Estimated Taylor Rules updated for the post-crisis period

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NON-TECHNICAL SUMMARY

A Taylor Rule-type equation is a commonly used method to describe, in simple terms, the behaviour of a central bank in adjusting short-term interest rates in response to economic conditions. We use the Taylor Rule approach as a framework for analysing monetary policy in New Zealand, Australia, and the US since the early 1990s. The policy targets of the three countries are all now quite similar, so the focus of this exercise is on understanding how each central bank responds to changing conditions.

This framework faces several challenges. Most importantly, Taylor Rules are at best an approximate description of how monetary policy is run. Other issues include how output gaps (the difference between actual and potential output) in each economy are estimated, structural economic changes over time (such as changes in the neutral interest rate), changing methods of implementing monetary policy (such as the switch to the Official Cash Rate in New Zealand), and the greater availability of data today compared to what policymakers had access to when setting monetary policy.

With these limitations in mind, we find that the response of monetary policy to economic conditions is similar in New Zealand and Australia. Both central banks respond to the output gap. Although both central banks also react to inflation, the magnitude of this reaction is less aggressive than both Taylor’s original 1993 rule for the US, and earlier estimates for Australia and New Zealand by Huang (2002), but in line with results found by Hofmann and Bogdanova (2012) for a group of advanced economies over the period 2001 to 2008. The smaller reaction to inflation may be due to better-anchored inflation expectations over our sample period – monetary policy doesn’t need to react much to inflation fluctuations if firms and households believe that those fluctuations will be short lived. Overall, in line with Huang (2002) and RBNZ (2007), we do not find evidence that the conduct of monetary policy has been significantly different in New Zealand, Australia, and the US, although the poor fit of our estimated rule for the US means that comparison with Australia and New Zealand is difficult. We also find some evidence that neutral nominal short-term interest rates have declined in New Zealand and Australia over the sample period.

Since the global financial crisis, wholesale short-term interest rates in New Zealand have been almost 400 basis points lower than the estimated Taylor Rule would have indicated. Australian short-term interest rates have been lower than a Taylor Rule would have indicated, but only by around 200 basis points. More negative output gaps in each economy since the crisis than estimated by the method used in our primary specification would explain a substantial portion of this deviation. Almost 200 basis points of New Zealand’s divergence from the estimated Taylor Rule prediction can be explained by the wider spread between retail mortgage rates (the rates facing final borrowers) and wholesale short-term interest rates (the rate more directly influenced by the Reserve Bank) since the crisis.
1. INTRODUCTION

Since Taylor's 1993 seminal work, researchers and policymakers have used variants of the "Taylor Rule" to understand and model the behaviour of monetary policy, where monetary policy is represented by a short-term interest rate. In the simplest form of the Taylor Rule, monetary policy sets the short-term interest rate in response to the prevailing economic situation as captured in the current inflation rate and current output gap. Examples of applications of Taylor Rules include Taylor (2009) and Bernanke (2010) (both for the US), and Peersman and Smets (1999) (for the euro area). Gagnon and Ihrig (2004) provide Taylor Rule estimates for New Zealand and several other industrial countries within a consistent framework. A range of papers have used Taylor Rules to examine monetary policy issues focusing on New Zealand, including Björksten et al. (2004), Huang (2002), Huang et al. (2001), Plantier and Scrimgeour (2002) and RBNZ (2007).

In this paper, we revisit estimated policy rules to determine whether the behaviour of monetary policy has changed in the wake of the GFC. Specifically, we use the Taylor Rule framework to help examine the behaviour of monetary policy in New Zealand, Australia and the US for a sample period starting from 1992 and including the post-global financial crisis period. The post-crisis period is of interest because it features quite different financial market conditions to the pre-crisis samples used in most empirical Taylor-Rule based studies of monetary policy. Also, in contrast to Taylor's original 1993 study, which used a (fairly short by today's standards) sample of quarterly data from 1987 to 1992 in the US, our sample is drawn exclusively from the period following the establishment of price stability in all three countries.

We make three main contributions.

First, we update and extend the work done in Huang (2002) and RBNZ (2007) and see if their conclusions hold for our post-price stability, pre-crisis sample period of 1992Q1 to 2008Q2 (before the sudden deepening of the crisis). Huang's sample runs from 1987Q1 to 2000Q4 for the US, 1987Q1 to 2002Q1 for Australia and 1988Q2 to 2002Q1 for New Zealand (with a variant New Zealand sample also truncated at 1999Q2, to exclude the post-OCR period). The sample in RBNZ (2007) runs from 1992Q1 to 2006Q4 for all three countries. In particular, we re-examine the finding of Huang (2002) and RBNZ (2007) that monetary policy in New Zealand would not have differed substantially had it been run using the Federal Reserve's or the Reserve Bank of Australia's apparent reaction functions as captured in estimated Taylor Rules.

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1 We wish to thank Anella Munro, Christie Smith, Michael Reddell, and other members of the Economics Department who provided feedback on earlier drafts of this note.
Although we generally confirm that finding, we also find that it appears much less statistically significant over our sample periods, particularly for comparisons with the US. This result is already somewhat evident in comparing results found in RBNZ (2007), which does not include pre-price stability data, with Huang’s, which does. Using our sample, it is difficult to find statistically precise estimates of the Taylor Rule for the US. Although this means that we do not reject the hypothesis that the estimated Taylor Rule coefficients were the same or similar for all three countries, it also means that, within our framework, the sample data are statistically consistent with quite a wide range of monetary policy reaction functions. In the post-price stability environment of more stable and subtle inflation dynamics, a structural modelling approach such as in Kam et al. (2009) may be more useful for comparing monetary policy across countries. The lack of statistical significance we find for the US Taylor Rule coefficients in our sample (both including and excluding the post-GFC period), in contrast to other econometric studies based on earlier time periods (e.g. English et al., 2003, which like Taylor, 1993 starts in 1987Q1 but ends in 2001Q4), suggests that the idea that Taylor Rules robustly describe monetary policy (in some timeless sense) should be treated with caution (see Orphanides, 2003, for a discussion of this point).

