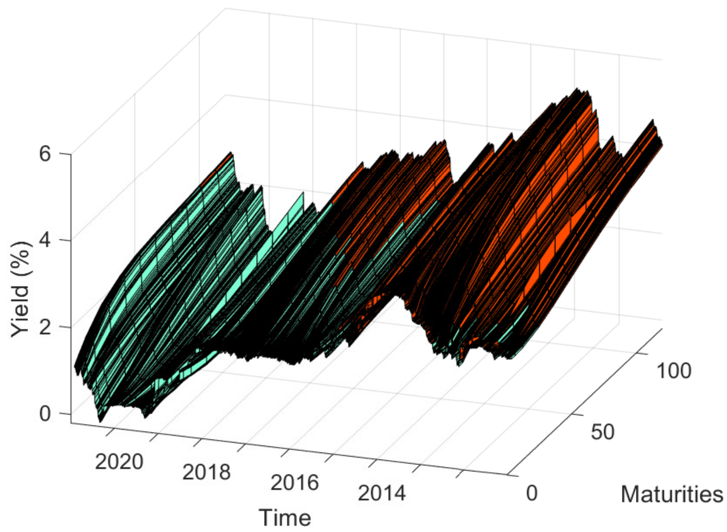

Figure 3: New Zealand term structure.

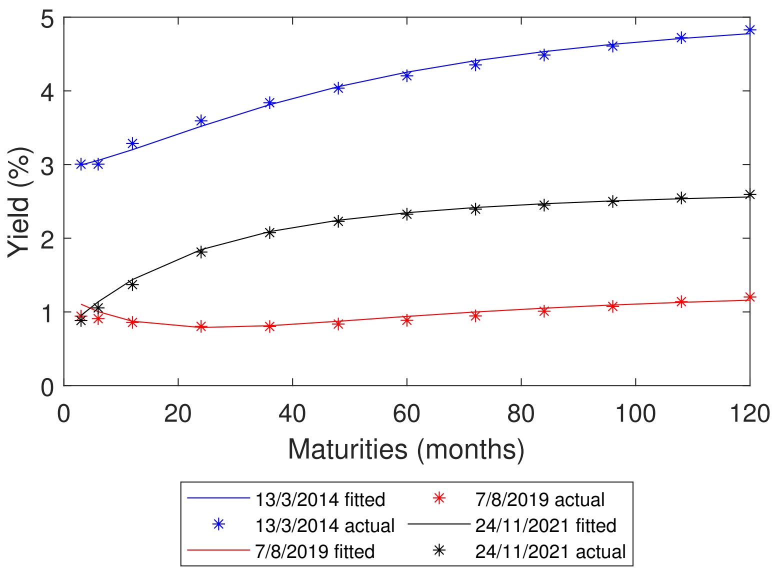

Figure 4: New Zealand yield curves on 13/3/2014, 7/8/2019, and 24/11/2021. *Notes.* The solid lines are fitted yield curves from estimating equation (1), while the asterisk points are actual zero-coupon yields from Refinitiv.

The three estimated Nelson-Siegel factors[8] are plotted in Figure 5. While

[8]We provide several estimation results using different samples in Online Appendix (Figure 1 and 2).

the level factor was relatively stable and had a clear decreasing trend, the slope factor and curvature factor fluctuated more widely. From early 2020 the three factors experienced significant changes. This was the time when the COVID-19 pandemic hit the economy, and the RBNZ made intensive use of unconventional monetary policy instruments.

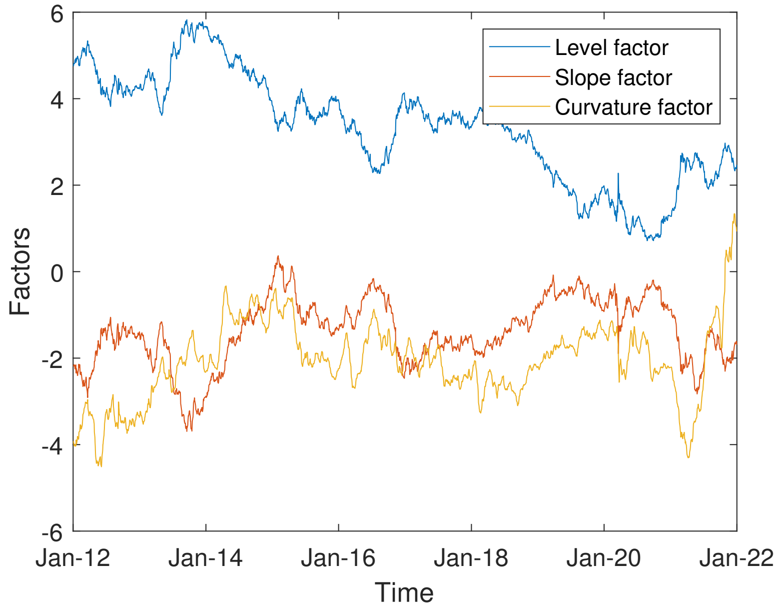

Figure 5: The estimated Nelson-Siegel factors.

Extensions on estimating the yield curve with the zero-lower bound exist (for example Krippner [2015]). As the OCR is not constrained by the zero-lower bound, we do not apply any extension in our model.

2.2 Measurement of monetary policy shocks

By plugging the estimated factors $[\beta^{\tau}_{1,t}, \beta^{\tau}_{2,t}, \beta^{\tau}_{3,t}]$ into equation (1), we obtain fitted daily yield curves from 03/01/2012 to 31/12/2021. Based on a list of the RBNZ's monetary announcement dates[9], we identify the monetary policy shock at each monetary announcement date t by taking the difference between the yield curve function on that day (i.e. time t) and one day before (i.e. time $t-1$)[10]. Let d_t be a dummy variable equal to 1 if there is a

[9] which is available at https://www.rbnz.govt.nz/monetary-policy/official-cash-rate-decisions

[10] The specification of one-day window of time, i.e. $\Delta y_t(\tau) = y_t(\tau) - y_{t-1}(\tau)$ was used by Inoue and Rossi [2021]. However, in their code, they used a two-day window of time instead, particularly by defining $\Delta y_t(\tau) = y_{t+1}(\tau) - y_{t-1}(\tau)$, that is, the change in the entire yield curve is the difference between the yield curve one day after the monetary announcement and the yield curve one day before the monetary announcement. We tried both specifications with New Zealand data and noticed that most of the results do not

monetary policy announcement at time t; $\Delta\beta^{\tau}_{j,t} = \beta^{\tau}_{j,t} - \beta^{\tau}_{j,t-1}; j = 1, 2, 3$ is the difference over time of the estimated factor; and $\Delta\beta^{d}_{j,t} = \Delta\beta^{\tau}_{j,t} \times d_t; j = 1, 2, 3$ is the change in the factor at monetary policy announcement, the functional monetary policy shocks $\epsilon_t(\tau)$ are calculated as

$$\begin{aligned}
\epsilon_t(\tau) &= [y_t(\tau) - y_{t-1}(\tau)] \times d_t \\
&= \Big[(\beta^{\tau}_{1,t} - \beta^{\tau}_{1,t-1}) + (\beta^{\tau}_{2,t} - \beta^{\tau}_{2,t-1})\Big(\frac{1 - e^{-\lambda\tau}}{\lambda\tau}\Big) \\
&\quad +(\beta^{\tau}_{3,t} - \beta^{\tau}_{3,t-1})\Big(\frac{1 - e^{-\lambda\tau}}{\lambda\tau} - e^{-\lambda\tau}\Big)\Big] \times d_t \\
&= \Big[\Delta\beta^{\tau}_{1,t} + \Delta\beta^{\tau}_{2,t}\Big(\frac{1 - e^{-\lambda\tau}}{\lambda\tau}\Big) + \Delta\beta^{\tau}_{3,t}\Big(\frac{1 - e^{-\lambda\tau}}{\lambda\tau} - e^{-\lambda\tau}\Big)\Big] \times d_t \\
&= \Delta\beta^{d}_{1,t} + \Delta\beta^{d}_{2,t}\Big(\frac{1 - e^{-\lambda\tau}}{\lambda\tau}\Big) + \Delta\beta^{d}_{3,t}\Big(\frac{1 - e^{-\lambda\tau}}{\lambda\tau} - e^{-\lambda\tau}\Big)
\end{aligned} \tag{2}$$

We calculate the monetary policy shocks $\epsilon_t(\tau)$ at a daily frequency using equation (2). To be able to estimate their effects we need to transform them into a monthly frequency to match the data on New Zealand output and inflation. As the RBNZ usually makes no more than one policy announcement per month, we simply attribute the shock to the month when it happened. If there is more than one announcement in a month (as only happened in 3/2020) the monthly shock is calculated as the average of all daily shocks occurring in that month[11].

Some examples are taken to help visualize how yield curves look like before and after each monetary policy announcement. In Figure 6 and 7 the solid line represents the term structure on the day before the announcement, while the dashed line represents the term structure on the day of announcement. We mention the period before 2020 as conventional time and the period from 2020 as unconventional time. It is because the RBNZ explicitly announced the use of unconventional monetary policy instruments from March 2020. Note that forward guidance is usually considered an unconventional monetary policy instrument, but it has been used by the RBNZ in both conventional and unconventional times.

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change much, except for the unconventional monetary policy shock on 16/3/2020. On this day, the RBNZ both cut the OCR by 0.75% and provided forward guidance. If we use $\Delta y_t(\tau) = y_{t+1}(\tau) - y_{t-1}(\tau)$, yield curve shows the change in the short end only, which might be interpreted as conventional monetary policy and forward guidance has no effect on long-term yields. If we use $\Delta y_t(\tau) = y_t(\tau) - y_{t-1}(\tau)$, yield curve shows a parallel shift, which looks more reasonable. Therefore, all the results reported in this paper are derived from the use of one-day window specification.

