Modelling Structural Change:

The case of New Zealand[1]

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Abstract

This paper documents the Reserve Bank of New Zealand's current approach to dealing with structural change, an important feature of New Zealand's recent macroeconomic history after the profound economic reforms undergone in the past twenty years. Traditional estimated macroeconomic models of New Zealand have broken down over time, which led to the mid 1990's creation of the Forecasting and Policy System (FPS). In this paper, we analyse why the FPS has proved more robust to structural change and discuss steps we are taking to develop carefully chosen alternative models to complement FPS. Because those alternative models are clearly subject to structural change as well, in developing them we have looked hard at estimation approaches that allow for structural instability. In this paper, we document the results of subjecting some key nominal relationships to stability tests and explicit modelling of structural change. We find preliminary evidence that New Zealand's inflation targeting regime has caused structural shifts in pricing behaviour and expectations formation.

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Introduction

Macroeconomic models are clearly vulnerable to structural change in at least two related ways. Firstly, parameters can shift, introducing errors into historically estimated relationships. Secondly, macroeconomic models are generally based on a limited set of causal relationships, which may have been relevant in a historical period but can become irrelevant over time.

Perhaps the most famous example is the international reliance on monetary aggregates as a leading indicator of inflation and activity in the 1970s and 1980s: it seems increasingly clear that the indicator value of monetary aggregates has dramatically weakened as a result of financial deregulation and other structural change.

The Reserve Bank of New Zealand's Forecasting and Policy System (FPS) (see Black et al (1997), Hunt et al (2000)) was constructed in 1997 after a prolonged period of structural change in the New Zealand economy[4]. Since standard statistical inference relies on the stability of data, this structural change meant it was not possible to attempt a traditional estimated macroeconomic model at that time. Instead, as in a number of other economies subject to structural change[5], an increased amount of economic theory, and prior knowledge about the nature of the structural change and its implications, was used to calibrate this model.

FPS is fairly central[6] to the Reserve Bank of New Zealand's policy process, so the robustness of the relationships embedded in the model is important. This paper is about the methodologies we are currently applying in order to minimise the risks of reliance on a single, calibrated model of the economy. In section one, after a discussion of why the FPS model itself has proved more robust to structural change than its predecessors, we discuss these methodologies in general terms.

In the second section of this paper, we give specific examples, documenting the results of estimating key nominal relationships like the relationship between the costs faced by producers

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[4] New Zealand's reform program is described in some detail in Evans et al (1996).
[5] A similar approach was adopted with the Bank of Canada's economic model QPM (see Black et al. (1994) and there is a literature applying similar techniques to transitional economies in Eastern Europe (see Hall 1993, Greenslade and Hall 1996, Basdevant 2000).
[6] Hampton (2002) describes how FPS is used to generate the projections underlying the RBNZ's monetary policy statement. That paper stresses that while FPS is central to the system, the forecasts (and monetary policy recommendations) coming from FPS are made consistent with the views of the Monetary Policy Committee through

and the prices charged to consumers. In this work, we have put emphasis on the possibility of ongoing structural change, looking at that possibility by allowing some parameters to be time-varying using the Kalman filter.

A theme running through our empirical analysis is the need for justifications for treating a parameter as time-varying, based either on economic theory or knowledge about the economy being studied. Essentially, any estimated equation with time-varying parameters can fit the data more closely than a model with fixed parameters, but indiscriminate application of time-varying parameters will not lead to improved policy analysis or forecasting. Moreover, policymakers are unlikely to feel comfortable with a model where parameters are shifted too frequently and without justification. This suggests the need for a consultative process with policymakers where potential reasons for particular structural change are explored before they are incorporated into the model. In section three, we discuss a specific example: how evidence that the neutral real interest rate in New Zealand might have fallen was incorporated into policy.

1 Modelling an evolving economy

In this section we first discuss how structural change has influenced the development of FPS, and its evolution over the past five years (section 1.1). Then, in section 1.2, we discuss our more recent work developing stress testing procedures and alternative models that reduce our reliance on a single FPS-based view of the economy.

