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Estimating a Taylor Rule for New Zealand with a time-varying neutral real rate

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Abstract[1, 2]

Many critics of the Taylor rule claim that it is inferior to inflation forecast based (IFB) rules because it is not forward-looking, is not aggressive enough, and because of uncertainty surrounding the output gap. Nevertheless, the Taylor rule serves a constructive purpose because it abstracts from the Bank's macroeconomic model, FPS, and its performance is robust across various economic models. The Taylor rule thus provides a useful cross-check to the IFB rule, whose recommendations necessarily rely on a particular model structure, its dynamics and specific judgements over the forecast horizon. Additionally, this paper contends that any interest rate rule or model must account for the fall in the ex-ante real interest rate and the non-stationarity of short-term rates in New Zealand. We show how the neutral real interest rate (NRR) in the Taylor rule drifts downward since the second quarter of 1988, and explain why this presents additional real-time difficulties for the Taylor rule.

1 We would like to acknowledge the support and insightful comments of David Archer and Nils Björksten. We would also like to thank others who have commented on earlier versions of this work or assisted in other ways: Sean Collins, Yuong Ha, David Hargreaves, Leni Hunter, and Weshah Razzak.

1 Introduction

The greatest strength and weakness of the Taylor rule is its simplicity. The Taylor rule concisely encapsulates some of the key judgements that a policymaker must confront when deciding on the appropriate level of the short-term interest rate, and suggests how the policymaker should respond to these key judgements once they are made. However, its simplicity also leads many central bankers to conclude that it is impractical because it cannot possibly give them the correct response in all situations. While this is certainly true, the Taylor rule allows for an accounting of the key judgements made over time, and does not need to be interpreted strictly as a 'rule'. Instead, the Taylor rule provides a useful cross-check of the judgements made, and should be viewed simply as an alternative interest rate path to an inflation forecast based (IFB) rule, or any other reaction function.

Unsurprisingly, the Reserve Bank of New Zealand (the Bank or RBNZ) does not strictly adhere to the suggested interest rate setting derived from an IFB rule. Nor does any central bank follow any interest rate rule, or reaction function, quarter by quarter. Rather, the IFB rule used in the Bank's macroeconomic model, the Forecasting and Policy System (FPS), serves as a suggested baseline that policymakers are free to temporarily deviate from if they judge it necessary. The interest rate path resulting from the IFB rule simply gives the policymaker the best estimate of what policy changes are necessary to bring inflation back to target in a reasonable time frame.[3]

3 The IFB rule used in FPS responds to the deviation of forecast inflation rate in the 6th, 7th and 8th quarters from the midpoint of the 0 to 3 per cent target range. Therefore, inflation will not always return exactly to target in 2 years time. This rule is somewhat different than the 'strict' inflation targeting rule that Svensson (1997a) discusses because the 'strict' rule brings inflation back to target in a specified horizon, where the IFB rule does not. It is therefore closer to his 'flexible' rule than the 'strict' rule, see Svensson (1997b) for his opinion.

By contrast, the Taylor rule[4] is simply specified as

$$i = r^* + inflation \; + 0.5(inflation - inflation\ target) + 0.5\ output\ gap, \qquad (1)$$

where i is the short-term nominal interest rate, either the Official Cash Rate (OCR) or the 90 day bank bill rate, r^* is the neutral (or equilibrium) real interest rate, *inflation* is the current annual percentage change in the CPI and also represents the inflation premium, *inflation target* is the stated target of the central bank, and *output gap* is the per cent difference between the current level of output and potential GDP as calculated by the central bank. The simplicity of the Taylor rule is immediately evident in that it tells the policymaker to raise the real interest rate by ½ per cent if inflation is one per cent above target or if the output gap is one per cent above potential GDP. Note that the nominal interest rate must be raised by 1½ per cent if inflation is one per cent above target in order to raise the real rate by ½ per cent. Throughout this paper, the response coefficients in the Taylor rule are 1½ for inflation and ½ for the output gap.

Besides its simplicity, the chief advantages of a Taylor rule include its focus on variables that most policymakers consider important, its robust performance across various models of how the economy works, and its abstraction from a specific model. Generally, these advantages arise because the Taylor rule explicitly incorporates concern for a measure of excess demand (the output gap), inflation, and movements of the interest rate away from its perceived equilibrium level, and because the output gap, inflation and interest rate are key drivers in most models examined.[5] The first point is worth emphasising since the Taylor rule might be considered a first order static approximation of the policymaker's preferences. (This line of reasoning is developed in Appendix A.) If one views the

[4] This follows Taylor's original suggested weights for U.S. Fed. See Taylor, John B. (1993) "Discretion versus policy rules in practice", *Carnegie-Rochester Conference Series on Public Policy* 39: 195-214.

[5] Finan and Tetlow (2000) provide a good discussion of why parsimonious rules do well in forward-looking models of the economy. Basically, inflation, the output gap, and the interest rate are important state variables, and if a rule has interest rate smoothing, for example, it implicitly includes all past state variables.

Taylor rule as an efficiency or first order condition (see Svensson, 2001 and Weymark, 2001), then it should hold as long as the policymaker places a constant and positive weight on movements in the output gap, inflation, and interest rate. Of course, if the policymaker's preferences or views of the transmission mechanism change over time, then the neither the Taylor rule nor any other fixed rule will be a good approximation of actual policy.

In this paper, we claim that the Taylor rule is a reasonable approximation of the RBNZ's inflation control problem at any point in time, but that the equilibrium or neutral real interest rate embedded in the Taylor rule possesses a significant downward drift since 1988 Q2. This fall in the neutral real interest rate, r*, poses considerable real-time difficulties for any rule or model in New Zealand unless there is an explanation for why real interest rates have fallen. Because of this downward drift in the New Zealand ex-ante real interest rate, the Taylor rule with its constant r* would give policymakers misleading advice unless they continually revise their estimate of r*. This issue and the real-time output gap difficulties emphasised by Orphanides (2001) are not unique to the Taylor rule, and present problems for any rule or model that has an r* or output gap concept. Both problems arise because these variables are inherently "unobservable", and so they must be inferred based on the evolution of the economy. In New Zealand, the more pressing "unobservable" is probably the r* concept because the ex-ante real interest rate has fallen significantly since 1988 Q2, and this fall cannot be explained by the movements of the output gap and inflation relative to target.

Section 2 briefly reviews relevant parts of the literature on Taylor rules and monetary policy rules more generally. Section 3 discusses the data and methodological issues involved in estimating and using a Taylor rule in practice, and highlights the importance of how one treats the r* concept. Section 4 presents the results from three different estimation approaches to the r* concept for New Zealand, all of which suggest a significant fall in r* since 1988 Q2. Section 5 briefly discusses the policy consequences of using an incorrect or constant view of r*, and advises that policymakers should not use an r* based on an historical average. Section 6 concludes that the Taylor rule is an inherently useful benchmark, once a time-varying r* is allowed for, and often gives advice similar to the inflation forecast based rule used in the Bank's macroeconomic model, FPS.

2 Literature review

The Taylor rule uses current values of inflation and the output gap to set the interest rate target of a central bank, but many people view it as an approximation of an inflation targeting rule because the output gap and inflation are two primary indicators of future inflationary pressure. Svensson (1997a) shows that a strict inflation targeting rule can be written in terms of the current output gap and inflation for a simple two equation model. The model contains only an aggregate demand (IS) equation and a Phillips curve where inflation depends on the output gap. The interpretation of these coefficients in the Taylor rule is that they are informative for future inflation, not that the central bank cares explicitly about the current output gap or current inflation.

Svensson (1997a) also shows that a flexible inflation targeting rule, where the central bank places some explicit weight on the time path of the output gap, can be written in terms of the current output gap and inflation. The size of the response coefficients to the current output gap and inflation become smaller, and inflation does not always return to target in the specified horizon because the central bank cares about the time path of the output gap. Svensson (2000) further extends the analysis of inflation targeting to the open-economy. In his open-economy model, inflationary pressure arises from foreign shocks as well as from domestic sources. These international developments affect the domestic output gap, and at some stage domestic inflation. Therefore, the optimal rule in his model includes responses to international developments. On the whole, one should not discount the usefulness of a Taylor rule solely because it relies on the current output gap and inflation. Still, it is quite unlikely that the original Taylor rule will be optimal for all countries, especially since the economy is more complicated and its structure varies across countries.