[11] A possible alternative would weight the shocks by the number of days between the announcement and the end of month (which is when the estimation method implicitly puts it, see our Assumption (c) in Section 4). Inoue and Rossi [2021] report that such a weighting made no meaningful difference to their results.

Figure 6 plots yield curves around four policy announcements in conventional times. On the first three dates the RBNZ announced a cut of 0.25% in the OCR, while in the last one the OCR was cut by 0.5%. It can be seen that similar monetary policy announcements can have different effects on the yield curve. On 23/7/2015 a 0.25% cut in the OCR hardly impacts the yield curve over the entire range of maturity. On 10/11/2016 the same cut in the OCR decreases short-term yields and increases medium- and long-term yields, and on 8/5/2019 the yield curve experiences a small downward shift, which mostly affects medium-term yields. On 7/8/2019 the yield curve experienced a significant downward shift over the entire range of maturity. Note that monetary policy actions can affect not only short-term interest rates but also expectations for future interest rates. Changes in short-term interest rates might alter the short end of the yield curve while changes in expectations might influence its medium and long end. The simultaneous change in the entire yield curve reflects the overall effect of a monetary policy announcement, and thus might be different even though the announcement is similar.

Figure 7 plots yield curves around four policy announcements in unconventional times. On 16/3/2020 unconventional monetary policy was implemented with a cut of 0.75% in the OCR, and forward guidance providing the OCR would remain at 0.25% for at least 12 months. This combination of monetary policy actions created a parallel shift in the entire yield curve, with long-term yields the most affected. On 23/3/2020, large-scale asset purchases were approved, leading to a downward shift in the long-end of the yield curve, while leaving the short-end almost unchanged. Similar behaviour of the yield curve can be observed on 12/8/2020 when these purchases were expanded. On 14/7/2021, however, the RBNZ decided to discontinue this programme, leading to a parallel upward shift in the yield curve, showing the reduction of monetary stimulus in the economy. It can also be noted that unconventional monetary policy shocks mostly affect the medium and/or long end of the yield curve, which is consistent with the theory that unconventional monetary policy typically operates by affecting medium and long-term interest rate expectations.

Given the yield curve functions before and after each monetary announcement the functional monetary policy shocks are calculated as the difference between the two curves. Figure 8 plots some of the shocks in conventional and unconventional times. There are two important points to be highlighted. First, conventional and unconventional monetary policy shocks have different shapes, and the ability to affect long-term yields of unconventional shocks is much better compared to conventional ones. Second, conventional shocks might considerably differ from each other, and the same thing applies for unconventional shocks. Take Figure 8a for example, the change in the short end of the yield curve is similar for both shocks on 10/11/2016 and 8/5/2019, but the change in the long-end is different. Con-

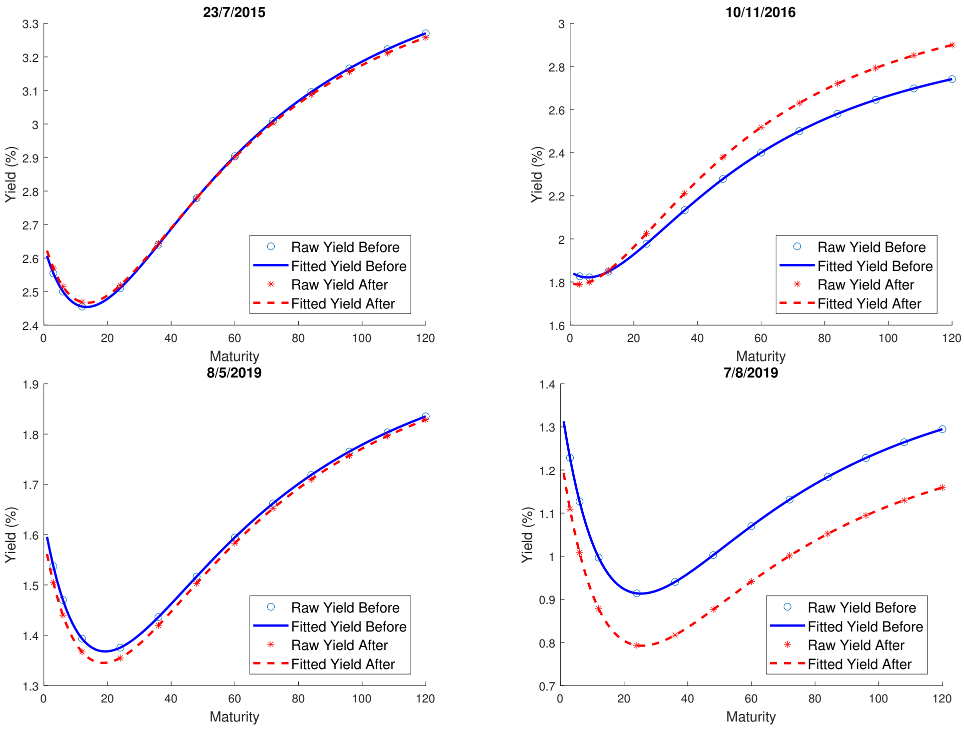


Figure 6: Yield curves around monetary announcements in conventional times. *Notes.* On 23/7/2015, 10/11/2016, and 8/5/2019 the OCR was cut by 0.25%, and on 7/8/2019 the OCR was cut by 0.5% . In each subfigure the blue solid line represents the (fitted) yield curve on the day before the announcement, while the red dashed line represents the (fitted) yield curve on the day of announcement. The asterisk points are actual zero-coupon yields from Refinitiv.

versely, the shocks on 8/3/2012 and 13/3/2014 similarly affect the long-term yields but have different impacts on the short and medium-term yields.

As mentioned earlier the three factors $[\beta^{\tau}_{1,t}, \beta^{\tau}_{2,t}, \beta^{\tau}_{3,t}]$ can be interpreted as the level, slope, and curvature factor of the yield curve. Changes in these factors themselves and their linear combinations can also be related to other important interpretations (Inoue and Rossi [2021]). The level factor $\beta^{\tau}_{1,t}$ describes any monetary policy effects that simultaneously shift the entire yield curve. The central bank might be able to do this by proportionally affecting both short-term and long-term expectations at the same time. The slope factor $\beta^{\tau}_{2,t}$ describes monetary policy shocks that affect the short run, and thus can capture conventional monetary policy which typically operates through short-term interest rates[12]. The curvature fac-

[12]The slope factor can also capture unconventional monetary policy which affects short-term interest rates. An example is Operation Twist in the U.S. in 2008 which involve the

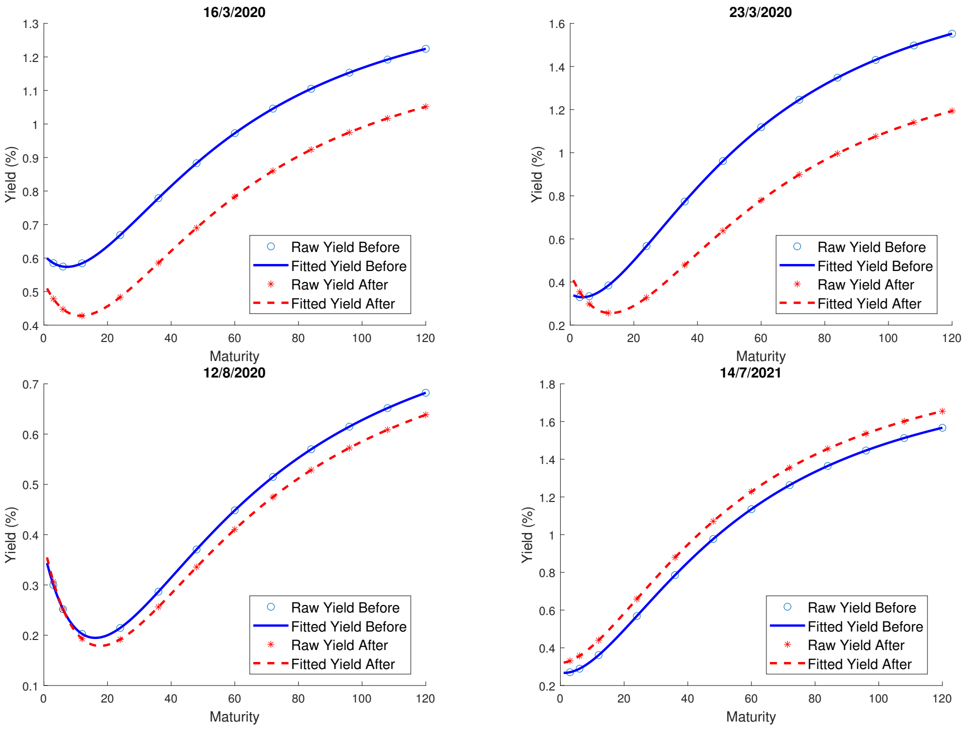
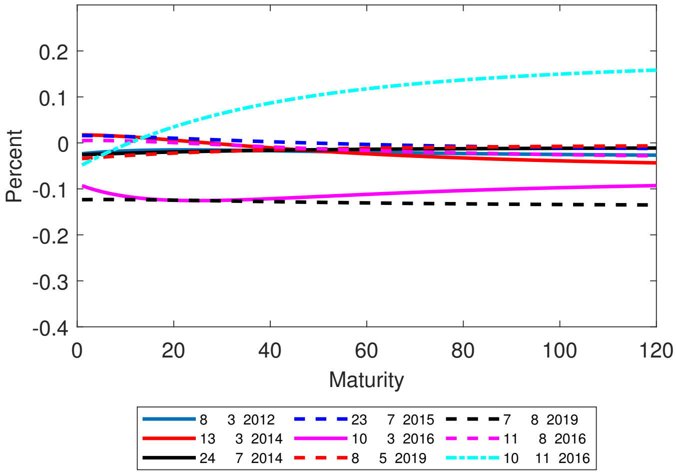