1.1 Identifying and Understanding Structural Change

In the early 1990s, the Reserve Bank estimated a cointegration based macro-model of the New Zealand economy, Model XII (see Brookes and Gibbs 1994). This model was used in the forecasting process in the early 1990s, but the structural relationships had broken down by 1994/95, when work began on a new model based on broadly similar lines to the UK National Institute's model NIDEM (see for example the discussion in Layard et al. 1991). However, it remained very difficult to estimate stable structural relationships, and this model was never closely integrated into the forecasting and policy process. Instead, in co-operation with some of the developers of the Bank of Canada's model QPM, work began on the creation of a model that relied more on theory than on the recent data, with a general equilibrium framework at the centre of the

an iterative process: the process can thus be described as model-based, but not fully model driven, similar to the proposed system documented in Laxton and Scott (2000).

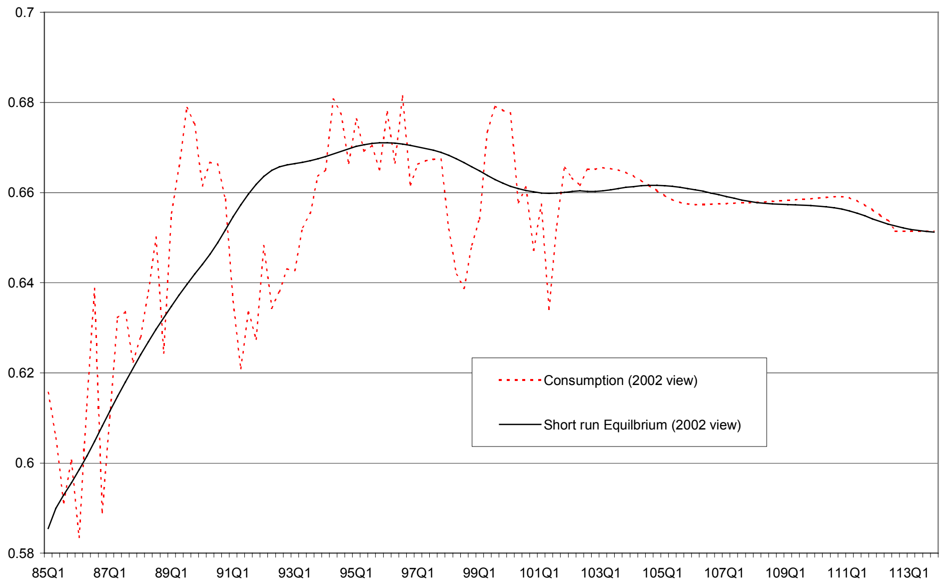
model, and the dynamic parameters determined more with reference to calibration techniques than direct estimation.

FPS was complete enough to be documented (see Black et al 1997), and utilised in economic projections, from 1997. Since then, it has become a significant part of the Reserve Bank's forecasting process and is often used for policy analysis. Pleasingly, FPS has proven very robust to the sorts of statistical revisions, like rebasing of the national accounts, which were a factor in the demise of some of the estimated models discussed above.

A key reason for the stability of FPS is that the key behavioural equations are written in terms of deviations from equilibrium, or "gaps". For example, the deviations of consumption (as a proportion of output) around an equilibrium value are modelled by the FPS consumption equation. The equilibria for macro variables are determined using a combination of the historical data and the steady state value which it is assumed the variable will eventually converge to. The mathematical technique used to do this for many variables is the LRX filter, a variant of the HP filter developed by Laxton, Rose and Xiu which is able to put explicit weight on a postulated end point value[7]. As an example, the chart below shows New Zealand's consumption to GDP ratio, which rose dramatically between the mid 1980s and the mid 1990s. As the chart shows, the model converges the ratio on a steady state value we have set, which is slightly below the current value.

[7] Some variables have equilibria computed using a more complicated process: for example, a multivariate filter determines potential output. Also, some variables equilbria are determined residually to satisfy standard identities: for example, equilibrium consumption is solved for using the national accounts add-up.