Our second contribution is to look at the post-crisis period in the three countries in closer detail. Interest rates in all three countries ran well below the predictions of our simple estimated Taylor Rules over this period. We measure the average divergences from a Taylor Rule prediction using a simple dummy variable for the period and discuss some possible explanations for the divergence.

Finally, we test alternative specifications for the Taylor Rule in New Zealand, such as allowing for a direct response to the exchange rate, building on the speculations in Taylor (2001) and tested for a number of emerging market countries by Mohanty and Klau (2004). We do not find evidence of a direct response to the exchange rate using standard estimation procedures. However, we do find a significant response to long-term US interest rates: short-term interest rates in New Zealand appear to respond to global financial conditions – possibly in order to reduce or offset exchange rate effects. This may be a result of the endogeneity of the exchange rate preventing the detection of an interest rate response directly to the exchange rate. But this result may also be picking up a simultaneous decline in neutral interest rates internationally.

The rest of the paper proceeds as follows. Section 2 sets out our Taylor Rule setup, the data and our estimation approach. Section 3 reports the results, and section 4 concludes.
2. DATA AND ECONOMETRIC SETUP

The classic Taylor rule was defined in Taylor (1993) as $i_t = i^* + b_\pi \pi_t + b_\gamma \gamma_t$, where $i_t$ is the (nominal) policy interest rate, determined by $i^*$, the 'neutral' interest rate; $\pi_t$, the current inflation rate minus target; and $\gamma_t$, the current deviation of output from its potential level. Taylor’s original proposed rule, which in his view "captures the spirit of the recent research [on interest rate policy rules] and which is quite straightforward" (p. 202), sets coefficients of 0.5 for $\gamma$ and 1.5 for $\pi$ (or equivalently 0.5 for a Taylor Rule specified with the real interest rate adjusted for current inflation as the dependent variable).

In this paper we use as a base case the more elaborate specification in English et al. (2003), Huang (2002) and RBNZ (2007) that allows for (i) gradual adjustment or "smoothing" of the interest rate to the rate specified by the classic Taylor Rule, and (ii) for serially correlated errors. Also following the earlier authors, we estimate by nonlinear least squares the following system, capturing these effects:

\begin{align*}
    i_t^R &= i^* + b_\pi (\pi_t - \pi^T) + b_\gamma \gamma_t \\
    i_t &= (1 - \lambda)i_t^R + \lambda i_{t-1} + v_t \\
    v_t &= \rho v_{t-1} + \varepsilon_t
\end{align*}

where $i_t^R$ is the interest rate that the classic Taylor Rule would prescribe, the degree of smoothing is captured by $\lambda$ (higher values correspond to more smoothing), serial correlation in the error term $\varepsilon_t$ is captured by $\rho$, and all other variables are as defined before.\(^2\)

As discussed by English et al. (2003), allowing for serially correlated errors accounts for the presence of serially correlated omitted variables, which are likely to be present as the Taylor Rule is only an approximation of the conduct of policy. However, central banks may wish to smooth their policy rate movements even in the absence of serially correlated errors, for several reasons. First, by moving policy slowly, they can influence the outlook for future interest rates, and so may be able to influence output and inflation with relatively small movements in short-term interest rates. Second, slow adjustment of policy rates may be desirable when there is uncertainty about the structure of the economy and the available data. We account for this policy smoothing via the lagged interest rate term, $\lambda$.

All data we use are quarterly. Figure 1 shows that inflation between 1987 and 1992, (the whole of the Taylor (1993) sample and a substantial part of the English et al.
(2003) and Huang (2002) samples) was a period of higher and more variable inflation than afterwards (figure 1).

**Figure 1: Inflation rates since 1987**

We begin our sample in 1992Q1, to exclude the high inflation period, and run the sample until 2012Q4. We measure \( \pi_t \) by headline CPI inflation for Australia and New Zealand and by PCE inflation for the United States.\(^3\)

We set \( \pi_T \) at the midpoint of the target range for Australia (2.5 percent) and at 2 percent for the United States. For New Zealand \( \pi_T \) varies depending on the relevant Policy Targets Agreement in each period. The policy rate \( i_t \) is proxied by the 90 day bank bill rate for Australia and New Zealand, and by the federal funds target rate for the United States.\(^4\)

\( \gamma_1 \) is estimated as the percentage deviation of actual output (as measured by real GDP) from trend output estimated by an HP filter over the whole sample with \( \lambda =1600 \), in line with Huang (2002) and RBNZ (2007). As the policy maker clearly does not have access to the ex-post estimated trend at the time a decision is made, the results should be treated with caution, as noted by Orphanides (2001).\(^5\)

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\(^3\) The Reserve Bank of Australia and the Reserve Bank of New Zealand have explicit agreements to target headline CPI inflation. The Federal Reserve announced a formal inflation goal of 2 percent based on the PCE measure [FOMC (2012)]. For the purposes of this paper we assume that the Federal Reserve have behaved as though this has been there implicit target throughout the sample period, which is a limiting assumption given the slightly higher average rates of inflation in the earlier part of our sample. The inflation measure for the US is the only difference in data source from RBNZ (2007). The use of CPI inflation in the US in place of PCE inflation made no material difference to the results. Econometric estimates were done on series excluding the impact of changes in the Goods and Services Tax in Australia and New Zealand over the sample (not removed in chart).