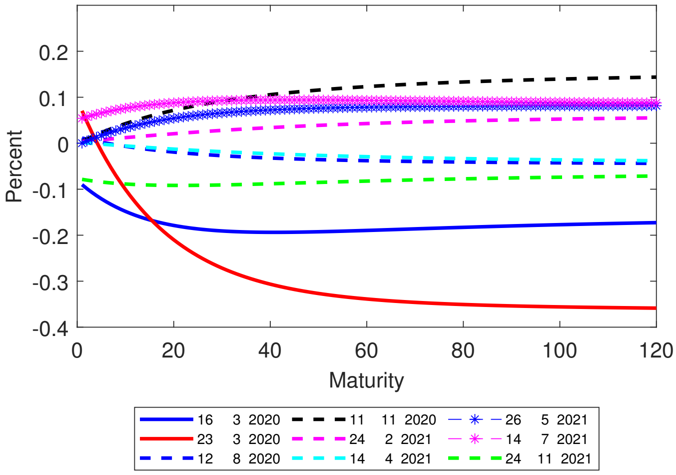
Figure 7: Yield curves around monetary announcements in unconventional times. *Notes.* On 16/3/2020 the OCR was cut by 0.75% and forward guidance provided that the OCR would remain at 0.25% for at least 12 months. Large-scale asset purchases were approved on 23/3/2020, expanded on 12/8/2020, and discontinued on 14/7/2021. In each subfigure the blue solid line represents the (fitted) yield curve on the day before the announcement, while the red dashed line represents the (fitted) yield curve on the day of announcement. The asterisk points are actual zero-coupon yields from Refinitiv.

tor $\beta_{3,t}^{\tau}$ describes monetary policy shocks that affect the medium run, and thus can capture unconventional monetary policy which affects long-term expectations and/or risk premia without changing short-term interest rates. Risk premia is defined as the gap between yields and actual expectations

central bank selling short-term securities and purchasing long-term securities at the same time. In principle, this program can have opposite effects on short-term and long-term interest rates. By selling short-term securities, the central bank increases their supply, lowering their price and raising their interest rates. By purchasing long-term securities, the central bank increases their demand, raising their price and lowering their interest rates. Therefore, short-term rates are pushed up and long-term rates are pushed down. However, if the central bank leaves short-term rates unchanged, only long-term rates will be affected. This is the case for the U.S. in 2012 when the Fed committed to keeping the federal funds rate near zero until labor market conditions improve, and Operation Twist would lower long-term rates while maintaining short-term rates.



(a) In conventional times.



(b) In unconventional times.

Figure 8: Monetary policy shocks in different times. *Notes.* A monetary shock is measured by the difference between the yield curve after and before each monetary policy announcement. Each line in these subfigures represents a monetary policy shock corresponding with a particular monetary policy announcement.

(Gürkaynak and Wright [2012]), thus any change in long-term yields must be generated by a change in long-term expectations, risk premia, or both.

Figure 9 plots monthly changes in the three factors $[\beta^{\tau}_{1,t}, \beta^{\tau}_{2,t}, \beta^{\tau}_{3,t}]$ corresponding to monthly monetary policy shocks. Similar to Inoue and Rossi [2021]'s finding using the U.S. data, the behaviour of $\beta^{\tau}_{1,t}$ is relatively stable over time while $\beta^{\tau}_{2,t}$ and $\beta^{\tau}_{3,t}$ are more volatile and become larger in magnitude in some periods, suggesting important changes in the short-run and medium-run components of monetary policy. For example, a signifi-

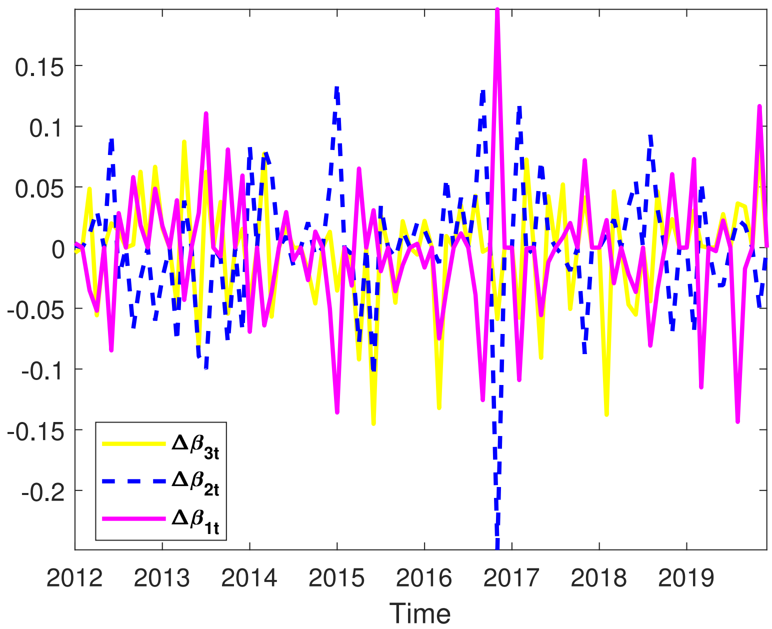


Figure 9: The components of monetary policy shocks. *Notes.* This figure plots $\Delta\beta^{\tau}_{1,t}$, $\Delta\beta^{\tau}_{2,t}$, and $\Delta\beta^{\tau}_{3,t}$ over time. They are monthly changes in each of the three factors $\beta^{\tau}_{1,t}$, $\beta^{\tau}_{2,t}$, $\beta^{\tau}_{3,t}$, and represent three components of (monthly) monetary policy shocks. Note that if there is one monetary policy announcement in a month, daily changes in factors are the same as monthly changes. If there is two or more monetary policy announcements in a month, the monthly changes are calculated as the average of all daily changes in factors occurring in that month.

cant decrease in $\beta^{\tau}_{2,t}$, representing a strong conventional monetary stimulus, was experienced in late 2016. At this time, weak global conditions and low interest rates relative to New Zealand put upward pressure on the New Zealand dollar exchange rate, which generated negative inflation in the tradables sector and kept headline inflation below the target range. To support strong GDP growth and prevent further declines in inflation expectations the RBNZ significantly expanded its monetary policy by cutting the OCR three times in March, August and November 2016. Similarly, a strong unconventional monetary stimulus, captured by a sharp decline in $\beta^{\tau}_{3,t}$, was experienced in early 2020. This was the time when the RBNZ started to use a range of unconventional instruments to provide extra support for the economy in response to the COVID-19 pandemic.

Linear combinations of the Nelson-Siegel parameters also provide useful information of monetary policy. While $(\beta^{\tau}_{1,t} + \beta^{\tau}_{2,t})$ equals the instantaneous yield[13], $(\beta^{\tau}_{3,t} - \beta^{\tau}_{1,t})$ captures changes in long-run expectations or risk pre-

[13] As explained earlier: $\beta^{\tau}_{1,t} + \beta^{\tau}_{2,t} = y_t(\infty) + [y_t(0) - y_t(\infty)] = y_t(0)$, which is the

mia which exclude simultaneous shifts in the entire yield curve. Therefore, looking at changes in these linear combinations (Figure 10) can help understand changes in the instantaneous yield, long-run expectations or risk premia resulted by monetary policy shocks.

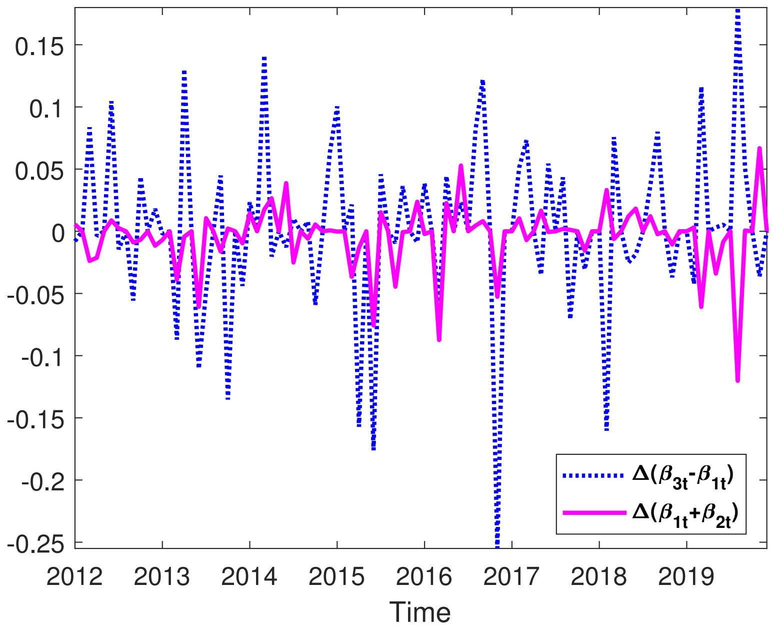


Figure 10: Linear combinations of the components of monetary policy shocks. *Notes.* This figure plots $\Delta(\beta^{\tau}_{1,t} + \beta^{\tau}_{2,t})$ and $\Delta(\beta^{\tau}_{3,t} - \beta^{\tau}_{1,t})$ over time (monthly changes).