2.1 Not always optimal policy rule

Because the response coefficients in the Taylor rule and the correct equilibrium real interest rate, r*, differ across countries and over time, it makes sense to estimate coefficients that match the behaviour of the interest rate on average, and allow for any structural breaks in r* due to other factors. These parameters can be adjusted to match the underlying structure of the economy and the objectives of the central bank, so we should not be too concerned with the size of the response coefficients. Whether the response coefficients to the inflation and output gap are 1½ and ½ in New Zealand, respectively, is more of an empirical issue, and we will attempt to estimate the parameters for New Zealand. Theoretically, some authors have considered the question of what the optimal response coefficients are, and we briefly review some of these papers.

The literature on optimal rules or investigations of policy rules for central banks is quite extensive, so we will limit our attention to a few particularly relevant ones. Lansing and Trehan (2001) perform an interesting theoretical investigation using a small model, and demonstrate what is required to make a Taylor rule optimal under discretion. They show that it depends crucially on how forward-looking the underlying structure of the model is. They find that the Taylor rule becomes optimal when there is "a high degree (of) forward-looking behaviour in the aggregate demand equation (IS), a low degree of forward-looking behaviour in the term structure equation, or a large, but still plausible, interest rate sensitivity parameter in the aggregate demand equation (IS)." Their overall conclusion is that the Taylor rule can not be ruled out as possibly being optimal given the wide range of parameters that could make it optimal under discretion.

Strictly speaking though, the Taylor rule is not a very aggressive rule, in that the response coefficients are rather small, and is not optimal in models of the economy where the IS and Phillips curve (PC) equations are mostly backward looking. The backward looking nature of the IS and PC equations makes it optimal for the central bank to be quite aggressive and forward-looking. However, given the uncertainty about how much forward-looking behaviour exists in the true model of the economy, it remains possible that the Taylor rule with its small response coefficients will be optimal or close to optimal. In particular, Lansing and Trehan note that "increasing the degree of forward-looking behaviour in the IS equation can significantly attenuate the optimal policy response." In regards to the PC, they note that "as the Phillips curve becomes highly forward-looking, the inflation coefficient in the policy rule drops sharply and the gap coefficient shoots up."

By contrast, the Bank's own research on interest rate policy rules suggests that only rules that respond quite aggressively to forecast inflation and the output gap can achieve the best results. Even rules that respond to forecast inflation several quarters ahead recommend response coefficients that are significantly larger than the 1½ in the Taylor rule. For example, the current rule used in FPS projection rounds requires a response of roughly 5 to 1 for deviations of forecast inflation from target inflation. Of course, the optimality of this sort of rule depends quite substantially on the underlying structure of FPS, which has a mostly backward looking PC equation, and forecast inflation does not move around a great deal.[6] While it is true that interest rate rules that respond only to contemporaneous inflation and the output gap can be close to optimal in the Bank's macroeconomic model, they tend to be quite aggressive in their response to observed inflation, well over the 5 to 1 ratio mentioned above.

When confronted with such divergent conclusions regarding the correct interest rate rule to use as a baseline, it is important to understand the underlying assumptions, how variations in these assumptions change the results, and attempt to assess whether the assumptions are valid. Batini and Nelson (2001) find that the optimal response horizon for an IFB rule varies between 2 quarters ahead and 15 quarters ahead for the UK, and that the optimal horizon depends crucially on how forward-looking the model is. Generally, a shorter horizon is optimal when they use a structural model of the UK economy that allows for forward-looking behaviour. On the

[6] Examples of RBNZ research on optimal monetary policy rules include Gaiduch and Hunt (2000), Ha (2000), Drew and Hunt (1999), Drew and Hunt (1998), and Conway, Hunt, and Scott (1998). For related issues and various perspectives, see Hetzel (2000), Levin, Wieland and Williams (2001), Sack and Wieland (2000), Sack (2000), Taylor (1999), Williams (1999), and Woodford (1999a, 1999b).

other hand, a much longer horizon is optimal when they use an estimated VAR, which is backward-looking. Batini and Nelson's (2001) paper demonstrates the dramatic effect of forward-looking behaviour on the optimal response horizon, and their results further suggest that the Taylor rule might be close to optimal in forward-looking models of the economy. Moreover, their results suggest that the performance of an IFB rule with a given horizon varies with the degree of forward-looking behaviour in the economy.

By and large, the more forward-looking the public is, the less forward-looking the central bank needs to be and the more likely a Taylor rule is optimal or close to optimal. A maintained assumption in most analyses of interest rate rules is that the model used has the correct structure, or degree forward-looking behaviour. While we do not directly address this point in a forward-looking model for New Zealand economy, Razzak (2002, 1997) has found empirical support for the notion that the Phillips curve in New Zealand is reasonably forward-looking. Given this evidence for New Zealand, it seems appropriate to examine rules whose performance is robust across different views of how the economy works, eg the Taylor rule.

2.2 Robust policy rule

McCallum (1997, 1988) and others raise the robustness issue, and ask whether it is more important for a rule to perform well across various views of how the economy works. This approach suggests that the extensive research on optimal rules has been useful if each exercise involves different views of how the economy works, so that we can scrutinise the performance of a number of rules across models. Taylor (1999) and Levin, Williams and Wieland [LWW (2001)] do precisely this exercise. In Taylor (1999), the Taylor rule with response coefficients on the output gap of ½ or 1 proves the most robust of the set of response coefficients considered. LWW (2001) explore a range of models with varying degrees of forward-looking behaviour in the structural equations, and search for robust interest rate rules that do well over a number of models. Somewhat differently from Taylor, LWW (2001) find that rules that respond to the contemporaneous output gap, forecast inflation four quarters ahead and involve significant interest rate smoothing are the most robust rules.

The first finding of LWW (2001) is consistent with previous Bank research that showed the performance of the Bank's IFB rule could be enhanced if there were some positive response to the output gap, Drew and Hunt (2000). The second finding runs somewhat counter to the Bank's previous research because it indicates that the Bank should shorten its horizon somewhat, although this is consistent with Batini and Nelson (2001) if the economy is more forward-looking. Past Bank research found that it would be better to extend the horizon significantly, say to 2 ½ years, because this would put the Bank on a lower variability tradeoff between output and inflation, see Ha (2000). Again, this result derives mainly from the less forward-looking nature of FPS, and is therefore heavily model dependent. The last finding of significant interest rate smoothing partially arises due to a constraint placed on the amount of quarter to quarter variability of the short-term interest rate, but mainly arises because of the forward-looking nature of the models in question. This result runs counter to previous Bank research that suggests the best rules are the most aggressive, and suggests that the optimal amount of interest rate smoothing is also model dependent.

LWW (2001) also note that outcome based rules like the Taylor rule perform reasonably well in most models, and that it is close to optimal in models that are more forward-looking. Despite this, the results in LWW suggest that the most robust rules are ones that commit to a gradual short run response, but a much more persistent response. These rules achieve this by using significant amounts of inertia through dependence on lagged interest rates. This recommendation suggests that as long as the output and inflation gaps are positive (negative), policy should continue to raise (lower) interest rates.

While little research has been done at the Bank exploring this type of rule, the effects of significant interest rate smoothing were explored in Drew and Plantier (2000), and show that interest rate smoothing in a partial adjustment framework is not too costly in FPS. If interest rate smoothing in the partial adjustment framework were increased along with the long run response coefficients to forecast inflation and the output gap, then the Bank's model would produce similar results to LWW (2001), see forthcoming paper by Plantier

and Scrimgeour (2002). According to LWW (2001), a gradual policy response in the short run is not a bad approximation of a robust policy, but a more aggressive response would be necessary if shocks were persistent or all occurred in the same direction.