\(^4\) 90 day bank bill rates are common benchmarks in Australia and New Zealand, while not so common in the US. Prior to the crisis the 90 day bank bill rate was a reasonable proxy for the policy rate, or the rate most heavily influenced by monetary policy in New Zealand and Australia. The federal funds rate was originally used as the policy variable in Taylor (1993), and so is used here also. The close relationship between the federal funds rate and other short-term interest rates mean that the results are little changed based on this choice for the US.

\(^5\) Using historical data on the Reserve Bank of New Zealand's estimated output gap in real time was not suitable because of the unavailability of data covering the whole of our sample period. The Reserve Bank of New Zealand did not use an output gap concept in the early 1990s.
For testing the relevance of the exchange rate and global financial conditions in the New Zealand Taylor Rule we used the IMF unit labour cost real effective exchange rate (REER) measure and the yield on ten year US Treasury notes.\(^6\)

In regressions to estimate each country’s “pre-crisis” Taylor Rule, we terminate the sample at 2008Q2.\(^7\)

### 3. RESULTS

We first report results from estimating our base case Taylor Rule system for the post-price stability, pre-crisis period in the three countries. We then look at the results from Taylor Rules estimated on the whole sample but including a dummy variable for the post-crisis period, which measures of the impact of the crisis on the constant term. Finally, we report results from experimenting with including the exchange rate, and short- and long-term US interest rates as arguments in the Taylor Rule.

#### 3.1. PRE-CRISIS SAMPLE

Table 1 shows the results for the estimation of the system on pre-crisis data for New Zealand, Australia, and the US.

<table>
<thead>
<tr>
<th>(HAC standard errors in parenthesis)</th>
<th>New Zealand</th>
<th>Australia</th>
<th>United States</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Coefficient</td>
<td>p-value</td>
<td>Coefficient</td>
</tr>
<tr>
<td>Neutral interest rate ((i^*))</td>
<td>6.66 (0.44)</td>
<td>0.000</td>
<td>5.93 (0.38)</td>
</tr>
<tr>
<td>Response to inflation ((b_{\pi}))</td>
<td>0.46 (0.21)</td>
<td>0.032</td>
<td>0.37 (0.27)</td>
</tr>
<tr>
<td>Response to output gap ((b_{y}))</td>
<td>0.52 (0.23)</td>
<td>0.030</td>
<td>0.78 (0.70)</td>
</tr>
<tr>
<td>Coefficient on last period’s interest rate ((\lambda))</td>
<td>0.68 (0.14)</td>
<td>0.000</td>
<td>0.79 (0.12)</td>
</tr>
<tr>
<td>Serial correlation in errors ((\rho))</td>
<td>0.41 (0.14)</td>
<td>0.004</td>
<td>0.53 (0.21)</td>
</tr>
<tr>
<td>Adjusted R(^2)</td>
<td>0.83</td>
<td>0.90</td>
<td>0.97</td>
</tr>
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</table>

#### 3.1.1. NEW ZEALAND RESULTS

The coefficients on both the output gap and inflation are close to 0.5 and statistically significant for New Zealand. The results are similar to RBNZ (2007), reflecting that the sample is similar (although the coefficients on the output gap and inflation were not statistically significant in that work).

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\(^6\) The choice of real exchange rate measure did not affect the results.

\(^7\) A Chow test at this date rejects the null hypothesis of no structural break at the 1% significance level for Australia and New Zealand, and at the 5% level for the US.
Notably, although the coefficient on the output gap in New Zealand is the same as that proposed in Taylor (1993), that on inflation is rather different to Taylor's 1.5, and well below 1. This result is in line with that found by Hofmann and Bogdanova (2012), who find a mean estimate of close to 0.5 for both the output gap and the inflation reaction parameter in an estimated Taylor Rule for an aggregate of advanced economies in a sample period running from 2001 to 2008. A plausible explanation for this apparently (much) lower reactivity to inflation relative to the Taylor recommendation is that in our sample, price stability prevailed, in contrast to the period to which Taylor informally matched his rule. If inflation expectations were relatively well-anchored over our sample, the (ex-ante) real interest rate would not be affected as much by contemporaneous changes in the inflation rate. As a result, the nominal interest rate response to contemporaneous inflation required to generate a real interest rate response may be lower than in the pre-price stability period. During the period of higher and more variable inflation in the US to which Taylor's original rule was matched, it is likely that inflation expectations were less well anchored. In his paper Taylor in fact explicitly links expected inflation one-for-one to actual inflation. In this view, to ensure that real interest rates rise when inflation rises and thus stabilise future inflation, monetary policy has to ensure a greater than one-to-one response to inflation, implying a coefficient on inflation higher than 1.