Take the day 10/11/2016 when there was a 0.25% cut in the OCR for example, changes in the yield curve showed a small decrease in short-term yields and a significant increase in both medium- and long-term yields (Figure 6). This might be explained by the fact that, on that day, monetary policy shock affected the yield curve by reducing the instantaneous interest ($\Delta(\beta^{\tau}_{1,t} + \beta^{\tau}_{2,t}) = -0.053$) and affecting the long-term expectations or risk premia ($\Delta(\beta^{\tau}_{3,t} - \beta^{\tau}_{1,t}) = -0.255$). Conversely, on 23/3/2020, by approving large-scale asset purchases, the RBNZ generated an increase in the instantaneous yield ($\beta^{\tau}_{1,t} + \beta^{\tau}_{2,t}$), while affecting medium- and long-term interest rates by reducing ($\beta^{\tau}_{3,t} - \beta^{\tau}_{1,t}$).

Comparison with Inoue and Rossi [2021] Our results for New Zealand have two main differences compared to the results of Inoue and Rossi [2021] for the U.S. The first difference is that in conventional times we find more interest rate movements at long maturities compared to short maturities.

instantaneous yield.

This suggests that the RBNZ's monetary policy announcements in conventional times affects long-term rates more than short-term rates, which is consistent with forward guidance being used in New Zealand.

The second difference is that our monetary policy shocks in unconventional times (Figure 8b) are smaller than those of Inoue and Rossi [2021], which means that unconventional monetary policy announcements lead to smaller changes in medium- and long-term interest rates. This suggests that the RBNZ's unconventional monetary policy has less impact on longer term interest rates compared to the Federal Reserve's.

The difference in unconventional monetary policy effectiveness might result from different volumes of unconventional instruments used by the two central banks and/or different economic conditions in the two economies. However, a back of the envelope calculation suggests this is unlikely: the RBNZ did quantitative easing of roughly 13% of GDP (LSAP was $53.5 billion in 2020 GDP of $320 billion) while the Fed did roughly 13%, 4% and 13% of GDP in QE1, QE2 and QE3, respectively.[14] We therefore interpret that being a small open economy means the RBNZ has less influence over long-term interest rates, despite spending similar amounts of quantitative easing (in terms of GDP).[15]

This result is consistent with Rios and Shamloo [2017] who find that asset purchase programs in small open economies including the United Kingdom, Sweden and Switzerland have limited impact on long-term interest rates compared to those in the U.S. By comparing the responses of 10-year government yields around asset purchase announcements by central banks in these countries the authors suggest that in general changes in long-term rates around monetary policy announcements by the Bank of England, the Riksbank and the Swiss National Bank are significantly smaller than changes in long-term rates around the Federal Reserve's announcements. To understand this they decompose long-term bond yields into an expectation of future short rates, and a term premium. They find all Central Banks' purchase programs can move expected future short rates, but only the Federal Reserve's monetary policy regularly shifts the global term premium. Asset purchase programs in the small open economies operate in smaller sized bond markets compared to those of the U.S.[16], and thus are unable to affect the global term premium component of the yields.

[14]About $2 trillion for QE1 in 2008, $0.6 trillion for QE2 in 2010, $4.5 trillion for QE3 in 2012 and 2013. QE4 in 2020 was not in the time period studied by Inoue and Rossi [2021]. U.S. GDP of $14.8 trilliopn in 2008, $15 trillion in 2010, $16.2 trillion in 2012, and $16.8 trillion in 2013.

[15]Note that it is possible that RBNZ was simply "less surprising". Our shocks only measure the unexpected component of unconventional monetary policy.

[16]"For example, by the end of 2015, the sizes of the stock of outstanding nominal government debt in the U.K. and Sweden were approximately 20 percent and 1 percent, respectively, of the size of U.S. Treasury bond market." - Rios and Shamloo [2017].

3 Impacts of monetary policy shocks on the economy

Local projections (Jordà [2005]) propose estimating the impulse responses of X_t to shock directly at each horizon h

$$X_{t+h} = \mu_h + \Theta_h shock_t + \varphi X_{t-1} + v_{h,t+h} \tag{3}$$

where X_t is the interested variable at time t; $h = 1, 2, ..., H$ is the horizon of the response; μ_h is the intercept term at time h; Θ_h is the response at time $(t + h)$ to a structural shock in $shock_t$.

Jordà [2005] shows that local projections have several advantages compared to VARs. First, as no specification is imposed local projections are more robust to model misspecification. Second, by directly estimating impulse response coefficients local projections can provide valid inference using HAC robust standard errors. Third, local projections can be easily extended to accommodate nonlinearities and flexible specifications. On the other hand, local projections also have several drawbacks. First, the error terms in local projections are serially autocorrelated. Second, local projections consume data along both the lag (p) and the lead (h) dimensions, and thus requires more data than VAR does. Third, local projection estimators have significantly higher variance than that of VAR, especially at intermediate or long horizons.

Under standard nonparametric regularity assumptions[17] Plagborg-Møller and Wolf [2021] prove that the impulse response functions estimated by VARs and local projections are equivalent in population, but might be different in finite samples, especially at long horizons. In practice, local projection estimators might have smaller bias, but larger variance compared to VAR estimators, which is sometimes described as the bias-variance trade-off in impulse response estimation between local projection and VAR methods (Li et al. [2021]).

Under standard local projections the structural shock is a scalar at every period t and might be identified as exogenous changes in interest rates at a particular maturity, for example the policy rate or three-month interest rate. As changes in interest rates at different maturities are not considered standard local projections will miss unconventional monetary policies and also forward guidance. We follow Inoue and Rossi [2021] to address this misidentification problem by considering changes in the entire yield curve as monetary policy shock. Note that the monetary policy shock $shock_t$ is a function parametrized by $[\Delta\beta^{\tau}_{1,t}, \Delta\beta^{\tau}_{2,t}, \Delta\beta^{\tau}_{3,t}]$ (see equation 2) and the

[17] i.e. the data are covariance stationary and purely non-deterministic, with an everywhere nonsingular spectral density matrix and absolutely summable Wold decomposition coefficients.

method is modified[18] to handle these functional shocks. In dealing with the problem of estimation uncertainty, we smooth the estimated impulse responses by fitting a fourth-order polynomial to Θ_h across horizons[19].

Data We use monthly data on monetary policy shocks calculated in part 2 to estimate their effects on inflation and output in New Zealand. For inflation, we use monthly data on CPI (percent change year over year) from Refinitiv [2022].[20] For output, we use monthly data on the New Zealand Activity Index from StatsNZ [2022].[21] Note that we use the Activity Index as an alternative to GDP as our model uses monthly data and GDP data in New Zealand is not available at monthly frequency.

While the data on the New Zealand Activity Index are originally at monthly frequency, the monthly data on CPI are likely to be interpolated from quarterly data.[22] We therefore use quarterly data as a robustness check and find that the quarterly results broadly agree with the monthly results. Detailed information is provided in Online Appendix (Figure 7 and 8).

The data used to estimate monetary shocks run from 03/01/2012 to 31/12/2021 in which the last two years cover the unconventional time for monetary policy in New Zealand. As the unconventional time experienced wild fluctuations in the three components of monetary policy shocks as well as inflation, including this period might mislead the estimated impulse responses. Therefore, we end the study period at 31/12/2019.[23]

Model Following Inoue and Rossi [2021], impacts of monetary policy shocks on macroeconomic variables are estimated using functional local projections, and the regression model is

$$\begin{aligned} X_{t+h} = \mu_h &+ \Theta_{1,h}(L)\Delta\beta^d_{1,t} + \Theta_{2,h}(L)\Delta\beta^d_{2,t} + \Theta_{3,h}(L)\Delta\beta^d_{3,t} \\ &+ \varphi(L)X_{t-1} + e_{h,t+h} \end{aligned} \tag{4}$$

[18]We refer readers to Inoue and Rossi [2021] for detailed explanation of functional local projections.

[19]Barnichon and Brownlees [2019] and Miranda-Agrippino and Ricco [2021] propose different methods to address the estimation uncertainty problem of local projections.

[20]Refinitiv RIC code: aNZCCPIYE/A. This is the seasonally adjusted, % year on year, standardized CPI based on source quarterly data (Stats NZ).

[21]The data are available on the Statistics NZ COVID-19 data portal and begin from 10/2003.

[22]We do not believe that the interpolation of the CPI data could mislead the estimated results as we include the lag of dependent variables in the regression model. Note that if we were using a VAR to estimate impulse response the use of interpolated data would be problematic. By contrast with a linear projection it seems fine.

[23]The estimation using the whole sample (from 03/01/2012 to 31/12/2021) can be found in Online Appendix (Figure 3 and 4).

where X_t is either inflation or output at time t; $h = 0, 1, ..., H$ is the horizon of the response; $[\Theta_{1,h}, \Theta_{2,h}, \Theta_{3,h}]$ are the responses at time $(t + h)$ to a structural shock in $\Delta\beta^d_{j,t}; j = 1, 2, 3$.

To correctly identify the effects of monetary policy shocks, a set of identification conditions need to be assumed as following

(a) Shock identification condition: Inflation and output are not contemporaneously affected by yield curve shocks.

(b) Relevance condition: A change in the yield curve on an announcement date is only due to the monetary policy shock.

(c) Exogeneity condition: The change in the yield curve after an announcement date in the sampling period is not due to the monetary policy shock.

Assumption (a) implies that inflation and output do not respond to a monetary policy shock within the month. Empirical evidence on the persistence of prices and production suggested that it takes time to adjust prices and production, typically several months, and the adjustment is heterogenous across sectors (for example Alvarez et al. [2006], Dhyne et al. [2006], Krol [1992], or Dua and Mishra [1999]). As data on inflation and output for New Zealand do not exist at a higher frequency (such as weekly or fortnightly), the combination of monthly data and assumption (a) seems reasonable.