3 Methodological issues with a NZ Taylor Rule

To assess whether a Taylor rule matches the dynamics of the short term interest rate, we use data on the New Zealand 90-day bank bill interest rate, real GDP, CPI inflation (π) excluding GST (consumption tax) and credit services, and expected inflation one year ahead (π^e). We also use a historical measure of the Bank's inflation target (π^*), and concentrate on the period after 1988 Q2 because it coincides with Governor Brash's tenure.[7] This data set presents immediate difficulties because the 90-day bank bill interest rate is I(1), while all the other variables are I(0). We refer the interested reader to Table 3 for results of the ADF and Phillips-Perron tests. Due to the non-stationarity of the 90-day rate, we are necessarily suspicious of our OLS results because they may be spurious, but we discuss this more fully after we examine the residuals in section 4.

In many cases, empirical studies assume that the inflation target is constant, see Judd and Rudebusch (1998), but we employ our own internal measure of publicly stated inflation targets to minimise any persistent error that using a constant might introduce. Another perspective might view the inflation target as an unobservable variable like r* and the output gap. However, we believe that the Bank's stated inflation target matches its operational target more closely than a constant. The issue of whether the Bank tried to achieve these inflation targets with the same vigour should be reflected in the stability of the Taylor rule parameter estimates.

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7 This internal measure of π^* was constructed for empirical work inside the Bank, and goes back to 1984 Q3, see Figure 2. The series uses the midpoint of the target range after 1992, the average inflation of New Zealand's trading partners before there was a stated range, and interpolates between this two periods so that the inflation target becomes 1 per cent by 1992 Q4 as required by legislation. In 1997 Q1, the inflation target range widen to 0 to 3 per cent, so the inflation target jumps up to 1.5 per cent. This series is available upon request.

The question of the appropriate parameterisation of a Taylor rule necessarily depends on what matches the observed behaviour of the short-term interest rate in New Zealand over time, and on the underlying structure of the New Zealand economy. We attempt to find a few Taylor rules that look to be appropriate for New Zealand. In general terms, a Taylor rule can be expressed as

$$i_t = r_t^* + \pi_t + g(y_t - y_t^*) + h(\pi_t - \pi_t^*) \qquad (2)$$

where i_t is the short-term nominal interest rate at time t, say the 90-day bank bill rate, r_t* is the neutral (or equilibrium) real interest rate at time t, π is the current annual percentage change in the CPI, π_t* is the stated inflation target of the central bank at time t, $(y_t - y_t^*)$ is the per cent difference between the current level of the output and potential GDP as calculated by the central bank, and g and h represent the response coefficients to the output gap and inflation gap, respectively. Note that r* and π* both contain time subscripts because they may be time-varying.

A number of issues arise with a New Zealand Taylor rule (NZTR). Firstly, the appropriate r* for New Zealand needs to be determined. For example, soon after the adoption of the OCR regime in early 1999, an r* between 4 to 5 per cent seemed to work fairly well, and was consistent with the r* used in the Bank's macroeconomic model, FPS. This implies a neutral nominal rate between 5.5 to 6.5 per cent when inflation is at the midpoint of the target range, 1.5 per cent. However, r* should not be viewed as something that is a constant for all time periods, and there exists significant uncertainty surrounding it.

One interpretation of the neutral real interest rate, r*, in the Taylor rule is that it captures all other factors that might make a central bank's inflation control problem harder or easier than current information on inflation and the output gap indicate. Therefore, one can think of the Taylor rule as holding these other factors constant, ie, world economic growth, the exchange rate, asset prices, et cetera, in order to focus attention on recent developments in inflation and the output gap. In this light, r* is likely shifting around all the time, but the policymaker takes a stand on where the average r* will be over some time period. If some other real or cyclical factors, eg a

global slowdown or the lack of housing price inflation, indicate that inflationary pressure might be easier, then r* would need to be adjusted accordingly. On the other hand, a low level of the exchange rate may argue in the opposite direction and for a higher r*.

We take three approaches to the issue of the appropriate r* in the NZTR over history. The first approach uses OLS and recursive OLS estimates to demonstrate that the estimate of r* ranges from 4.0 to 6.0 per cent at the end of the sample, and that the estimate of r* falls significantly over time. This suggests that some factor(s) caused the estimate of r* to be much higher early on and much lower later on. The second approach assumes that r* has a linear deterministic trend since 1988 Q2, and further confirms the downward drift in r*. The third approach builds on this evidence, and allows r* in the Taylor rule to gradually vary over time. We employ a state-space approach to back out a filtered time-varying estimate of r*.

Secondly, the appropriate measure of inflation in the Taylor rule presents some difficulties. At first glance, the most appropriate measure of CPI inflation is the one that the Bank gets judged upon, yet there are issues about whether this measure is a good indicator of future inflationary pressure, which most inflation targeters seek to minimise. Because there are many one-offs that raise or lower this measure of CPI inflation, an increase (decrease) in this measure of inflation does not always imply that future inflation will increase (decrease). This argues for using some measure of core inflationary pressure or even some measure of expected inflation to better gauge future inflationary pressure. We use two measures in estimating Taylor rules for New Zealand, CPI ex GST and credit services inflation and expected inflation one year ahead, but recommend that the policymaker use more than one measure of inflation to ensure robust policy advice.

Lastly, there is the issue of what information policymakers actually possess when they make their interest rate decisions. In our regressions, we only utilise lagged data, since policymakers do not possess contemporaneous information about inflation or the output gap. The preferred lag for estimation in New Zealand is one period for inflation and two periods for the output gap because this matches what was known at date t, eg, the actual inflation and output data possessed by the policymaker. For the unobservable output gap, we use a reasonably close approximation to the Bank's MV (multi-variate) filter, namely the HP (Hodrick-Prescott) filter with λ set at 1600, but ignore the problems related to the real-time estimates of the output gap pointed out by Orphanides (2001).

We are comfortable with using the HP filtered output gap because it matches the MV filtered output gap over history, and any difference between the real-time view and historical view is unlikely to cause the persistent errors discussed by Orphanides (2001). The reason is that the Bank's reasonably flexible view of potential GDP growth ensures that these errors should not persist too long. Moreover, a recent study by Huang et al (2001) suggests that the Bank responds to its view of the output gap even when one uses real-time data on the output gap and its forecast of inflation.

The endpoint of the HP filter will move around somewhat more than that of the MV filter, but these differences will typically be rather small given the current parameterisation of the MV filter. Over the past five years, the difference between the two filters has been small because there have been few structural shifts. On the whole, it seems a reasonable approximation to use the HP filter estimate of y* in any estimation of Taylor rules for New Zealand. Figure 1 shows the output gap estimates for the two filters, and demonstrates the effects of structural reforms in the late 1980's, which made y* higher for the MV filter.

Finally, we rewrite equation (2) as

$$i_t = (r_t^* - h\pi_{t+4}^*) + g(y_{t-2} - y_{t-2}^*) + (1+h)\pi_{t-1}, \qquad (3)$$

With the appropriate lags for y and π, we estimate the response to the output gap, g, and the response to inflation, 1+h. Because the Bank's internal estimate of π* has a downward trend initially, we lead π* four quarters ahead so that the estimated coefficients are not attenuated towards zero due to the Bank's forward-looking behaviour, although this effect is rather small. Given that we have reasonable approximations of π* and y*, only r*, g and (1+h) require

estimation. If one views the Taylor rule as picking the parameters g and (1+h) to reflect how much they lead to future inflationary pressure, then r* technically captures all other factors that might make the central bank's inflation control problem harder or easier. We now turn to our results for r*, g and (1+h).

4 Estimation results for a New Zealand Taylor rule

In this section, we examine three empirical approaches to the New Zealand Taylor rule that treat the neutral real interest rate (NRR) in different ways. These approaches respectively view the NRR as being a constant, following a deterministic linear trend, or time-varying since 1988 Q2. The best approach to the NRR would view it as time-varying, but we contrast any differences and attempt to find out what results are robust across these three approaches, if any. Emphasising the importance of this, all three approaches suggest that the NRR has fallen since 1988 Q2.

4.1 OLS and recursive OLS, constant r*

The first approach employs OLS and recursive OLS to estimate the Taylor rule, and uses CPIX inflation lagged one period and the output gap lagged two periods.[8] Figure 5 demonstrates how the estimates of r*, g and h change over time as additional data are added. It is clear that the estimated coefficients in the Taylor rule change dramatically. First, r* starts very high at around 9 per cent, and then falls to between 5 and 6 per cent by the middle of the 1990s. This pattern suggests that additional data points initially lowered the estimate of the NRR because the marginal data were below the sample average. Figure 4 provides some intuition and plots the 90-day bank bill in New Zealand. From figure 4, a clear downward trend is evident, and it does not seem to be explained solely by the behaviour of inflation and the output gap based on the OLS evidence.