To check the plausibility of this view of the inflation expectations process, we run a simple regression of two-year ahead inflation expectations against current inflation (not reported). Results were that current inflation can explain only 28 percent of the variance in inflation expectations, and that the response of inflation expectations is less than a fifth of the change in inflation (additional leads or lags of inflation did not change this). Therefore, the response of nominal interest rates to current inflation is stronger than the response of inflation expectations to current inflation. Indeed, consistent with this, we find that when the real interest rate adjusted by two-year ahead inflation expectations is used as the dependent variable in the estimation procedure, the response to changes in inflation is still positive (albeit slightly smaller). Additionally, if two-year ahead inflation expectations are used as a regressor in place of headline inflation, this suggests a large (coefficient of 2.36) 90 day rate response to inflation expectations, which is statistically significant at the 10 percent level.8

As a robustness check, we estimated different specifications of the above equation for New Zealand using real interest rates calculated using different forms of inflation (e.g. lags, contemporaneous and leads). These were not found to improve the fit of the model, although the endogenous relationship between current interest rates and future inflation prevents this being tested satisfactorily. We also estimated a two-stage

8 We did not find a statistically significant response to inflation expectations for Australia or the US, using the Melbourne Institute consumer inflation expectations series and the University of Michigan Survey of Consumers expected change in prices series respectively, perhaps due to the different nature of these surveys.
least squares model using four lags of each variable as instruments for the independent variables to control for possible endogeneity of the current short-term interest rate, the output gap, and inflation. Our results did not differ significantly. Estimating the equation with either the first or second lag of the output gap rather than the contemporaneous output gap produced similar estimates.

Finally, we note that New Zealand's pre-crisis Taylor Rule also seems to include considerable smoothing, similar to the result found by English et al. (2003). A result of 0.68 for $\lambda$ means that each quarter, the policy maker seeks to adjust around one third of the way towards the current underlying rate suggested by the rule. This is also consistent with the findings of Hofmann and Bogdanova (2012), who find a mean estimate of around 0.7 for the smoothing parameter in an aggregate of advanced economies.

3.1.2. COMPARISON WITH AUSTRALIA AND THE UNITED STATES

The estimated coefficients for reactions to inflation and the output gap in Australia appear similar to New Zealand. However, over our sample, the estimated coefficients on inflation deviations and output gaps for Australia and the United States are neither individually nor jointly significantly different from zero. Particularly in the US, an ARMA(1,1) model with high degrees of smoothing and serial correlation in the error terms would do almost as good a job at explaining interest rates. Interestingly, the data reject the original Taylor coefficients of 0.5 and 1.5 respectively at the 1 percent confidence level for all three countries. The estimated coefficients for $\lambda$ are similar in all three countries, suggesting that short-term interest rates are smoothed to a similar degree.

Like RBNZ (2007), coefficient restriction tests show that coefficients on the output gap and inflation for the US and Australia are not significantly different from those found for New Zealand, thus not rejecting the proposition that monetary policy behaviour in response to output gaps and inflation are the same in all three countries. However, this result is based on imprecisely estimated coefficients in the case of the US and Australia, which suggests that an approach that imposes more structure on the data may be more appropriate for comparing monetary policy across countries. For instance, Kam et al. (2009) examine the preferences (rather than rules) of the Reserve Bank of New Zealand, the Reserve Bank of Australia, and the Bank of Canada, and find little difference between them.

As a robustness check, headline inflation for each of the measures above were replaced with respective core (ex food and energy) measures of inflation for each

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9 As a robustness check, we estimated a Taylor Rule for Australia using Real Gross Domestic Income to construct the output gap rather than Real GDP, to better allow for capturing a response to movements in the terms of trade. This did not improve the results.
country (with GST removed). The results were very similar to those obtained using headline measures.

3.2. EXTENDING THE SAMPLE TO INCLUDE THE POST-CRISIS PERIOD

Next, we use the Taylor Rule estimated for New Zealand on pre-crisis data to predict interest rates for the rest of the sample and look at the variance of interest rates around the (assumed constant) neutral rate (figure 2).\textsuperscript{10}

This allows us to examine, within the Taylor Rule framework, whether interest rate behaviour appears to have changed since the crisis. Changes could occur for several reasons: a change in the policy rule, a change in economic structure (e.g. the neutral interest rate is not in fact constant), or an unusual pattern of shocks compared to earlier.\textsuperscript{11}

Figure 2: Breakdown of movements in 90 day interest rates around neutral (projected forward from estimate to 2008Q2, 2010 GST increase removed)

It is interesting to examine the component of 90 day interest rates in New Zealand unexplained by the pre-crisis estimated Taylor Rule. This is the difference, shown in red bars, between the predicted Taylor Rule rate (with smoothing) and the actual rate. In the pre-crisis period these red bars appear to be relatively small (figure 2). But since the crisis, the unexplained component of interest rates has been persistently large and negative, which suggests that a change in the monetary policy rule may have taken place, or that there have been large and persistent shocks or structural

\textsuperscript{10} Equivalent charts for Australia and the US are presented in the appendix.

\textsuperscript{11} In explaining Taylor Rule residuals (based on his proposed 1993 rule) from the mid-2000s period in the US, Taylor (2009) emphasises a normative interpretation, for example viewing the departures as "clearly evidence that there were monetary excesses during the period leading up to the housing boom" (p. 3). A little later in that article he allows that one can criticise the conclusion that the residuals represent bad policy by criticising the Taylor Rule benchmark, but does not really explore the reasons why the Taylor Rule's descriptive value might diminish over time.
change in the economy. The size of the unexplained component may be understated by the size of the red bars, as each unexplained setting of the policy rate causes a larger smoothing component in the next period, so some of the persistently large size of the green bars post-GFC is attributable to unexplained factors.\textsuperscript{12}

To be a bit more precise about how policy has systematically changed since the crisis, we include a dummy variable in the first equation in the system (the "pure" Taylor Rule equation), that is 0 until 2008Q2 and 1 from 2008Q3 onwards, for all three countries. The coefficients on these dummy variables represent the extent to which the average levels of policy rates are different from those in the rest of the sample, controlling for the other variables. That difference could represent, for example, views by the central banks that effective neutral interest rates have been lower since the crisis. The post-crisis sample is probably too short to satisfactorily test for any more complex changes. Results are shown in table 2.