Assumption (b) implies that the monetary policy shock is the only reason for any changes in the yield curve on an announcement date. While the use of a one-day window to identify monetary policy shocks is consistent with Gürkaynak et al. [2004], a possible limitation of the assumption is that if there are changes in the yield curve on an announcement date because of reasons other than monetary policy actions, they will be interpreted as a (part of) monetary policy shock. The limitation might be related to the central bank information effect whose role is under researchers' argument. On one hand, the literature on the central bank information effect (for example Nakamura and Steinsson [2018], Miranda-Agrippino and Ricco [2021], and Bu et al. [2021]) argued that central bank's announcement might contain both pure monetary policy shocks and information shocks (for example, revisions in the central bank's preferences or economic forecasts). While pure monetary policy shocks, let's say exogenous increases in the policy rate, have conventional, negative effects on macroeconomic variables, information shocks, such as central bank's forecasts of stronger economic growth, might have positive effects instead. Therefore, if the information shocks are not separated from pure monetary policy shocks, they generally lead to smaller responses as two opposite effects cancel out each other. As Inoue and Rossi [2021] did not explicitly consider the central bank information effect, it might be possible that their identified monetary shocks are correlated with developments in economic conditions. On the other hand, recent evidence by Hoesch et al. [2020] argued that the information effect exists, but its role might not be considerable in recent years because there are significant improvements in the central bank's communication and transparency. Using Blue Chip forecasts Bauer and Swanson [2021] also argue that there is no information effect. Motivated by these recent studies, we do not focus on the information effect in this paper.

Assumption (c) implies that there is only one monetary policy shock in a given month. Inoue and Rossi [2021] satisfied it by attributing the shock to the month when the shock occurred, or taking the average of the shocks if there is more than one shock in a month. The authors also suggested to interpret the results as if the shock realizes at the end of the month. In the New Zealand data, there is only ever at most one shock in a month, with the sole exception of 16/03/2020.

Inoue and Rossi [2021] also assumed that monetary policy shocks affect the entire yield curve by changing $[\beta^{\tau}_{1,t}, \beta^{\tau}_{2,t}, \beta^{\tau}_{3,t}]$ at the same time, and thus the response of macroeconomic variables to the monetary policy shock $\epsilon_t(\tau)$ is identified as $\frac{\partial X_{t+h}}{\partial \epsilon_t(\tau)}$. Since $\epsilon_t(\tau)$ is a function of maturity τ (see equation 2) instead of a scalar, the differential here is a Gateaux differential (see Inoue and Rossi [2021] for detailed derivations)

$$\frac{\partial X_{t+h}}{\partial \epsilon_t(\tau)} = \frac{\partial X_{t+h}}{\partial \Delta \beta^d_{j,t}} \frac{\partial \Delta \beta^d_{j,t}}{\partial \epsilon_t(\tau)} = \sum_{j=1}^{3} \Theta_{j,h} \Delta \beta^d_{j,t} \tag{5}$$

where $\Theta_{j,h}$ is estimated in the equation 4, and $\Delta\beta^d_{j,t} = \Delta\beta^{\tau}_{j,t} \times d_t$ is as calculated in part 3.2. Note that the response depends on the change in the term structure occurring on the monetary policy announcement day, which is parametrized by $[\Delta\beta^{\tau}_{1,t}, \Delta\beta^{\tau}_{2,t}, \Delta\beta^{\tau}_{3,t}]$. Therefore, each monetary policy announcement has a unique impulse response because the effect of each announcement on the yield curve is represented by a unique combination of $[\Delta\beta^{\tau}_{1,t}, \Delta\beta^{\tau}_{2,t}, \Delta\beta^{\tau}_{3,t}]$[24]. For example, a 0.25% cut in the OCR on 10/11/2016 which reduces short-term interest rate and increases medium- and long-term interest rates $[\Delta\beta^{\tau}_{1,t} = 0.196, \Delta\beta^{\tau}_{2,t} = -0.249, \Delta\beta^{\tau}_{3,t} = -0.059]$ and the same cut in the OCR on 8/5/2019 which reduces interest rates at all maturities $[\Delta\beta^{\tau}_{1,t} = -0.003, \Delta\beta^{\tau}_{2,t} = -0.031, \Delta\beta^{\tau}_{3,t} = 0]$ will have different effects on X_{t+h}. This conclusion would significantly differ if instead we identified monetary policy shocks as exogenous changes in the short-term interest rate, and there would be only one impulse response of macroeconomic variables to a one standard deviation increase in the short-term interest rate. The identification might be misleading as (i) unconventional monetary policy shocks

[24]If two monetary policy announcements were to produce the exact same change in the yield curve, i.e. the exact same $[\Delta\beta^{\tau}_{1,t}, \Delta\beta^{\tau}_{2,t}, \Delta\beta^{\tau}_{3,t}]$, then they would generate the same impulse response, but in practice this does not occur.

that do not affect the short-term interest rate might be ignored, and (ii) two monetary policy shocks that cause similar changes in the short-term interest rate might be considered as having similar macroeconomic effects. By using the functional shock approach, these issues can be addressed because (i) monetary policy shocks are changes in the entire yield curve instead of changes in the short-term interest rate only, thus unconventional monetary policy shocks can be well captured, and (ii) each monetary policy shock has a unique macroeconomic effect implied by different impulse responses. This is an important advantage of Inoue and Rossi [2021]'s methodology: it allows us to look at every monetary policy announcement and analyse its macroeconomic effect at different time horizons.

In practice, following Inoue and Rossi [2021], we report a smoothed estimate, obtained by fitting a fourth-order polynomial to $\Theta_{j,h}$ across horizons to avoid excessive variations in the local projection estimates[25]. We also have the same experience as Inoue and Rossi [2021], that is $\Delta\beta^d_{1,t}$ and $\Delta\beta^d_{2,t}$ appear to be collinear, and using both of them as equation 4 might increase the estimation uncertainty[26]. Therefore, we drop $\Delta\beta^d_{1,t}$ in the estimation of the impulse responses. As our sample is not too large, we choose 16 horizons and include two lags of the dependent variables[27].

Results Figure 11 plots the impulse response functions of inflation and output to selected conventional monetary policy shocks. In 7/2015, the yield curve almost remained unchanged after the monetary policy announcement, which resulted from a decrease in the level factor ($\Delta\beta^\tau_{1,t} = -0.019$) and an increase in both the slope and curvature factors ($\Delta\beta^\tau_{2,t} = 0.035, \Delta\beta^\tau_{3,t} = 0.026$). In response to the increase in $\Delta\beta^\tau_{2,t}$ and $\Delta\beta^\tau_{3,t}$, inflation and output had different behaviour. Inflation almost remained unchanged in the short run and then increased in the long run, while output experienced a short-run decrease and then recovered. Similarly, the shift of the yield curve in 8/2019 involved increases in both the slope and curvature factors ($\Delta\beta^\tau_{2,t} = 0.023, \Delta\beta^\tau_{3,t} = 0.036$), and thus resulted in similar responses of inflation and output. In 11/2016, however, changes in the yield curve were caused by decreases in both $\Delta\beta^\tau_{2,t}$ and $\Delta\beta^\tau_{3,t}$, causing inflation and output to respond in opposite ways. In 5/2019, $\Delta\beta^\tau_{2,t}$ decreased while $\Delta\beta^\tau_{3,t}$ was unchanged the responses of inflation and output thus had similar directions but smaller magnitudes compared to those in 11/2016.

An important question relating to the different effects of various dimensions of monetary policy on inflation and output could be analysed by

[25] This method can be considered as a limiting case of Barnichon and Brownlees [2019]'s estimator.

[26] The correlations of these factors can be found in Table 2 in Online Appendix.

[27] We use different model specifications as robustness checks. In Online Appendix (Figure 5 and 6), we report the estimated impulse responses of inflation and output when controlling for exchange rates and show that the differences are minor.

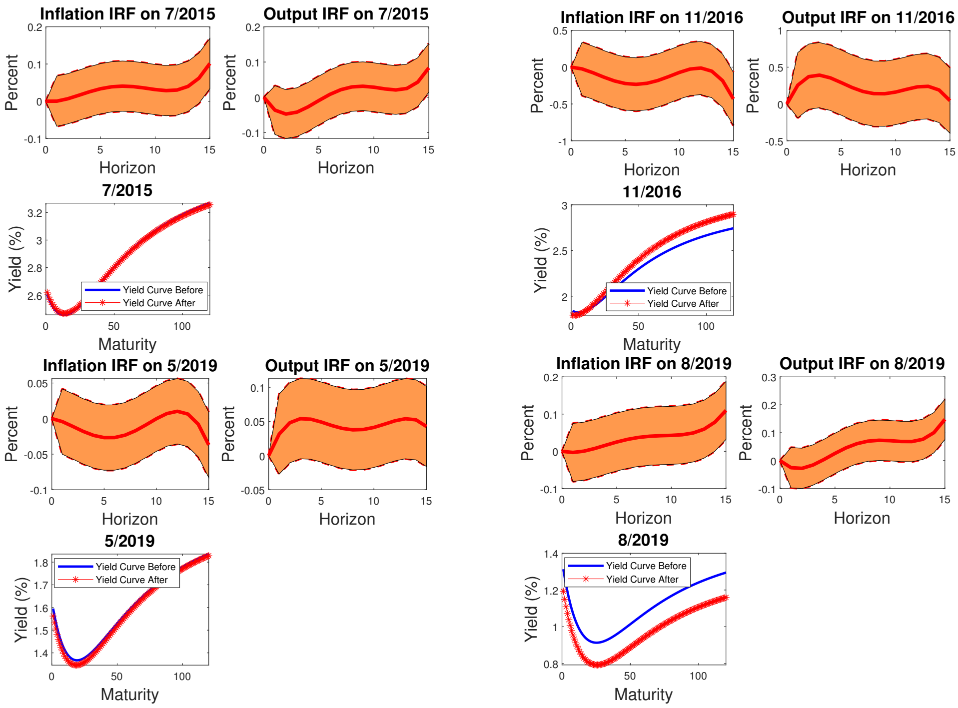


Figure 11: Responses of inflation and output to selected conventional monetary policy shocks. *Notes.* The figure plots impulse response functions of inflation and output to the monetary policy shock together with 90% confidence bands.

looking at the decomposition of inflation and output responses on individual days (Figure 12 plots the decomposition on some selected days). The general comment on the responses of output and inflation is that in the short run the responses of output are mostly driven by changes in the slope factor, but in the long run the contribution of the curvature factor becomes more and more significant. For inflation, both factors have insignificant effects in the first five periods and more considerable effects after roughly ten periods, which helps explain the persistence of inflation in the short run (as seen in Figure 11).