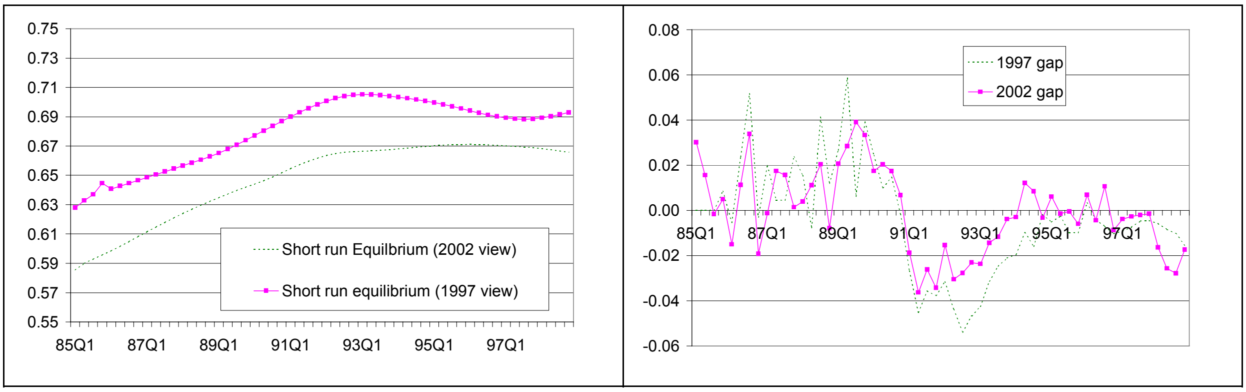
Figure 1: Consumption to output ratio (actual and short run equilibrium)



It seems clear from the chart above that the filtering has removed a trend of some description from the consumption to output ratio. Moreover, this trend would not have been well captured using a linear trend – most of the upward drift occurred in the early part of the period. Working with detrended (or "gap") consumption allows us, under the maintained assumption that we have accurately uncovered the cyclical component of consumption behaviour, to calibrate the economic relationships between consumption and determinants such as interest rates and income. It is not necessary to model why there was a pronounced shift up in the consumption to output ratio through the mid-1980s. This would be much more difficult and may not be of primary interest in monetary policy formulation anyway.

The left-hand chart below compare a recent view of the trend or short run equilibrium path of consumption with the view we had in early 1997. It is clear that the equilibrium path has been substantially revised. While the revision is by a fairly constant amount over much of the period (relating to a rebasing of the national accounts), it is not exactly a linear shift. The right-hand chart shows that this change in view about the equilibria has left us with a similar view of the cyclical component of consumption behaviour. This illustrates that the filtering framework we use before putting data into the model[8], while it can be criticised as arbitrary, makes modelling an evolving historical dataset much more tractable.

Figure 2 Evolving views of the Consumption/Output ratio: Short-run Equilibrium and gap



While FPS has not broken down over the last five years, many key dynamic responses within the model have been significantly revisited. For example, the large depreciation of the New Zealand dollar over 1999-2001 led FPS to persistently over-predict exports, and under-predict imports. From this, we eventually concluded that our initial calibration choices (based on the data available at the time of the model's initial creation) overestimated the power and speed of the real exchange rate's impact on the New Zealand economy, and recalibrated accordingly.

This was more an example of learning about the nature of the economy by analysing how the economy behaved after a substantial shock, than an example of identifying a structural change. Most of the recalibrations we have performed have similarly been the result of learning more about the model as a result of using it for forecasting and policy analysis[9]. While this is likely to continue to be the case, we have begun to consider more formal methods of assessing the fit of FPS, such as estimation with time-varying parameters using the sorts of techniques we apply in section 2.