Table 2: Estimated Taylor rule for New Zealand, 1992Q1-2012Q4

<table>
<thead>
<tr>
<th></th>
<th>New Zealand</th>
<th></th>
<th>Australia</th>
<th></th>
<th>United States</th>
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<tr>
<td></td>
<td>Coefficient</td>
<td>p-value</td>
<td>Coefficient</td>
<td>p-value</td>
<td>Coefficient</td>
<td>p-value</td>
</tr>
<tr>
<td>Neutral interest rate ($i^*$)</td>
<td>6.60 (0.42)</td>
<td>0.000</td>
<td>5.82 (0.30)</td>
<td>0.000</td>
<td>-0.92 (5.42)</td>
<td>0.866</td>
</tr>
<tr>
<td>Response to inflation ($b_i$)</td>
<td>0.50 (0.22)</td>
<td>0.027</td>
<td>0.39 (0.16)</td>
<td>0.018</td>
<td>0.01 (0.24)</td>
<td>0.963</td>
</tr>
<tr>
<td>Response to output gap ($b_y$)</td>
<td>0.55 (0.21)</td>
<td>0.009</td>
<td>0.42 (0.21)</td>
<td>0.055</td>
<td>0.74 (0.39)</td>
<td>0.058</td>
</tr>
<tr>
<td>Coefficient on last period's interest rate ($\lambda$)</td>
<td>0.67 (0.09)</td>
<td>0.000</td>
<td>0.61 (0.16)</td>
<td>0.000</td>
<td>0.73 (0.09)</td>
<td>0.000</td>
</tr>
<tr>
<td>Coefficient on GFC dummy</td>
<td>-3.59 (0.61)</td>
<td>0.000</td>
<td>-1.87 (0.64)</td>
<td>0.000</td>
<td>3.38 (1.68)</td>
<td>0.049</td>
</tr>
<tr>
<td>Serial correlation in errors ($\rho$)</td>
<td>0.38 (0.09)</td>
<td>0.000</td>
<td>0.62 (0.12)</td>
<td>0.000</td>
<td>0.97 (0.03)</td>
<td>0.000</td>
</tr>
<tr>
<td>Adjusted R²</td>
<td>0.93</td>
<td>0.90</td>
<td>0.90</td>
<td>0.90</td>
<td>0.98</td>
<td>0.98</td>
</tr>
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</table>

These results suggest that the change in the apparent neutral interest rate in the policy rule in New Zealand since the crisis, at almost -400 basis points, has been much greater than in Australia at almost -200 basis points. Other estimated coefficients are very similar to the estimates on pre-crisis data. Notably, the estimates of the response of short-term interest rates to inflation and the output gap in Australia are more precise than previously, and are now statistically significant at the 5 and 10 percent levels respectively. As with the pre-crisis sample, we are unable to reject the null hypothesis that these coefficients are equal for Australia, New Zealand, and the US. However, comparison with the US should be avoided, given that the estimated coefficient on serial correlation in the errors was close to unity for this equation, suggesting material mis-specification. In addition, it is worth noting the negative estimate for the neutral interest rate, the positive coefficient on the GFC dummy, and

\textsuperscript{12} Additionally, comparison to the suggested Taylor rate is only meaningful on a static basis, as different interest rate decisions in the past would have resulted in different outcomes for inflation and output, and hence different suggestions for interest rates in each future period.
the large standard errors of most coefficient estimates. The zero lower bound on interest rates (which has been binding in the US since the crisis) and method for estimating the output gap may be contributing to this.

In all three countries, estimates of the deviation from the estimated Taylor Rule since the crisis may reflect an incorrect estimate of the output gap. The simple HP-filter approach we use to produce output gap estimates can be highly uncertain, particularly close to the end of the sample period. Actual output gaps in each economy could have been more negative than we measure, explaining some of the deviation from our estimated Taylor Rules. Table 3 demonstrates that, using the HP-filter approach, all three countries were estimated to have had positive output gaps over 2012 - close to 1 percent in New Zealand and the US – much higher than other estimates of the output gap, such as that of the OECD.

Table 3: Average HP-filter and OECD output gap estimates over 2012

<table>
<thead>
<tr>
<th></th>
<th>New Zealand</th>
<th>Australia</th>
<th>United States</th>
</tr>
</thead>
<tbody>
<tr>
<td>HP-filter ((\lambda=1600))</td>
<td>0.84</td>
<td>0.27</td>
<td>0.92</td>
</tr>
<tr>
<td>OECD</td>
<td>-1.50</td>
<td>-0.88</td>
<td>-3.0</td>
</tr>
</tbody>
</table>

Source: Haver

As a demonstration of the effect of different output gap estimates, when the above equation for New Zealand was estimated using the Reserve Bank’s real-time published contemporaneous output gap (available only from 1997Q3), the coefficient on the GFC dummy fell to below 200 basis points, while the coefficients on other variables were similar (although as a point of caution, the serial correlation of the error term was notably higher). The lower coefficient on the GFC dummy reflects the fact that this output gap series is substantially more negative in the post-crisis period than the HP-filter output gap (for example, an output gap of -1.46 compared to 0.61 in 2012Q1).