A more systematic understanding is provided by Figure 13 and 14 which plot responses of inflation and output to particular changes in $\Delta\beta^{\tau}_{2,t}$, $\Delta\beta^{\tau}_{3,t}$ and their combination. In each figure, there are four panels, each panel plots changes in inflation or output (the left picture) corresponding to changes in the yield curve (the right picture) caused by changes in $\Delta\beta^{\tau}_{2,t}$ only (panel a); changes in $\Delta\beta^{\tau}_{3,t}$ only (panel b); changes in similar direction in $\Delta\beta^{\tau}_{2,t}$ and $\Delta\beta^{\tau}_{3,t}$ (panel c); and changes in opposite direction in $\Delta\beta^{\tau}_{2,t}$ and $\Delta\beta^{\tau}_{3,t}$ (panel d).

Figure 13(a) shows that when the yield curve shifts upward because

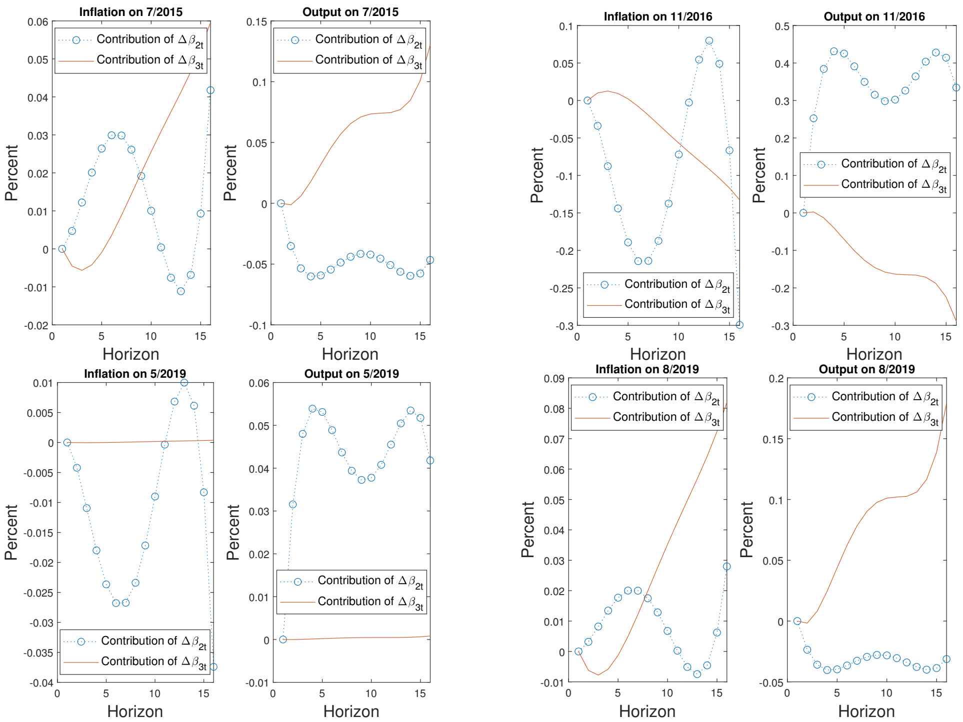
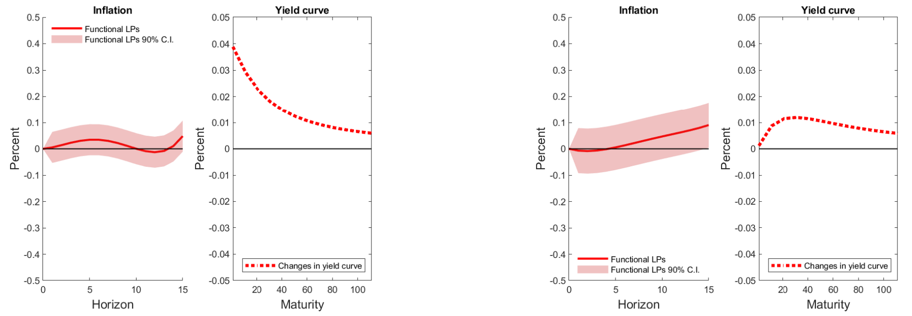


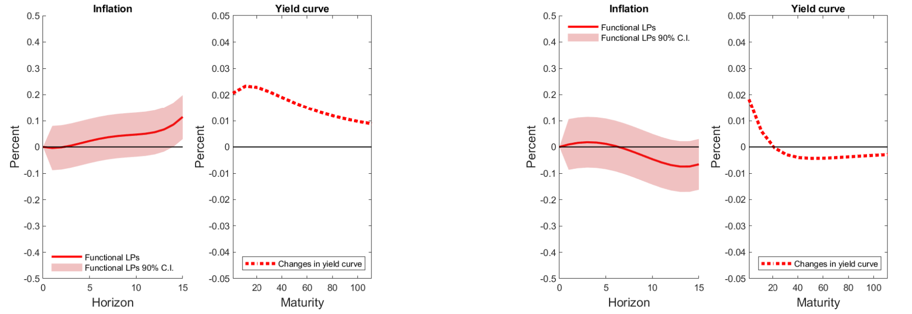
Figure 12: Decomposition of inflation and output responses to selected conventional monetary policy shocks.

of the slope factor, representing contractionary monetary policy, inflation increases and then decreases. Panel (b) shows that an increase in the yield curve resulting from the curvature factor slightly decreases inflation in the short run before increasing it in the longer run. When the yield curve shifts upward because of both the slope and curvature factors moving in the same direction as in panel (c), inflation experiences a minor short-run decrease following by a long-run increase. When one factor increases and the other decreases as in panel (d) the movement of inflation depends on the magnitude and sign of these changes. For example, when short-term interest rate increases and long-term interest rate decreases more (represented by an increase in the slope factor and a bigger decrease in the curvature factor), inflation goes up in the short run before declining in the long run. Overall, Figure 13 suggests that the conventional part of a monetary policy shock, which is the slope factor, has a traditional effect on inflation with a lag, while the unconventional part of a monetary policy shock, which is the curvature factor, has small impact in the short run and more significant impact in the long run. Therefore, an increase in the short end of the yield curve typically decreases inflation after a few periods, and an increase in the long end of the yield curve tends to increase inflation in the long run.

Output reacts similarly to inflation in response to variations in these fac-



(a) $\Delta\beta^{\tau}_{2,t} = 0.04$; $\Delta\beta^{\tau}_{3,t} = 0$. (b) $\Delta\beta^{\tau}_{2,t} = 0$; $\Delta\beta^{\tau}_{3,t} = 0.04$.

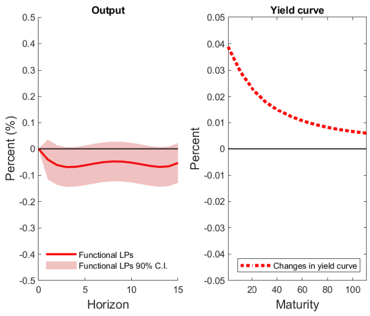


(c) $\Delta\beta^{\tau}_{2,t} = 0.02$; $\Delta\beta^{\tau}_{3,t} = 0.04$. (d) $\Delta\beta^{\tau}_{2,t} = 0.02$; $\Delta\beta^{\tau}_{3,t} = -0.04$.

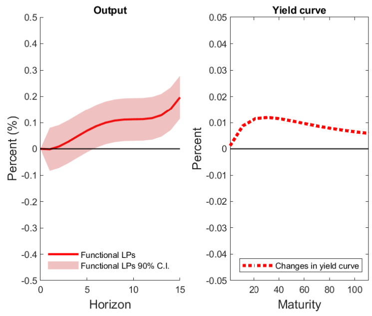
Figure 13: Responses of inflation to different components of monetary policy shocks. *Notes.* There are four panels which plot responses of inflation to particular changes in $\Delta\beta^{\tau}_{2,t}$ (panel a), $\Delta\beta^{\tau}_{3,t}$ (panel b), and the combinations of $\Delta\beta^{\tau}_{2,t}$ and $\Delta\beta^{\tau}_{3,t}$ (panel c and d). In each panel, the right picture plots changes in the yield curve, and the left picture plots changes in inflation.

tors (Figure 14). While increases in short-term interest rates (represented by an increase in the slope factor $\Delta\beta^{\tau}_{2,t}$) leads to decreases in output, increases in medium-term interest rates (represented by an increase in the curvature factor $\Delta\beta^{\tau}_{3,t}$) only leads to minor and temporary decreases in output (panel a and b). In general, Figure 14 suggests that a monetary policy shock has a traditional effect on output, but how long the effect lasts depends on the nature of the shock (that is, whether the shock impacts short-term or medium-term interest rates or both). Furthermore, increases in the short-end of the yield curve typically have negative impacts on output, while increases in the long-end of the yield curve might have opposite impacts.