[8] Table 1 reports the full sample, 1988 Q2 to 2001 Q3, OLS parameter estimates for r*, g, and (1+h) as well as the R^2 and DW statistic. The recursive estimates and residuals for each regression are shown in figures 5 – 8, respectively.

Figure 5 also shows that the other parameters, g and 1+h, change over time. Initially, both g and 1+h are insignificantly different from zero, but these recursive estimates rise and approach 0.5 and 1.5, respectively, as Taylor (1993) suggested. One interpretation of this evolution of r*, g and 1+h is that the Bank needed to build credibility early on, so it kept the real rate high and did not respond vigorously to actual inflation and the output gap. However, this interpretation masks the general downward drift in the NRR that becomes evident when one uses a linear trend or a state-space approach. Evidence of this downward drift appears in the final graph in figure 5, and demonstrates that the OLS residuals from the full sample possess significant serial correlation. In fact, these residuals appear non-stationary at the 1 per cent level unless one assumes a linear trend.

Figure 6 presents the results from the same approach when applied to the Taylor rule using lagged value of one year ahead expected inflation rather than lagged CPIX inflation. Despite the different measure of inflation, the results are quite similar to those in figure 5. The estimated NRR starts above 9 per cent initially, falls quickly after 1993, and then gradually declines to around 5 per cent in 2001. Again, this pattern suggests that the marginal data caused the estimate of r* to fall over time, and suggests that r* was much lower in the latter part of the sample period.

The other parameters in figure 6 also have similar patterns to those in figure 5, but the response to inflation appears slightly higher near the end of the sample period. The slightly higher inflation response arises because expected inflation is smoother than actual CPIX inflation, see figures 2 and 3. Initially, the estimated response to inflation is insignificantly different than zero, and then rises to around 2. The estimated response to the output gap starts below zero, although it is statistically insignificant, and rises to around 0.5. Lastly, the final graph in figure 6 shows that the residuals from OLS over the whole sample still possess significant serial correlation.

Overall, both sets of recursive OLS results suggest that r* falls over time. Moreover, the full sample OLS results assuming a constant r* indicate a downward trend in the residuals, a significant serial correlation problem, and suggest that the OLS results with a constant

r* may be spurious. For this reason, we now allow for a simple linear trend in r*.

4.2 OLS and recursive OLS, constant and linear trend in r*

We now address whether a linear trend sufficiently captures the downward trend in r*, whether the serial correlation problem can be fully corrected, and how robust the results from the first subsection are. Generally, when we added a linear deterministic trend, the estimated response to inflation in the Taylor rule never rises above 1.5, but remains significantly positive and less than one. Also, the NRR falls at a rate of about 10 basis points per quarter since 1988 Q2.[9] This downward trend in r* does not appear to depend on the measure of inflation used in the Taylor rule, and both of the estimated inflation responses are around 0.6 with a standard error slightly over 0.2.

Figures 7 and 8 show the estimate of r* when we add a linear trend, as well as the parameters g, 1+h, and the residuals. With constantly falling r*, the estimated response to inflation falls considerably, below 1 in many cases, but the response to the output gap remains roughly the same and around the 0.5 that Taylor (1993) suggested. This estimated inflation response coefficient is inconsistent with Taylor's (1994) suggestion that central banks should respond more than one to one to an increase in inflation, so that policy stabilises inflation. However, the high estimate of r* in the early part of the sample may capture the fact that the RBNZ leaned against inflation pressure more generally, and appears to now be leaning less actively against it more recently. In this case, the estimated response to inflation, CPIX or expected, should be treated with caution because it is most likely capturing only the short run response to our two measures of inflation, and may explain the smaller estimated response to inflation.

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9 The equations for the neutral real interest rate were $r^* = 8.970 + -0.0969*time$ for lagged CPIX inflation, and $r^* = 8.965 + -0.0951*time$ for lagged expected inflation since 1988 Q2. The variable time takes a value of 1 in 1988 Q2, and increases by one each quarter.

Overall, the Taylor rule with a linear trend makes the residuals stationary, and reduces the amount of serial correlation. However, there still exists some positive serial correlation, with the DW statistic at 1.0 compared to 0.5 previously. The remaining serial correlation suggests that a linear trend in r* does not sufficiently capture the non-linear time path of r*. One solution to the serial correlation problem is to embed the Taylor rule in a partial adjustment approach, see Judd and Rudebusch (1998) and Drew and Plantier (2000). This approach makes the policy response conditional on the level of last period's interest rate and the change in last period's interest rate, and addresses the serial correlation problem but deviates from Taylor's original formulation. To more adequately address this issue, we move to state-space estimation, and allow r* to follow an unrestricted AR(1) process.

4.3 State-space approach to NRR (r*)

The state-space approach is a flexible way of estimating an unobserved variable using the Kalman filter, and allows us to explore various assumptions and examine their effects.[10] For example, we can generalise the structure of r*, estimate the resulting time path for r*, and potentially still estimate the Taylor rule response coefficients using maximum likelihood method. Specifically, we assume a general AR(1) structure for r*, and examine what structure matches the errors in the Taylor rule best. The nature of the errors in the previous two subsections indicates that imposing the assumption of a random walk on r* may be the most appropriate specification for investigating the Taylor rule. However, we do not necessarily think that the true underlying NRR (or r*) is a unit root once all factors are taken into account.

In some applications, there are many measurement equations, and many unobserved state (transition) equations. For example, see Laubach and Williams (2001) for more sophisticated analysis applied to US data where they analyse r*, productivity growth, their relationship to each other and the effects of monetary policy on the

[10] Harvey (1989) provides an excellent general discussion of the state-space approach and the Kalman filter. Scott (2000) demonstrates how to estimate unobserved potential GDP for NZ with a state-space approach.

economy. For simplicity though, we assume that there is only one measurement equation, the Taylor rule, and one unobserved state equation, the structure of r*.

In order to estimate the key parameters in the Taylor rule, some restrictions must be placed on our state-space representation. Firstly, we choose the variance of the measurement equation based on the observed noise in inflation and the output gap, the standard deviation of their first difference ≅ 0.5 and 0.9 respectively, and set the standard deviation of ε_t at 0.8, 1.0 and 1.3 per cent. Secondly, we assume that the errors of the two equations in our system are uncorrelated, and we do not attempt to relax this assumption because it would require us to estimate another parameter. Lastly, we tried using a general AR(1) structure for r*, but found that we only got sensible estimates of the AR(1) coefficient when we imposed the coefficients in the Taylor rule. When we imposed various response coefficients, we always found that the shocks to r* were very persistent and indistinguishable from a random walk.[11] Based on this evidence, it may appear that the output gap and inflation relative to target do not capture changes in monetary policy well in New Zealand, but we view these shocks as moderately sized yet highly persistent errors to the Taylor rule.

We assume the following specification below, and experimented with some different restrictions regarding the response coefficients in the Taylor rule and the aforementioned amount of noise in the measurement equation.

$$i_t = (r_t^* - h\pi_{t+4}^*) + g(y_{t-2} - y_{t-2}^*) + (1+h)\pi_{t-1} + \varepsilon_t \tag{4}$$

(see earlier discussion on timing),

and the unobserved state variable follows

$$r_t^* = \alpha + \rho r_{t-1}^* + \eta_t \tag{5}$$

[11] This finding partially confirms the interpretation of interest rate smoothing in Rudebusch (2001). Rudebusch (2001) suggests that the high degree of estimated interest rate smoothing, see empirical section of Drew and Plantier (2000), might be the result of persistent errors to the presumed structure of the desired rate, ie the Taylor rule, rather than inertial behaviour by central banks.

where the ε_t and η_t are the serially and mutually uncorrelated random error terms for the measurement and state equation, respectively. As mentioned above, we impose $\alpha = 0$, $\rho=1$, and the variance in the measurement equation. We choose the variance so that the log likelihood and AIC perform better than the Taylor rule with a constant r*, but worse than with a linear trend in r*. The practical effect of these assumptions is that our estimate of r* does not move around too much unless there is a significant and persistent error in the Taylor rule. Essentially, we impose a relatively smooth adjustment on r*.