3.2.1. TIME-VARYING NEUTRAL INTEREST RATES

Previous studies have found evidence of variation in neutral interest rates in New Zealand (Plantier and Scrimgeour, 2002, Kirker, 2008), and overseas (see, for example, Mesonnier and Renne, 2007). Figure 3 shows that the neutral interest rate for New Zealand, estimated either by progressively extending the sample at the end, or by using a fixed-length moving sample window, appears to have changed over time.\(^\text{13}\)

These results are similar to those found using the more sophisticated frameworks focussed on examining time-varying neutral rates in Plantier and Scrimgeour (2002)

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\(^{13}\) An 11 year rolling window was chosen as this was the shortest-length window that produced stable coefficient estimates over the entire sample.
and Kirker (2008), and suggest that neutral rates have probably fallen over time, with perhaps a slight pause during the mid-2000s. Consistent with our estimated GFC dummy above, estimates of the neutral rate fall relatively quickly as the sample period is extended to include more of the post-GFC period. Interestingly, a similar pattern is found for Australia.

Figure 3: Estimated neutral nominal 90 day rate for different sample periods, Australia and New Zealand

The possibility of a time-varying neutral interest rate is another factor suggesting caution in interpreting our simple estimated Taylor Rule-type equations. In these equations, the neutral interest rate is assumed to be constant, so if this is not the case, coefficient estimates could be biased. Changing economic structure, or a change in the actual or implicit inflation target, are examples of some reasons why neutral nominal interest rates could change over time.

4.3. POSSIBLE ADDITIONAL FACTORS INFLUENCING MONETARY POLICY SETTING IN NEW ZEALAND

Our results from the regressions with dummy variables suggest that, after the crisis, something changed to cause New Zealand’s interest rates to be set at a level consistently below that at which they would have been set in the past, given the contemporaneous output gap and rate of inflation. In this subsection we explore some possible reasons for these results, with the general caveats that the metric of the change is very simple, that the time period since the crisis is short, and that other factors such as time variation in the neutral interest rate or incorrect output gap estimates may be biasing our estimates.

4.3.1. FINANCIAL MARKET DISRUPTION AND THE ROLE OF SPREADS

Most obviously, the crisis caused many ructions in financial markets, and not all of these factors will be captured by the variables in this model. An example is that the funding costs of New Zealand banks increased markedly, as raising and hedging
offshore funds (especially at term) became much more expensive, also in turn bidding up the cost of retail deposits relative to the short-term wholesale interest rate. This lead to a substantial widening in the gap between the floating mortgage rate, a key part of the transmission mechanism for monetary policy in New Zealand, and the 90 day interest rate (our left hand side variable) more directly influenced by the policy maker. Figure 4 shows what appears to be a close relationship between the unexplained portion of 90 day interest rates, and the floating-90 day rate spread.

Figure 4: Floating-90 day rate spread and the unexplained portion of 90 day rates

The co-movement of the two series appears to be particularly strong at the beginning and the end of the sample, where there is the most variation in the spread.

There is substantial additional variation of the unexplained factor beyond that corresponding to the spread. When both the unexplained and "smoothing" component are considered, the deviation from the suggested "pure" Taylor rate since the crisis is even more pronounced, suggesting that the increase in funding costs may not be the only factor at play. Other factors that may be relevant, besides those discussed in the previous section, include that the neutral 90 day bank bill interest rate may have fallen particularly sharply since the crisis, due perhaps to a persistent shift towards credit or risk aversion ("deleveraging") on the part of households or firms, or a view that expected returns to investment have fallen persistently. The short duration of post-crisis data makes it difficult to test this conjecture formally.

When we use floating mortgage rates as the left hand side variable instead of 90 day interest rates, the magnitude of the unexplained component since the GFC is approximately halved. However, the floating mortgage rate is a proxy for the actual policy rate, so the equation is only valid if the central bank is acting to smooth floating mortgage rates rather than the 90 day rate - which may be the case since the GFC,
where changes in the spread between the 90 day rate and the floating mortgage rate have been large, but perhaps somewhat less so before the GFC.

In recognition of this modelling limitation, we use the spread between floating mortgage rates and 90 day rates as a term in the pure Taylor rule equation of the model, in order to estimate the degree to which the 90 day rate responds to this spread. This method produces unreasonable coefficients.

We conjecture that this result is due to the sample including the period in which the Reserve Bank of New Zealand used a Trade Weighted Index (TWI) comfort zone, and subsequently a Monetary Conditions Index (MCI), approach to the implementation of monetary policy, rather than an explicit instrument such as an interest rate. This approach, in which the Reserve Bank made statements about its degree of comfort with the overall level of monetary conditions as reflected in market interest rates and the exchange rate, prevailed for about a decade until the OCR system was introduced in 1999 (see Archer et al. (1999) and Guthrie and Wright (2000)).

These systems may have induced quite different short-term dynamics between 90 day rates and the spread to mortgage rates. In figure 5 it is evident that the short-term volatility of the 90 day rate prior to 1999 was higher than subsequently, and this probably reflects the relatively tight relationship between the 90 day rate and the exchange rate (which is typically volatile) under these systems. Banks may have been less inclined to adjust floating mortgage rates in response to relatively volatile movements in 90 day rates, for example for "menu cost"-style reasons. This would mean that 90 day rates rising would cause the spread to fall - the reverse direction of causality to that assumed in the Taylor Rule framework. The strong negative correlation between the 90 day rate and the spread from this source during the signalling period creates difficulties for the estimation (it tends to swamp the Taylor Rule effects). Precise estimates for the coefficients in the Taylor Rule equation could not be obtained when the pre-OCR period was excluded, reflecting the substantially smaller sample size.