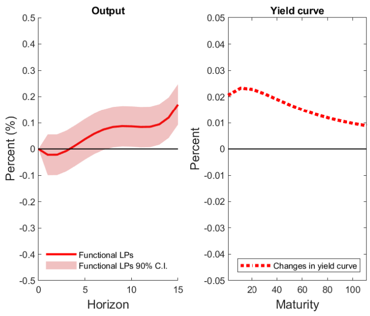
Comparison with Inoue and Rossi [2021] Findings of Inoue and Rossi [2021] relating to output responses to monetary policy shocks for the U.S. are similar to our findings about output responses in New Zealand (Figure 14). To make it clear for inflation, we describe responses of inflation to monetary policy shocks (Figure 13) and find that both output and inflation have



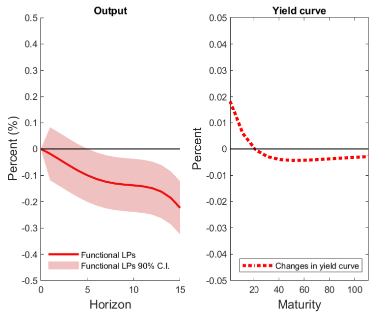
(a) $\Delta\beta^{\tau}_{2,t} = 0.04$; $\Delta\beta^{\tau}_{3,t} = 0$.



(b) $\Delta\beta^{\tau}_{2,t} = 0$; $\Delta\beta^{\tau}_{3,t} = 0.04$.



(c) $\Delta\beta^{\tau}_{2,t} = 0.02$; $\Delta\beta^{\tau}_{3,t} = 0.04$.



(d) $\Delta\beta^{\tau}_{2,t} = 0.02$; $\Delta\beta^{\tau}_{3,t} = -0.04$.

Figure 14: Responses of output to different components of monetary policy shocks. *Notes.* There are four panels which plot responses of output to particular changes in $\Delta\beta^{\tau}_{2,t}$ (panel a), $\Delta\beta^{\tau}_{3,t}$ (panel b), and the combinations of $\Delta\beta^{\tau}_{2,t}$ and $\Delta\beta^{\tau}_{3,t}$ (panel c and d). In each panel, the right picture plots changes in the yield curve, and the left picture plots changes in output.

relatively similar reactions in response to variations in the two components of monetary policy shocks. This strengthens the common knowledge about conventional monetary policy, which is increases in short-term interest rates lead to decreases in output and inflation, and also suggests that unconventional monetary policy might have a different effect, which is increases in long-term interest rates tend to increase output and inflation.

Our finding that increases in long-term interest rates increase inflation might also be interpreted along the lines of Uribe [2022] who divides monetary shocks into transitory and permanent changes in the interest rate. Uribe [2022] finds standard results for transitory shocks but that permanent interest rate increasing shocks have neo-Fisherian effects raising inflation in both short run and long run.

4 Functional local projections versus standard local projections

To emphasize the advantages of functional local projections in capturing effects of unconventional monetary policy, we re-estimate using standard local projections and compare the results. We measure the scalar monetary policy shock as one-day change in the fitted three-month yield around monetary policy announcement[28]; fitted refers to the estimated Nelson-Siegel yield curve from Section 2. We then estimate the impulse responses of inflation and output to the scalar monetary policy shock in a standard local projection using otherwise the same model specifications as in Section 3.

Figure 15 plots changes in the yield curve on two particular days. On 11/6/2015 the RBNZ reduced the OCR by 25 basis point to 3.25% given low inflationary pressures and the expected weakening in demand. After the monetary policy announcement the three-month yield sharply declined while the 10-year yield almost remained unchanged, leading to a downward shift at the short end of the yield curve while the long end was almost unaffected. This could be interpreted as a conventional monetary policy shock which mainly affects short-term interest rates. By contrast, on 13/2/2019 the RBNZ decided to remain the OCR at 1.75% and provided their expectation to keep the OCR at this level through 2019 and 2020. The decision was made in the context that employment was near its maximum sustainable level but core CPI remained below target, which necessitated continued supportive monetary policy. After the monetary policy announcement the three-month yield slightly rose while the 10-year yield significantly increased, leading to an upward shift at the long end of the yield curve while the short end was almost unaffected. This is a good example of how the RBNZ provides forward guidance on the future path of interest rates in conventional times and that forward guidance is an important part of the RBNZ's monetary policy.

Figure 16 plots the estimated impulse responses to the two - scalar and functional - monetary policy shocks on 6/2015. As most changes happened at the short end of the yield curve, the unconventional part of the shock is minor and hence the standard monetary policy shock can do a relatively good job in capturing monetary policy movements. As a result, the estimated impulse responses using standard local projections (the green lines) and functional local projections (the red lines) are almost exactly the same for inflation, but suggest a minor bias in the standard estimates for output.

[28] The standard approach would instead be to use the one-day change in the actual three-month yield around monetary policy announcements. We do this in Online Appendix (Figure 11), and the difference from the results reported here are small. We prefer to report the results using the shocks in the fitted three-month rates as that way our shocks in the standard local projection and functional local projection coincide exactly at the three month maturity.

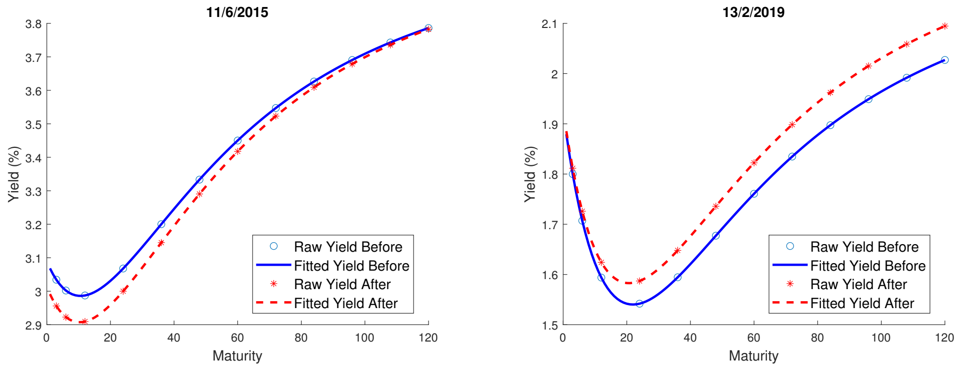


Figure 15: Changes in yield curve on 11/6/2015 and 13/2/2019. *Notes.* On 11/6/2015 most changes happened at the short end of the yield curve, while on 13/2/2019 most changes happened at the long end of the yield curve. In each subfigure the blue solid line represents the (fitted) yield curve on the day before the announcement, while the red dashed line represents the (fitted) yield curve on the day of announcement. The asterisk points are actual zero-coupon yields from Refinitiv.

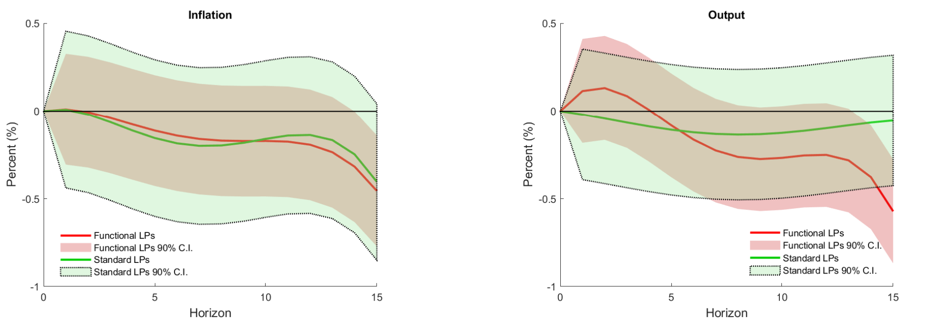


Figure 16: Responses of inflation and output to monetary policy shock on 6/2015. *Notes.* On 6/2015 most changes happened at the short end of the yield curve. Functional local projections and standard local projections result in similar estimated impulse responses, especially for inflation. In each subfigure the red and green lines are estimated impulse response, while red and green filled areas are 90% confidence intervals.

Figure 17 plots the estimated impulse responses to the two monetary policy shocks on 2/2019. As most changes happened at the long end of the yield curve, the unconventional part of the shock is significant and hence the standard monetary policy shock can do a poor job in capturing monetary policy movements. In other words, the standard monetary policy shock is misidentified and as a result, standard local projections provide biased estimates of the impulse responses.