Using our two different measures of inflation, namely expected and CPIX inflation, we estimate and impose the Taylor rule coefficients given the structure in equations (4) and (5). Table 2 reports the coefficient estimates and summary statistics from these four approaches with the standard deviation of equation (4) set to 1.3 per cent, and figures 9 through 12 show the resulting time paths for r* in the Taylor rule. Table 2 also includes the estimated standard errors or root mean squared errors when appropriate.

The results from the state-space approach to r* are broadly similar to the results with a linear deterministic trend in r*. For example, the estimated response to inflation appears to be less than one, see table 2, but the estimates have large standard errors that do not allow us to reject either Taylor's 1.5 suggestion or 0. The most robust result appears to be the estimated response to the output gap, g. When we estimated the Taylor rule, the response to the output gap is always significantly different from zero and insignificantly different from 0.5. Therefore, the response to the output gap appears consistent with Taylor's suggested response to the output gap, namely 0.5, and is insignificantly different in every regression considered.

Additionally, the general pattern of r* is broadly similar across the various approaches we considered, although the point estimate of r* differs at any point in time. Generally, figures 9 through 12 show that the filtered estimate of r* starts quite high at around 7 to 9 per cent, falls rather quickly to 4.5 to 6.5 per cent by 1993/94, and then falls again after 1998. Table 2 reports the final point estimate of r* for each approach, 2001 Q3, and they are 3.66, 2.57, 4.00, and 3.35 respectively. However, each of these point estimates has a rather

wide prediction interval around it of about ± 150 basis points, which implies a potential high of about 5.5 per cent and a potential low of just over 1 per cent, but all are significantly lower than the early part of the sample.[12] Despite the differences in endpoints, the results here are insignificantly different than the OLS approach with a linear trend in r*, which produced an estimate of just under 4 per cent.

5 The importance of getting the NRR right

Taylor (1994) demonstrated why an incorrect view of the NRR (r*) causes problems for a central bank that wants to prevent persistent deviations of inflation from target. Using a simple model of the economy, Taylor (1994) shows that if the central bank systematically underestimates (overestimates) the NRR in the Taylor rule, then inflation will persist above (below) target. In steady state, the output gap equals zero, so Taylor derives the following expression for the inflation rate

$$\pi = \pi^* + (r^* - r^f)/h \qquad (6)$$

where π is inflation rate in steady state, π^* is the central bank's stated inflation target, r* is the actual NRR, r^f is the perceived NRR, and h is response coefficient to the inflation gap. The interpretation of equation (6) is that as long as r^f does not differ from r* persistently and h is positive and relatively stable, inflation should be near target on average.

However, if r* is greater (less) than r^f on average, then inflation will be above (below) the inflation target in steady state. How far the inflation rate is above or below the Bank's inflation target will depend on r* minus r^f, and the response coefficient to the inflation gap, h. For the Taylor rule with h set equal to 0.5, if r* is 1 per cent greater than r^f on average, then inflation will be 2 per cent above target, or 1/0.5.[13]

[12] We also imposed the variance on equation (5) and estimated the variance in equation (4), the reverse of our approach above. Generally, we found the results to be broadly similar, but that the fit worsened as we attenuated the variance of equation (5), much the same as if we increased the variance in (4).

The result is quite intuitive, and cautions central banks from using a constant NRR (r*) in any reaction function. Instead, central banks should continuously update their view of the NRR in a way similar to how they update their view of potential GDP growth. This is especially true since the NRR in the Taylor rule probably represents all other factors that affect future values of inflation and the output gap. In the case of New Zealand, the large unexplained fall in the NRR in the Taylor rule would cause problems for a central bank that had a fixed view of the NRR. With a constant view of the NRR, policy set with a Taylor rule would be too loose in the late 1980s and early 1990s, and too tight in recent years. On the other hand, the estimated downward drift in the NRR in this paper may just reflect the policymaker's changing concern regarding the unobserved 'general inflationary pressure', whatever that consists of.

Based on actual 90-day interest rate settings, the RBNZ appears to have adjusted down its view of the NRR over time, at least according to the Taylor rule. Whatever this decline in the NRR implies about the New Zealand inflation control problem, it is clear that the policymaker now judges that the NRR in the Taylor rule can be lower than in the late 1980s. The question remains what factors caused this judgement to be made and whether the downward adjustment was optimal. We leave this question for future research.

6 Conclusions

Two reasons for the popularity of the Taylor rule are its simplicity and its explicit concern for excess demand (the output gap), inflation and the interest rate relative to desired levels. This explicit concern for three key variables contrasts with an IFB rule's implicit concern for a much wider set of variables. In spite of its parsimony, the Taylor rule still performs well in many different models because it responds directly to these three key variables. Because of this robust performance, the Taylor rule should be viewed as a useful cross-

[13] Based on state-space estimation that does not impose the Taylor rule structure, the response to inflation appears to be higher early in the sample period and may indicate a desire by the policymaker to minimise any potential errors between the perceived r* and the actual r*.

check on the policy advice coming from an IFB rule and the Bank's more complex macroeconomic model.

The Taylor rule should be useful as an alternative baseline to the Bank's IFB rule because it usually indicates a change in policy at the same time as the IFB rule. However, there are times when the two rules give different advice due to the forward-looking nature of the IFB rule and the implicit response to a wider set of state variables. At these times, the policymaker must decide how he should weigh current information on the output gap and inflation against forecasts of future inflation. To a large extent, this depends on how confident the policymaker is regarding the Bank's model structure, its dynamics and specific judgements over the forecast horizon. If there are considerable reservations about these issues, then the Taylor rule provides a useful alternative interest rate path that will gradually adjust the interest rate as new information about the output gap and inflation arrive. While the Taylor rule will not look through temporary shocks as an IFB rule does, it will generally keep policy moving in the correct direction as new information arrives about the output gap and inflation. Of course, this strategy does not prevent the policymaker from consulting the IFB rule more closely in the future.

Two big problems presented by New Zealand data for modellers and policymakers are the non-stationarity of short-term interest rates, and the consequent downward drift in the NRR of the Taylor rule. For the modeller, these changes in the NRR are very persistent, and we are unable to reject that they are I(1) using an unobserved variable approach. For the policymaker, the downward drift in the NRR suggests that any interest rate rule or model with a constant NRR assumption may give misleading advice. Under these circumstances, the NRR should be treated as time-varying, and the policymaker should use their best estimate of its current value rather than the sample average. In addition, the large fall in the ex-ante real interest rates in New Zealand deserves more attention because it does not relate to the stationary movements in inflation and output relative to their target values.

The three approaches to the NRR in this paper give us some idea of how the r* in the Taylor rule has changed over time, but we should reflect on what is causing this gradual decline and where it might settle down. For example, we would not expect it to go below the US estimate for extended periods of time, and expect the US estimate to act as a lower bound.[14] So why has the r* in the Taylor rule fallen? One possibility is that we are witnessing some convergence towards the US neutral real interest rate, which relates to some other convergence occurring within the New Zealand or international economy. Other possibilities include a smaller risk premium required by foreign holders of New Zealand dollar assets, an increased stock of credibility, or some other contributing factors.

[14] Estimates for Taylor rules in the US usually range between 2 and 3 per cent, but of course this number varies over time. In a paper written at the US Federal Reserve, Laubach and Williams (2001) estimate the neutral real rate using a state-space method similar to ours. Among the differences, they take their signal from the IS curve and the Phillips curve, and relate potential GDP to their estimate of r*. For the end of 2000, their estimate of the US NRR was around 3.5 per cent, although it has probably fallen since then.