Although the increase in the spread between the floating mortgage rate and the 90 day rate cannot explain the entire divergence from our estimated Taylor Rule since the GFC, it can explain a significant portion. If the output gap has been more negative since the GFC than our estimate suggests, these two explanations could together account for the majority of the unexplained component of short-term interest rates post-crisis.14

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14 When an equation was estimated with the floating mortgage rate as the independent variable and the Reserve Bank's real-time published contemporaneous output gap series, the estimated coefficient on the GFC dummy fell to around 50 basis points, and was not statistically significant. However, this sample period is shorter than our main sample given the availability of the output gap series, and the serial correlation coefficient was high at 0.82.
4.3.2. FORWARD-LOOKING MONETARY POLICY

A general limitation of the Taylor Rule framework in the form used here is that it assumes no forward-looking behaviour from the policy maker beyond any future implications implicit in current output and inflation data. Such behaviour has been shown to be relevant in explaining US monetary policy decisions (Orphanides and Wieland, 2008) and is routinely emphasised by monetary policymakers in inflation targeting countries (Roger, 2009, Rose, 2007). In extreme situations (such as a large, sudden event with obvious macroeconomic consequences in the near future), this is likely to cause large unexplained differences between the 90 day rate and the suggested Taylor rate.

For example, consider 2009Q1, where the interest rate appears to be extremely low compared to the suggested rate, but the next period this difference is hugely reduced. This is because a severe worsening of conditions was likely, and hence a lower 90 day rate would be suggested by the Taylor rule soon. When we estimated forward-looking specifications of the model using leads of inflation and the output gap, we found that these specifications tended to increase the importance of inflation and decrease the importance of the output gap in the estimated Taylor rule. However, the endogenous relationship between current interest rates and future economic conditions means that these estimates are not likely to be very reliable compared to estimates using a structural framework. Specifications using inflation forecasts for New Zealand from Consensus Economics, constructed using the method in Gerlach et al. (2011), did not find a statistically significant response to inflation in the year ahead.

4.3.3. THE ROLE OF THE EXCHANGE RATE

It has been suggested that central banks respond (or should respond) to exchange rate developments. Taylor (2001) examines some rules that include exchange rate
terms, and speculates that estimations are not likely to find a strong independent exchange rate effect, as the effect of the exchange rate on output and inflation is already implicitly accounted for by the central bank. We follow the methodology of Mohanty and Klau (2004), who found significant reactions to exchange rate changes in the Taylor Rules of a number of emerging economies. Mohanty and Klau ran a regression taking the form of the following equation:

$$i_t = i^* + b_x (\pi_t - \pi_t^*) + b_y y_t + b_{x1} \Delta x_t + b_{x2} \Delta x_{t-1} + \lambda_1 \Delta r_{t-1} + \varepsilon_t$$

Where all symbols retain their previous meanings, and $\Delta x_t$ is the change in the log real exchange rate (with an increase corresponding to an appreciation). Results for this regression in New Zealand, over the same period as previously are presented in table 4.

### Table 4: Estimated Taylor rule for New Zealand including exchange rate, 1992Q1-2008Q2

<table>
<thead>
<tr>
<th></th>
<th>Coefficient</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant ($i^*$)</td>
<td>1.59 (0.44)</td>
<td>0.001</td>
</tr>
<tr>
<td>Response to inflation ($b_x$)</td>
<td>0.14 (0.09)</td>
<td>0.113</td>
</tr>
<tr>
<td>Response to output gap ($b_y$)</td>
<td>0.19 (0.07)</td>
<td>0.009</td>
</tr>
<tr>
<td>Response to change in REER ($b_{x1}$)</td>
<td>-2.49 (2.19)</td>
<td>0.259</td>
</tr>
<tr>
<td>Response to change in lagged REER ($b_{x2}$)</td>
<td>-0.19 (1.84)</td>
<td>0.917</td>
</tr>
<tr>
<td>Coefficient on last period’s interest rate ($\lambda$)</td>
<td>0.76 (0.07)</td>
<td>0.000</td>
</tr>
<tr>
<td>Adjusted R²</td>
<td>0.81</td>
<td></td>
</tr>
</tbody>
</table>

In both this model, and other specifications we tested that included the REER, the policy response to the exchange rate was not found to be statistically significant.\(^{15}\) We also estimated several equations with the real exchange rate included for Australia, and also found no statistically significant response. This result is in line with the findings of Lubik and Schorfheide (2007), who, using a small-scale structural general equilibrium model, find no response to exchange rate movements in Australia and New Zealand (which contrasts with their findings of a significant response by the Bank of England and the Bank of Canada).

The endogenous relationship between interest rates and the exchange rate may be hindering standard estimation procedures to test for a response to the exchange rate, especially as financial variables adjust quickly to changing conditions. Instead, it may be more informative to test for a response to clearly exogenous global financial variables that might affect New Zealand through the exchange rate channel. One such example would be foreign interest rates (e.g. through the effect of interest rate

\(^{15}\) Specifications were tested using combinations of real, nominal, levels, differences, logs and lags.
differentials in the exchange rate channel of transmission). Gray (2013) finds a statistically significant response of short-term interest rates to the US federal funds rate in a pooled regression of countries with well-developed central banks. However, we find that the US federal funds target rate was not statistically significant when included in New Zealand's estimated Taylor rule, which suggests that foreign short-term interest rates are not an independent determinant of New Zealand's policy rate. However, when we included a measure of long-term US interest rates (10 year Treasury note yields) in our estimation, we found a significant response, which we present in table 5. Foreign long-term interest rates may be a good proxy for pressure on New Zealand's exchange rate (e.g. through uncovered interest parity effects), so these results suggest that New Zealand monetary policy may act to offset such pressure.