To provide a more systematic understanding about the difference be-

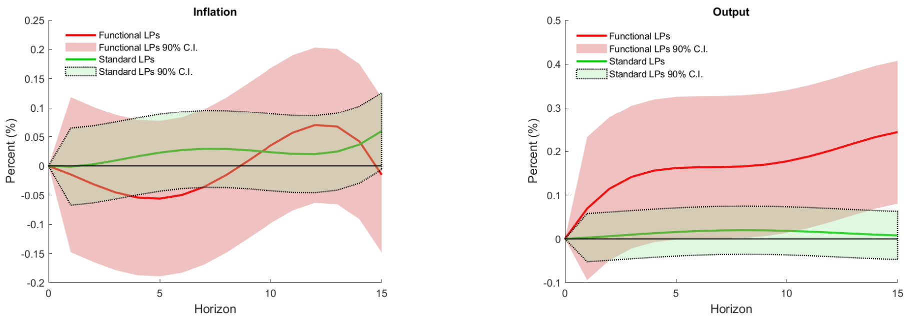
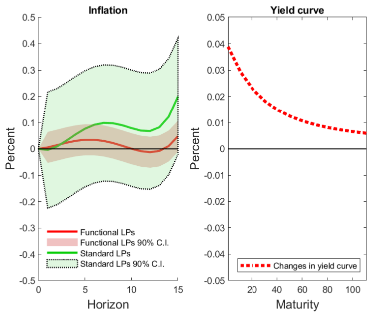


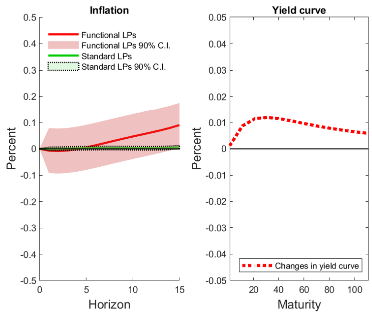
Figure 17: Responses of inflation and output to monetary policy shock on 2/2019. *Notes.* On 2/2019 most changes happened at the long end of the yield curve. Functional local projections and standard local projections result in different estimated impulse responses. In each subfigure the red and green lines are estimated impulse response, while red and green filled areas are 90% confidence intervals.

tween functional local projections and standard local projections, we reuse Figure 13 and add the estimated impulse responses of inflation to the scalar monetary policy shock (the green lines) to produce Figure 18. In panel a the increase of the slope factor causes an upward shift of the whole yield curve and an increase in the three-month yield. As most changes happen at the short end of the yield curve the estimated impulse responses of inflation using functional local projections and standard local projections are relatively similar. In panel b, however, the increase of the curvature factor causes an upward shift in the long end of the yield curve while leaving the three-month yield almost unchanged, leading to different results of impulse responses. While inflation increases substantially in the long run in response to the functional monetary policy shock, the almost-zero scalar monetary policy shock does not trigger any inflation reaction. In panel c the slope factor and curvature factor both increase, leading to a scenario similar to panel a and the two impulse response estimates are nearly identical. Panel d shares some similarity with panel b, with the slope factor and curvature factor moving in different directions, leading to an increase in short-term rates but decrease in long-term rates. As the scalar monetary policy shock misses all changes in long-term rates the estimate by standard local projections is very different from the estimate by functional local projections.

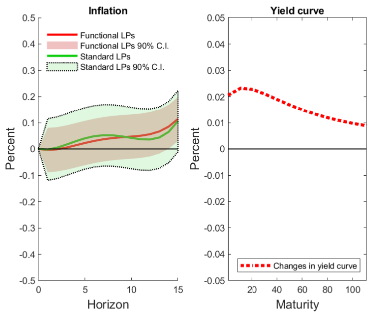
We do the same thing with output in Figure 19 and witness a similar result as inflation. When most changes happen at the short end of the yield curve and the scalar monetary policy shock can somewhat capture the general monetary policy movement, the estimated impulse responses of output using functional local projections and standard local projections are broadly similar (panel a and c). When most changes happen at the



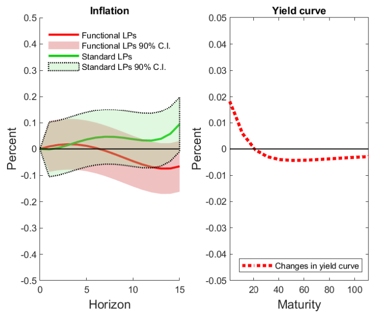
(a) $\Delta\beta^{\tau}_{2,t} = 0.04$; $\Delta\beta^{\tau}_{3,t} = 0$.



(b) $\Delta\beta^{\tau}_{2,t} = 0$; $\Delta\beta^{\tau}_{3,t} = 0.04$.



(c) $\Delta\beta^{\tau}_{2,t} = 0.02$; $\Delta\beta^{\tau}_{3,t} = 0.04$.

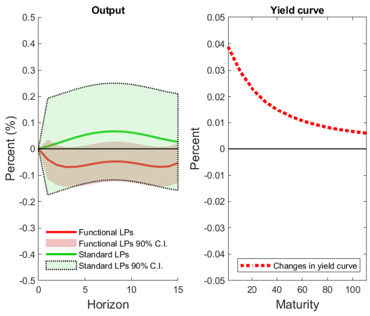


(d) $\Delta\beta^{\tau}_{2,t} = 0.02$; $\Delta\beta^{\tau}_{3,t} = -0.04$.

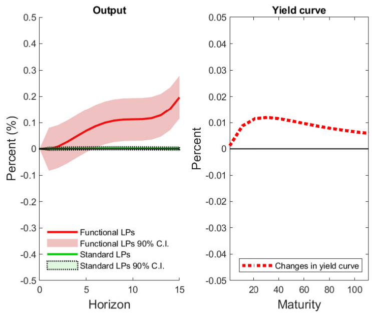
Figure 18: Responses of inflation to different components of monetary policy shocks. *Notes.* There are four panels which plot responses of inflation to particular changes in $\Delta\beta^{\tau}_{2,t}$ (panel a), $\Delta\beta^{\tau}_{3,t}$ (panel b), and the combinations of $\Delta\beta^{\tau}_{2,t}$ and $\Delta\beta^{\tau}_{3,t}$ (panel c and d). In each panel, the right picture plots changes in the yield curve, and the left picture plots changes in inflation.

long end of the yield curve or short-term rates and long-term rates move in different directions, the scalar monetary policy shock thus cannot capture all monetary policy movements and the impulse response estimated by standard local projections is biased/misleading as a result (panel b and d).

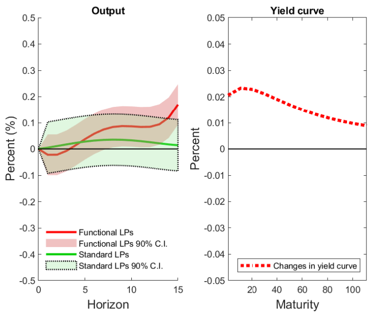
To summarize, the scalar monetary policy shock does capture monetary policy in short-rates, with only a minor bias in output. But it misses much of the impact of monetary policy when this occurs through the use of forward guidance. As the RBNZ started using forward guidance in concrete form in 1997 and have since provided forward guidance as a standard part of every monetary policy announcement, forward guidance has an important role in the RBNZ's monetary policy and cannot be ignored when studying the impacts of monetary policy on the economy. In fact, we also see more interest rate movements in long-maturity than short-maturity during the conventional period, consistent with forward guidance being used in New Zealand. The scalar monetary policy shock which ignores the unconventional monetary policy part including forward guidance is not a good measure of



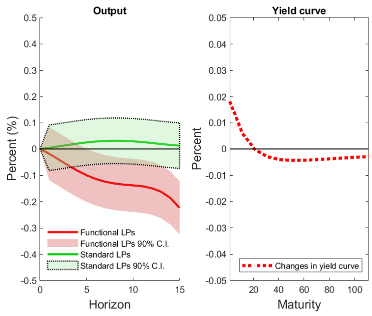
(a) $\Delta\beta^{\tau}_{2,t} = 0.04$; $\Delta\beta^{\tau}_{3,t} = 0$.



(b) $\Delta\beta^{\tau}_{2,t} = 0$; $\Delta\beta^{\tau}_{3,t} = 0.04$.



(c) $\Delta\beta^{\tau}_{2,t} = 0.02$; $\Delta\beta^{\tau}_{3,t} = 0.04$.



(d) $\Delta\beta^{\tau}_{2,t} = 0.02$; $\Delta\beta^{\tau}_{3,t} = -0.04$.

Figure 19: Responses of output to different components of monetary policy shocks. *Notes.* There are four panels which plot responses of output to particular changes in $\Delta\beta^{\tau}_{2,t}$ (panel a), $\Delta\beta^{\tau}_{3,t}$ (panel b), and the combinations of $\Delta\beta^{\tau}_{2,t}$ and $\Delta\beta^{\tau}_{3,t}$ (panel c and d). In each panel, the right picture plots changes in the yield curve, and the left picture plots changes in output.

the RBNZ's monetary policy movements, and as a result standard local projections are not a good method to estimate the impulse responses to the RBNZ's monetary policy.

5 Conclusion

Estimating the impulse responses of macroeconomic variables to monetary policy shocks is an ongoing interest of policymakers and economists. In this paper we apply the method proposed by Inoue and Rossi [2021] to estimate the impulse responses of inflation and output to monetary policy shocks using New Zealand data. The important feature of this method is to use the functional monetary policy shock which is defined as movements of the entire yield curve on monetary policy announcements. New Zealand has practiced forward guidance on interest rates since 1997 and so allowing for shocks to the whole yield curve seems particularly relevant here.

Our estimation process includes two separate parts. We first estimate the yield curve in New Zealand by fitting daily zero-coupon yields to the Nelson-Siegel model, and take differences between the estimated yield curves at different points of time to get the movements of the entire yield curves on monetary policy announcements which we define as functional monetary policy shocks. We then estimate the impacts of these monetary policy shocks on inflation and output using functional local projections. With the available data on New Zealand zero-coupon yields we can construct data on monetary policy shocks from 01/2012 to 12/2021 which covers the conventional and unconventional times for monetary policy in New Zealand. However, we decide to drop the unconventional monetary policy shocks and end the sample in 12/2019 because the unconventional time is short and experiences significant fluctuations in the estimated components of monetary policy shocks as well as inflation, and including this period might mislead the estimated impulse responses.

We find that monetary policy shocks have standard effects on inflation and output in the short run (i.e. increases in interest rates cause decreases in inflation and output) but it might not be the case for the long run. An increase in the short end of the yield curve typically decreases inflation and output in the short run, while an increase in the long end of the yield curve which can capture things like quantitative easings and forward guidance tends to increase inflation and output in the long run. We also provide empirical evidence that the effects of monetary policy shocks on output are relatively similar between a small open economy and a large economy, but unconventional monetary policy announcements in a small open economy have smaller impact on long-term interest rates.

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