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Appendix A:
Central bank preferences and the Taylor rule

One way to motivate the Taylor rule is to contemplate the loss function that might rationalise its use, and ask whether the Taylor rule is an efficiency condition that must hold around the steady state [see Svensson (2001) and Weymark (2001) for such an analysis]. Generally, suppose that the central bank believes that it takes j and k periods to affect inflation and output, respectively, by changing the interest rate (i_t), and cares about the values of inflation (π), output (y), and the nominal interest rate (i_t) relative to their desired or equilibrium levels. If j and k are set equal to 1, then the loss function of the central bank is

$$L_t = E_t[\alpha(\pi_{t+1} - \pi_{t+1}*)^2 + (1-\alpha)(y_{t+1} - y_{t+1}^P)^2] + \gamma(i_t - i_t^*)^2 \quad \forall\ t \geq 0. \tag{7}$$

With this static approximation (we ignore discounting and some timing issues) to a slightly more complicated intertemporal problem, we can totally differentiate this loss function and rearrange terms to arrive at

$$i_t = i_t^* + \frac{\alpha}{\gamma} E_t\left(\left|\frac{d\hat{\pi}_{t+1}}{d\hat{i}_t}\right| \hat{\pi}_{t+1}\right) + \frac{(1-\alpha)}{\gamma} E_t\left(\left|\frac{d\hat{y}_{t+1}}{d\hat{i}_t}\right| \hat{y}_{t+1}\right) \tag{8}$$

where d denotes the differential and the hat over a variable means that the variable is defined in terms of deviations from its desired or equilibrium level, eg, π*. In the analysis, i* = r* + π^e, where π^e is expected inflation. The assumption here is that the central bank naturally raises its view of i* one for one if π^e or r* rises.

A number of issues become evident when one attempts to view the Taylor rule as an efficiency condition. Firstly, the contemporaneous (lagged) values of the inflation and output gaps, or a linear relation of them, should be reasonable predictors of their future values. Secondly, the policymaker's preference can't change over time because they are assumed constant. Thirdly, the policymaker's view of how changes in the interest rate lead to changes in the inflation and output gaps must also be time invariant. Lastly, the preference weights multiplied by the perceived transmission mechanism effect must equal 0.5 to arrive at a Taylor rule. If we take the first assumption, we arrive at

$$i_t = i_t^* + \frac{\alpha}{\gamma} E_t\left(\left|\frac{d\hat{\pi}_{t+1}}{d\hat{i}_t}\right|\right)\hat{\pi}_t + \frac{(1-\alpha)}{\gamma} E_t\left(\left|\frac{d\hat{y}_{t+1}}{d\hat{i}_t}\right|\right)\hat{y}_t \qquad (9)$$

Equation (9) replaces $E_t[\hat{\pi}_{t+1}]$ and $E_t[\hat{y}_{t+1}]$ with contemporaneous (or lagged) values, and implies that these values are reasonable predictors of the future level of the variable. Given that the shocks to the output gap and the annual change in the CPI are persistent, this assumption appears reasonable, but the best prediction obviously involves consideration of all available information at time t. Finally, if $\frac{\alpha}{\gamma} E_t\left(\left|\frac{d\hat{\pi}_{t+1}}{d\hat{i}_t}\right|\right) = \frac{(1-\alpha)}{\gamma} E_t\left(\left|\frac{d\hat{y}_{t+1}}{d\hat{i}_t}\right|\right) = 0.5$, then we arrive at Taylor's suggested weights of 0.5 on the output and inflation gaps. Moreover, as long as $\pi^e = \pi$ on average, then the response coefficient to inflation would be 1½ as suggested by Taylor (1993).

$$i_t = i_t^* + 0.5\hat{\pi}_t + 0.5\hat{y}_t \qquad (10)$$

As the reader will have noticed, the Taylor rule with contemporaneous or lagged data does not appear to be a time-invariant efficiency condition that corresponds to a particular loss function, and requires too many heroic assumptions to achieve this status. Therefore, one should not expect a Taylor rule to hold every period because the above analysis illustrates that the optimal weights in the Taylor probably change over time, Svensson (2001). The fact that we find r* to empirically vary over time indicates that something in Taylor's original formulation is changing over time in New Zealand. What this changing r* or NRR represents is unclear, but it does warrant caution. The best advice for policymakers interested in referring to the Taylor rule is not to assume fixed coefficients because the nature of the transmission mechanism, the predictive value of lagged data, or other factors that affect r* all change.

Table 1: Results of OLS for Taylor rule [15]

Equation (3) $i = r_t^* - h(\pi_{t+4}^*) + g(y_{t-2}-y_{t-2}^*) + (1+h)\pi_{t-1}$							
	Key Parameters				***Summary Statistics***		
Results from	**Output Gap, g**	**Inflation (1 + h)**	**Neutral Real, r***	**r* trend**	**Log Likelihd**	**AIC**	**DW Stat.**
Figure 5	0.488^A (.098)	1.601^A (.354)	5.258^A (.325)		-102.0	3.889	0.50
Figure 6 (π^e)	0.467^A (.114)	1.858^A (.249)	5.112^A (.415)		-98.7	3.767	0.62
Figure 7	0.624^A (.0617)	0.607^B (.237)	8.97^A (.502)	-0.097^A (.0087)	-76.7	2.987	1.00
Figure 8 (π^e)	0.626^A (.071)	0.602^B (.265)	8.97^A (.645)	-0.095^A (.0107)	-78.2	3.044	1.00

15 Based on a comment by our colleague, Weshah Razzak, we investigated whether the restriction that the response to the inflation target equal –h had a significant effect on our results. When we ran our regressions with a separate and independent response to the inflation target, we found that it was significantly different than the –0.5, always positive, and that the fit was generally better. This result suggests that while the Bank appears to respond directly to inflation, it also tended to lower interest rates as its inflation target fell in the early part of the sample period. So, the inflation target might be viewed as the inflation premium or expected inflation. However, this would be somewhat different than Taylor's original formulation, so we do not report these results.

Table 2:
Results of state-space approach for Taylor rule

Equation (4) $i = r_t^* - h(\pi_{t+4}^*) + g(y_{t-2}-y_{t-2}^*) + (1+h)\pi_{t-1}$							
	Key Parameters				***Summary Statistics***		
Results from	**Output Gap, g**	**Inflation (1 + h)**	**Final r* Value**	**Δr^* Shock Variance**	**Log Likelihd**	**AIC**	**DW Stat.**
Figure 9	0.471^B (.219)	0.720 (.541)	3.662^A (.761)	0.147	-92.4	3.535	N/A
Figure 10	0.5 (N/A)	1.5 (N/A)	2.573^A (.789)	0.167	-95.6	3.578	N/A
Figure 11 (π^e)	0.469^B (.219)	0.678 (.689)	4.000^A (.762)	0.148	-93.4	3.569	N/A
Figure 12 (π^e)	0.5 (N/A)	1.5 (N/A)	3.348^A (.714)	0.118	-95.9	3.590	N/A

Table 3:
Unit root tests (Null is series is I(1))

(Type & ADF lag)	**Interest rate, i (c and t, 1)**	**Interest rate, i (c, 1)**	**Output Gap, $y-y^P$ (none, 0)**	**CPIX inf, π (c, 8)**	**Expected inf, π^e (c, 1)**
ADF test	-2.491 (Fail)	-2.068 (Fail)	-2.096 (5%)	-4.447 (1%)	-2.933 (5%)
PP test - 3	-2.178 (Fail)	-2.193 (Fail)	-2.270 (5 %)	-3.620 (1%)	-3.508 (5%)