Table 5: Estimated Taylor rule for New Zealand including foreign long-term interest rate, 1992Q1-2012Q4

<table>
<thead>
<tr>
<th>(HAC standard errors in parenthesis)</th>
<th>Coefficient</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant ($\text{\texttt{\textdagger}}$)</td>
<td>2.76 (1.05)</td>
<td>0.010</td>
</tr>
<tr>
<td>Response to inflation ($b_p$)</td>
<td>0.38 (0.20)</td>
<td>0.063</td>
</tr>
<tr>
<td>Response to output gap ($b_y$)</td>
<td>0.53 (0.20)</td>
<td>0.008</td>
</tr>
<tr>
<td>Coefficient on last period's interest rate ($\lambda$)</td>
<td>0.64 (0.11)</td>
<td>0.000</td>
</tr>
<tr>
<td>Coefficient on foreign long-term interest rate</td>
<td>0.73 (0.21)</td>
<td>0.001</td>
</tr>
<tr>
<td>Coefficient on GFC dummy</td>
<td>-1.77 (0.57)</td>
<td>0.003</td>
</tr>
<tr>
<td>Serial correlation in errors ($\nu$)</td>
<td>0.41 (0.11)</td>
<td>0.001</td>
</tr>
<tr>
<td>Adjusted R$^2$</td>
<td>0.93</td>
<td></td>
</tr>
</tbody>
</table>

The response to long-term US interest rates may be due to a trend decline in neutral interest rates in New Zealand, Australia, and the US, as 10 year government bond yields have moved together closely in all three countries (figure 6). When the equation in table 5 was estimated using a linear time trend rather than the US long-term interest rate, this term was not found to be statistically significant – but as our earlier moving sample estimates suggested, this may not be a simple linear trend. When the change in, rather than the level of, the US long-term interest rate was included in the estimation, the coefficient was similar, although the p-value was higher at 0.15. Interestingly, when long-term foreign interest rates are controlled for, the fall in the constant since the GFC appears to be smaller, and the serial correlation coefficient is lower. \(^{16}\)

90-day interest rates could also be responding to something other than exchange rate pressure, such as information contained in long-term foreign rates about the outlook for world growth.

\(^{16}\) When we estimated this equation for Australia, we obtained a similar coefficient on the foreign long-term interest rate, and a similar reduction in the magnitude of the coefficient on the GFC dummy, although the serial correlation coefficient was slightly higher.
5. CONCLUSION

In this paper we estimated simple Taylor Rule-type equations for New Zealand, Australia and the US allowing for policy rate smoothing and serial correlation in the error terms. Alternative specifications of the Taylor rule were investigated for New Zealand to examine whether incorporating further possible determinants of policy rates, such as mortgage rate spreads, foreign interest rates and the exchange rate, could improve the representations of the policy rule.

Policymakers react to what they can "see" at any point in time, which includes a wide range of indicators. The Taylor-Rule type equations estimated are simple rules that use only a few variables as inputs: inflation, previous values of the short-term interest rate, and estimates of the output gap. These output gap estimates are highly uncertain, and in many cases are very different from those that would have been available to policymakers at the time they were making decisions. Limitations such as these mean that these estimates should be treated with some caution.

Coefficient restriction tests suggest that the coefficients on the output gap and inflation for the US and Australia are not significantly different from those found for New Zealand, as in Huang (2002) and RBNZ (2007). Thus, we do not reject the proposition that monetary policy behaviour in response to output gaps and inflation is the same in all three countries. However, other approaches may be better suited for comparisons with the US, as our longer sample drawn exclusively from the post-price stability period produces a Taylor Rule with considerably less precisely estimated coefficients in the case of the US. Interestingly, the Taylor Rule coefficients on inflation in all three countries from the post-price stability period are all well below the 1.5 value proposed in Taylor (1993). We attribute this result to the better anchoring of inflation expectations in that period, and hence less need for the highly reactive...
monetary policy proposed originally by Taylor in the context of higher actual inflation in the US.

The estimated New Zealand Taylor Rule suggests that New Zealand has had a lower policy rate than expected since the crisis. We find a similar result for Australia, although the result is less marked. Comparison with the US in this regard is more difficult, given the poor fit of our estimated Taylor Rule for the US and the binding constraint of the zero lower bound on interest rates since the crisis. The method with which we construct our output gap estimates (a simple HP filter) may be contributing to the large and persistent deviations found from the estimated Taylor rule since the crisis. Given the uncertainty of output gap estimates, particularly near the end of a sample period, recent output gaps could have been considerably more negative, therefore explaining some of the recent deviation from Taylor Rule estimates. There is also some evidence that the spread between the floating mortgage rate and the 90 day rate (reflecting changes in funding costs) explains a significant portion of this deviation in New Zealand.

When tested for directly, New Zealand’s interest rates do not seem to respond to changes in the exchange rate. However, interest rates do appear to respond to long-term foreign interest rates. This response may be due to interest rates responding to offset exchange rate pressure due to changing global financial conditions, but the endogenous relationship between interest rates and the exchange rate masking this. However, we cannot rule out other explanations, such as long-term foreign interest rates capturing information about other relevant omitted variables, such as neutral interest rates or future world growth.

Overall, our results are consistent with Huang (2002) and RBNZ (2007) in suggesting that monetary policy conduct has been similar in New Zealand and Australia, although the poor fit of our estimated rules for the US makes comparison with the US more difficult. The binding zero bound in the US over the last few years further complicates comparisons between New Zealand and Australia on the one hand, and the US on the other.
REFERENCES


APPENDIX

Figure A1: Australia: breakdown of movements in 90 day interest rates around neutral (projected forward from estimate to 2008Q2, 2000 GST increase removed)

Figure A2: US: breakdown of movements in federal funds target rate around neutral (projected forward from estimate to 2008Q2)