1.2 Diversifying away from reliance on FPS

Recently, we have been considering the potential risks of concentrating economic analysis in a single model of the economy. There are obvious advantages of the single model approach, such as the fact that it focuses the debate of research staff around a single construct (see Stockton (2002)) and the relative ease with which results from a single model can be communicated to

[8] See Drew and Hunt (1998) for a more detailed description.
[9] Another example is the discussion of the Phillips curve in Drew and Hunter (2000), presented at a previous macro-modellers workshop.

policymakers (see Pagan (2002)). The key risks relate to the fact that a single model will inevitably contain only a subset of the possibly relevant economic theory and relationships (and might miss the important one, particularly if calibrated or estimated on historical data during a period of structural change), and that something may be lost by the way the single model approaches the data. In this section, we briefly describe some of the modelling work we are undertaking in order to attempt to counter these concerns.

1.2.1 Modelling outside of FPS

Some key data concerns with FPS relate to the fact that the model is calibrated and thus does not react "automatically" via re-estimation to evolving macroeconomic relationships, and the fact that the dynamic equations are written in gap terms, making the model reliant on assumptions about de-trending. In order to counter these risks, we have begun to put more effort into the development of small, estimated models that do not rely on filtering where possible (instead using linear de-trending or first differencing, or applying cointegration techniques).

While FPS has a fairly broad theoretical basis (for example, a classical long run structure is combined with a fairly Keynsian view of short run adjustment), it is only one of a range of possible theoretical constructs that could match the behaviour of the New Zealand economy. Thus, another concern has been to identify plausible theoretical paradigms that are not incorporated into FPS, and include those in the alternative models. For example, Razzak (2002) investigates a wide variety of inflation models incorporating variables missing in FPS like money and credit. An additional example is the Small Estimated Model (SEM) constructed by Ha and Hampton (2002), which is based on the model used by the Reserve Bank of Australia (Beechey et al (2000)) and incorporates an inflation process driven primarily by input costs rather than demand effects. Much of the work in the next section is based on the results of stability tests of the relationships in that model.

The recent efforts described above differ somewhat from the original plan for augmenting FPS with ancillary models. As described by Black et al. (1997), an important part of this plan was to incorporate "satellite" models of the economy that disaggregated FPS variables (such as FPS consumption, which includes stock-building and residential investment) to enrich the FPS-based analysis. While some "satellite" disaggregation of the FPS track does take place today, we now feel that it is more important to diversify our frames of reference, rather than concentrate on producing a more fully articulated FPS based forecast. No matter how fully articulated a FPS-based view is, it will still be vulnerable to structural change, and the associated risks described above.

1.2.2 "Stress-testing" FPS

We have also begun to do greater sensitivity analysis on the parameterisation of FPS, even where there is no evidence of structural change. This has involved developing a framework that facilitates running the projection quickly and easily (partly thanks to advances in computing power) under a range of alternative parameter assumptions. This allows us to provide informal tests of the key FPS assumptions in a given forecast. For example, after a large passthrough from exchange rate depreciation into tradable goods prices, we presented the MPC with simulations showing the implications of alternative assumptions about the feed through from the spike in CPI inflation into inflationary expectations.

We think these "alternative scenarios" are most interesting for policymakers when the change in assumptions has been made on the basis of an alternative economic interpretation, rather than an arbitrary choice. As an example, we have evaluated the view of the transmission mechanism incorporated into the European models described in Locarno et al (2001) and compared them with FPS. We identified some key differences, and are producing "alternative" versions of FPS where the relative weight of the exchange rate channel, consumption channel and cost of capital channels of monetary policy are closer to those posited in the European models.

These alternative scenarios can be thought of as a risk assessment around a particular assumption within FPS. While they do not provide evidence of structural change, they help us decide whether particular variations in the model would lead to substantial changes in the way we set monetary policy. This allows us to concentrate our analysis on looking for possible structural change in the most important parts of the model.

2 Evolution of key nominal relationships

A key robustness issue for policymakers is the possibility that parameters in estimated relationships have changed. Analysing a range of models (as discussed in section 1) can mitigate this problem, because the reduced-form parameters in one relationship may remain robust when another is breaking down. However, it can also be useful to incorporate the possibility of time-varying parameters explicitly into the estimation method. In this section, we present some results using time-varying coefficients, generally estimated using the Kalman filter[10].