Figure 1:
Bank's MV filter output gap versus HP filtered output gap

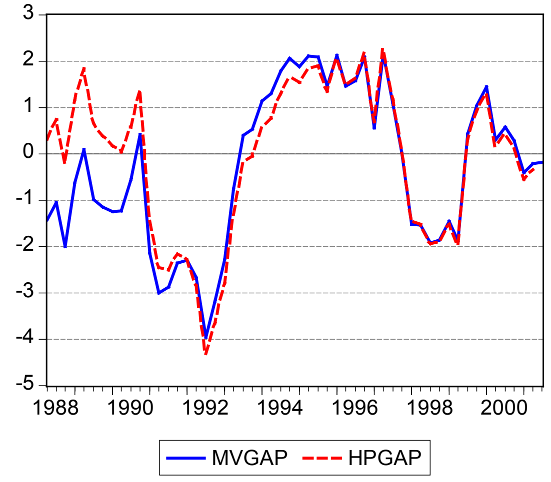

Figure 2:
Bank's inflation target vs. CPIX inflation

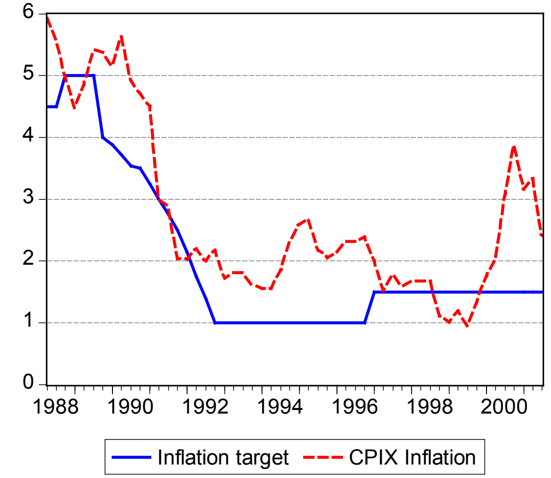

Figure 3:
Bank's inflation target vs expected inflation one year ahead

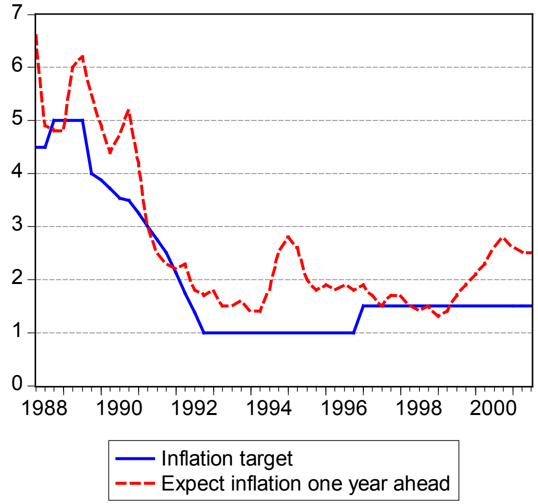

Figure 4:
NZ short rate and its linear trend

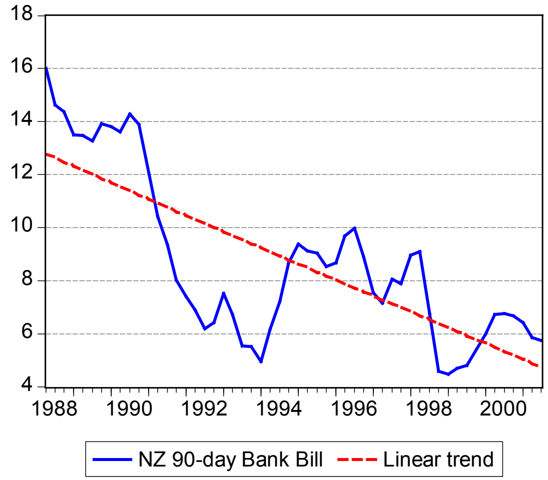

Figure 5:
Recursive OLS estimates w/ CPIX π

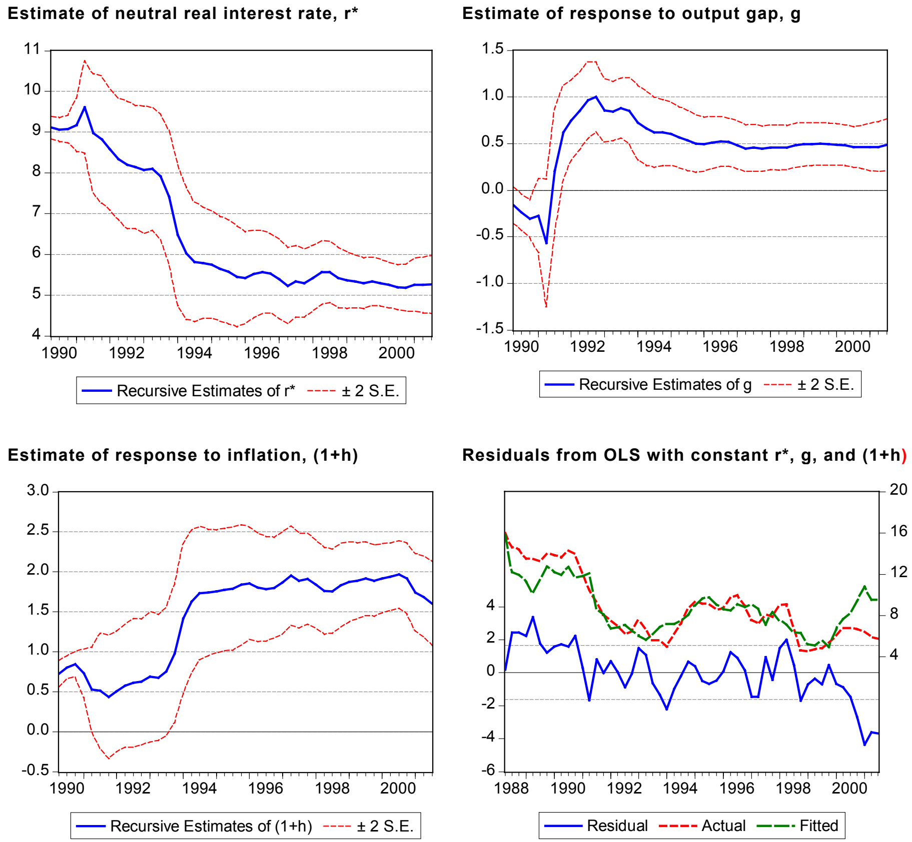

Figure 6:
Recursive OLS estimates w/ expected π one year ahead

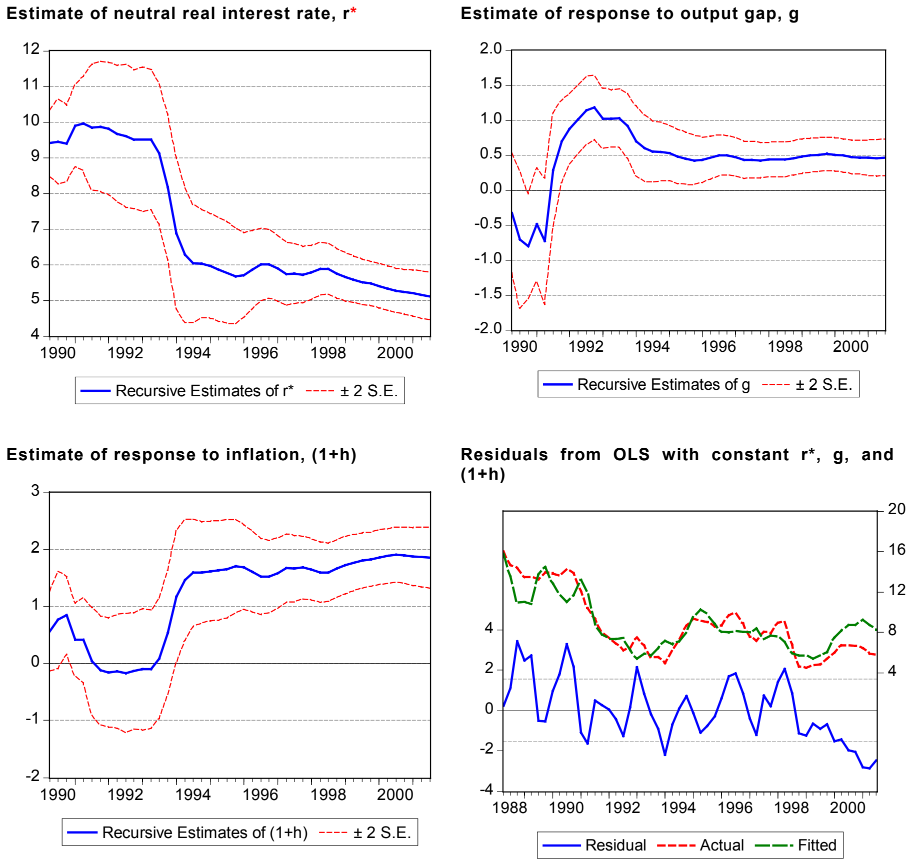

Figure 7:
Recursive OLS estimates w/ CPIX π and time trend

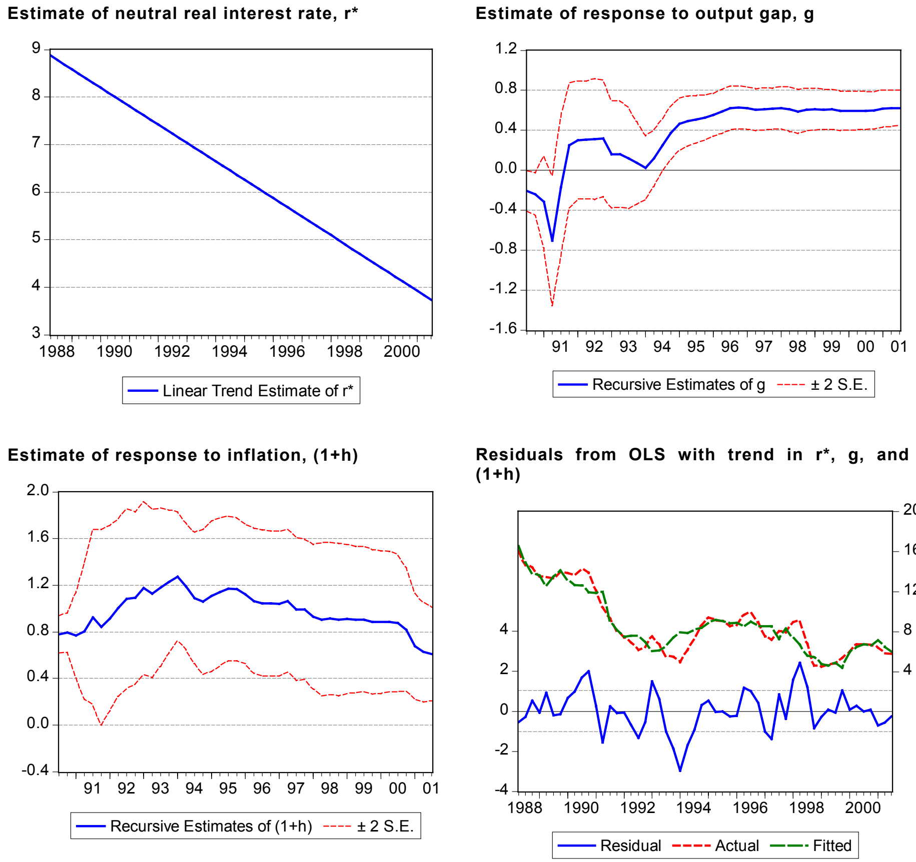

Figure 8:
Recursive OLS estimates w/ expected π and time trend

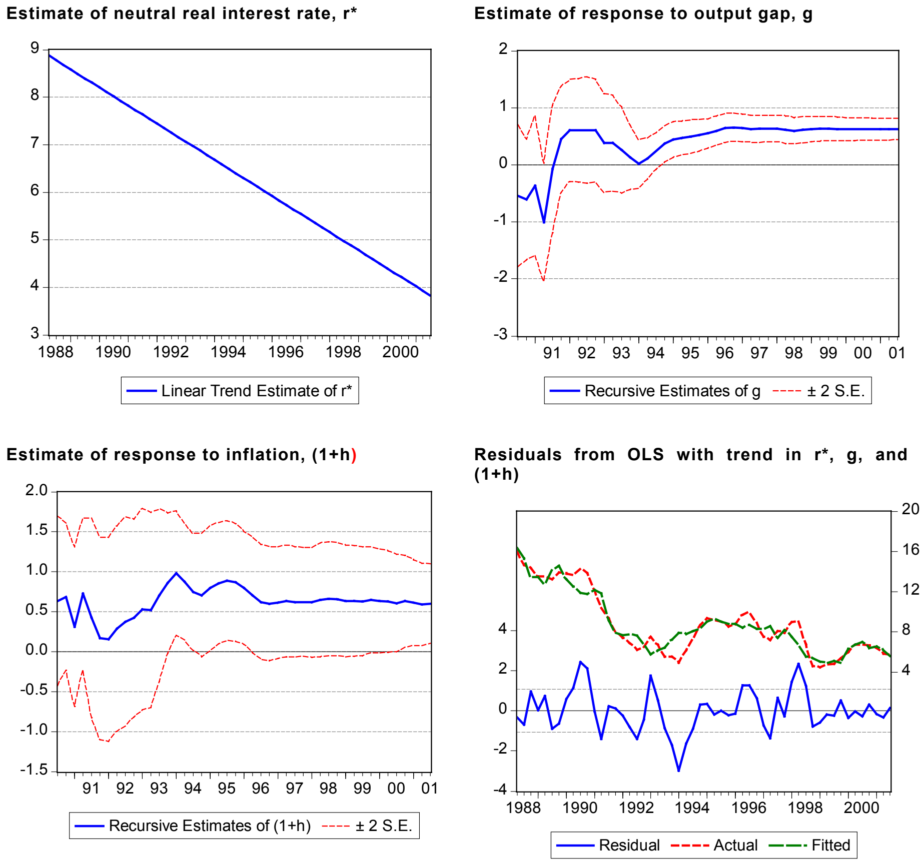

Figure 9:
Filtered estimate of r*, estimated coefficients

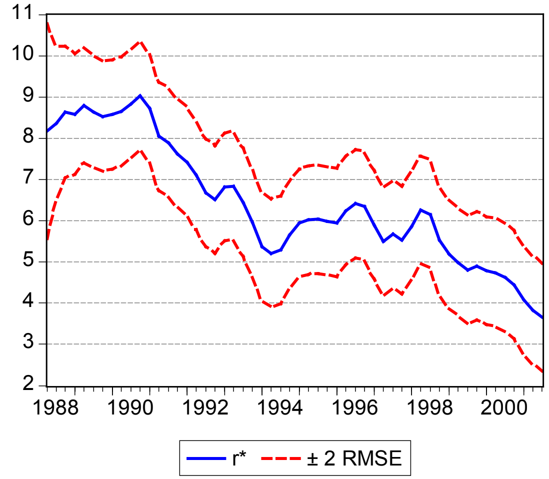

Figure 10:
Filtered estimate of r*, imposed coefficients

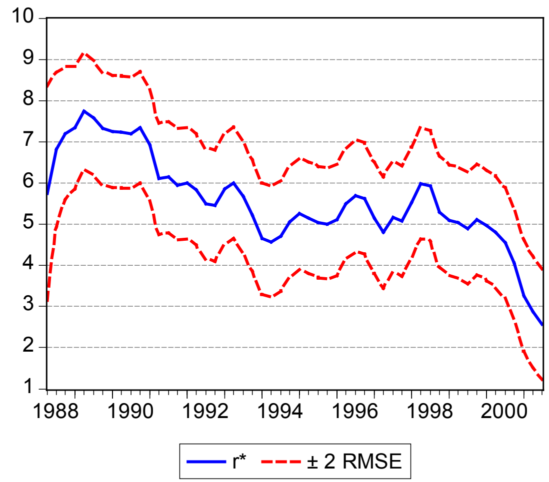

Figure 11:
Filtered estimate of r*, estimated coefficients

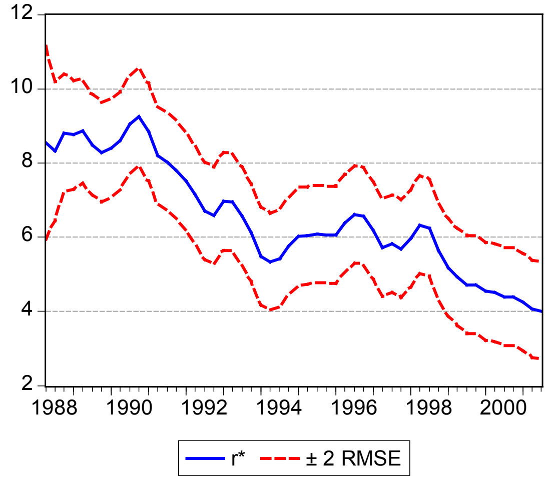

Figure 12:
Filtered estimate of r*, imposed coefficients