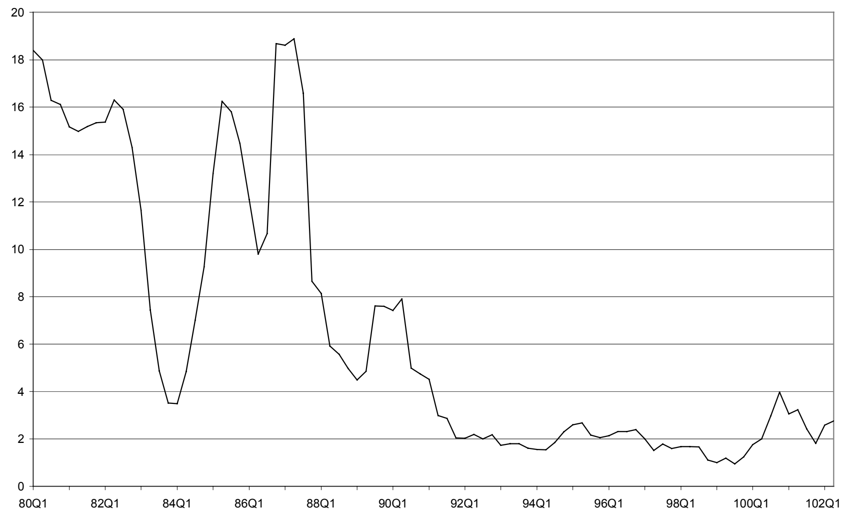
The use of the Kalman filter has been investigated in recent literature on modelling under structural change (see Barassi et al. 2000, 2001 or Greenslade and Hall 1996) and is related to the work of Hendry and Clements (1996, 1999, 2001) who demonstrate that changes in the deterministic component of a model may dominate its forecasting performance. However, if there is no underlying theory about why a coefficient should be time-varying, then although modelling it under a state-space model may give an excellent fit over the historical sample, it is unlikely to lead to strong forecasting properties unless it seems plausible that the parameter will have converged to a stable value at the end of the estimation period. To address this problem it is desirable to consider why a particular coefficient is time-varying. It may be that a variable can represent the structural change and lead to a new, stable, time-invariant equation.

In this section, we develop some analysis of possible time-varying relationships between nominal variables. Three particular issues are analysed:

- Firstly, we estimate a small system of equations including an inflation expectation equation, an AS curve, and an AD curve (see section 2.1). The structure we employ is parsimonious enough that a analytic solution for the form of rational expectations is possible, and we are able to look at whether New Zealand inflation expectations have tended towards rationality over the last decade.
- Secondly, we estimate a mark-up model of inflation and consider possible sources of instability in that relationship (see section 2.2).
- Thirdly, we look at how the stage one passthrough of exchange rate movements into domestic import prices has changed (see section 2.3).

[10] See Kalman (1960, 1963) for original contribution, Harvey (1989) for exhaustive presentation, Cuthbertson et al. (1992), Hall (1993) for applied contributions.

Figure 3: Annual rate of New Zealand CPI inflation, 1980 - 2002



We have focused in this paper on analysing nominal relationships because it seems plausible that New Zealand's transition to relatively low and stable inflation (Figure 3) has led to structural changes in expectations formation and price setting behaviour. Generally, our results suggest that the increased anchoring of New Zealand inflation around the inflation target may have led to structural changes (to markup processes and inflation expectations) that have dampened the propagation of inflationary shocks[11]. This is related to the ideas of Sargent (1982), who argued that a credible commitment to low inflation could cause inflationary expectations to lock in around the inflation target, making disinflation to that target "costless". While our results are not consistent with costless disinflation, they are consistent with a gradual reduction in the difficulty of the inflation control problem. This clearly has important implications. Rudebusch (2001) illustrates this by considering a particular possible reduction in the difficulty of inflation control (the transformation of the Phillips curve from a unit-root to a persistent but stationary process) and showing it greatly changes the optimal conduct of policy.

2.1 Inflationary expectations in a small system of equations

During the last few years many authors have investigated very compact macro-economic models, often of a forward-looking nature[12]. The so-called 'new Phillips curve' has micro-foundations (see Roberts 1995) and should therefore be less subject to the Lucas critique (see Lucas 1976). However these models tend to have problems fitting the data (see Clarida et al. 1999, Roberts 2001 or Rudebusch 2002), which has led many authors to work with hybrid models that mix

[11] Which is likely to increase the case for pricing to market (i.e. less passthrough of small exchange rate movements into the domestic currency price).

forward and backward looking dynamics.

Following an increasing literature on learning processes (see Lucas 1986, Woodford 1990, Beeby et al. 2001 or Orphanides and Williams 2002) we explored how those models can be reformulated by focussing on the rules that agents apply to form their expectations, rather than mixing rational and adaptive expectations. The main idea is that if models based on rational expectations do not fit the data well, it may be because they assume too much on the part of agents. Thus, it may be more realistic to assume that agents apply simple rules to form their expectations, and revise those rules when they make forecasting errors.

The previous work cited above has shown that rational expectation equilibria (REE) can be learned by agents. A potential issue raised by this work is that there are a range of ways of specifying the learning process, and different processes can have quite different implications for the nature and the stability of the REE[13]. Most of those contributions use least square estimations to simulate the learning process. Its convergence to REE depends on the set of prior information that agents will consider to form their expectations[14] (see Marcet and Sargent 1988, 1989a,b, Timmermann 1994, Sargent 1999, or Evans and Honkapohja 2001). Orphanides and Williams (2002) show that agents who know a reduced-form of the model can identify the functional form of the expectation rule under rational expectations, and can uncover the REE parameters by applying least square estimates to this functional form.

While the process that captures the learning process is usually based on least square estimates, Bullard (1992) showed that the Kalman filter can reproduce the general approach proposed by Marcet and Sargent (1989a). The advantage of modelling a learning process with a Kalman filter is that it nests the least square approach and the convergence results of Marcet and Sargent (1989a,b) remain valid (see Garatt and Hall 1997).

We follow Orphanides and Williams by building a small model, in which the REE is relatively simple and can be analytically calculated, and formulating it in a state space form. We then estimate the model, allowing for learning through time-varying parameters in the rule used by

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[12] See Lindé (2001) for a discussion of those different models.

[13] As an example Woodford (1990) considers that agents could adopt a sunspot variable to form their expectations.

[14] Let A_t be the optimal estimate at date t of an unknown vector A. The learning process can be viewed as updating A_t using a simple rule of the type: $A_t=TA_{t-1}$. It will converge towards REE if the true value A is a solution of the updating equation, the initial value chosen for A is close to the true value and if the matrix T has its eigenvalues within the unit circle.

agents to form inflation expectations.

2.1.1 The model

The underlying model is composed by a set of three equations: an AD curve, an AS curve and a monetary policy reaction function. The AS curve is forward looking, while we assume a backward looking AD curve. These choices follow other recent specifications of new Keynesian models for New Zealand which emphasise the forward looking nature of inflation and the backward looking nature of the output gap (see Razzak 2002 or NBNZ 2002)[15].

The AS curve is forward looking (see Roberts 1995):

(1) $$\pi_t = \pi^e_{t+1} + \phi y_t + \nu_t$$

where π_t is the inflation rate, π^e_{t+1} is the expectation of the inflation rate, based on information available up to period *t-1* (i.e. before π_t is observed), y_t the output gap and $\nu_t \sim N\left(0, \sigma^2_\nu\right)$.

The AD curve is backward looking (see Svensson 1997, Rudebusch and Svensson 1999):

(2) $$y_t = -\alpha_1\left(i_t - \pi^e_{t+1} - \bar{r}\right) + \beta y_{t-1} + \varepsilon'_t$$

where i_t is the interest rate, $\bar{r}$ the equilibrium real interest rate and $\varepsilon'_t \sim N\left(0, \sigma^2_{\varepsilon'}\right)$.

Finally the reaction function is specified as follows:

(3) $$i_t = \pi^e_{t+1} + \bar{r} + \alpha_2\left(\pi_t - \bar{\pi}\right) + \mu_t$$

where $\bar{\pi}$ is the inflation target and $\mu_t \sim N\left(0, \sigma^2_\mu\right)$.

The reduced form of this model can be written as follows:

(4) $$y_t = -\theta\left(\pi_t - \bar{\pi}\right) + \beta y_{t-1} + \varepsilon_t$$

(5) $$\pi_t = \pi^e_{t+1} + \phi y_t + \nu_t$$

With $\theta = \alpha_1\alpha_2$, $\varepsilon_t = \varepsilon'_t - \alpha_1\mu_t$ and $\sigma^2_\varepsilon = \sigma^2_{\varepsilon'} + \left(\alpha_1\right)^2\sigma^2_\mu$.

[15] This model could be easily extended to a forward-looking AD curve à la McCallum and Nelson (1999).

2.1.2 Rational expectations solution

Under rational expectations the following holds:

(6) $$\pi^e_{t+1} = \pi_{t+1} - e_{t+1}$$

With $e_{t+1} \sim N\left(0, \sigma_e^2\right)$.

The dynamic of y_t is stable and backward looking, while the dynamic followed by π_t is forward looking and unstable by nature. Nevertheless, this structure implicitly considers y as a state variable and π is a control variable. Therefore the solution of this problem is a rather standard saddle point, where only one trajectory is convergent towards the long-run equilibrium (where obviously $\pi = \overline{\pi}$ and $y=0$). Along this dynamic both y_t and π_t exhibit converging and stable dynamics that are given by (see annex 5.2):

(7) $$y_t = \Gamma y_{t-1}$$

(8) $$\pi_t - \overline{\pi} = \Lambda y_{t-1}$$

with $\Gamma<1$.

2.1.3 Learning process

We used the following functional form for inflation expectations:

(9) $$\pi^e_{t+1} \equiv \alpha_{1,t|t-1}\pi_{t-1} + \alpha_{2,t|t-1}\overline{\pi} + \alpha_{3,t|t-1}y_{t-1}$$

This is estimated from the data as an updating rule. After observing actual inflation in period t+1, agents update the parameters of the expectations equation:

(10) $$\pi_{t+1} = \alpha_{1,t}\pi_{t-1} + \alpha_{2,t}\overline{\pi} + \alpha_{3,t}y_{t-1} + \varepsilon_t$$

With:

(11) $$\forall i \in \{1,3\} \quad \alpha_{i,t} = \alpha_{i-1,t} + \xi^i_t$$

This specification is sufficiently general to encompass adaptive expectations as well as rational expectations. If the dynamic of inflation expectation was purely adaptive then the time-varying coefficients would converge towards the following values:

(12) $$adaptive \quad \begin{cases} \alpha_{1,t} \to 1 \\ \alpha_{2,t} \to 0 \\ \alpha_{3,t} \to 0 \end{cases}$$

Under rational expectations we should have:

$$\text{(13)} \qquad \textit{rational} \quad \begin{cases} \alpha_{1,t} \to 0 \\ \alpha_{2,t} \to 1 \\ \alpha_{3,t} \to \Lambda \end{cases}$$

The model was estimated by maximum likelihood, with the following results:

$$\text{(14)} \qquad y_t = -\underset{(-0.09)}{0.08}\left(\pi_t - \overline{\pi}\right) + \underset{(7.76)}{0.89}\, y_{t-1} + \varepsilon_t$$

$$\text{(15)} \qquad \pi_t - \overline{\pi} = \pi_{t+1}^{e} - \overline{\pi} + \underset{(0.35)}{0.02}\, y_t + \nu_t$$

Given those parameters the value for Λ is 0.104 (see annex 5.2 for the analytic expression of Λ). The residuals do not exhibit significant auto-correlation when testing at a 5% level.

The final values for the time-varying parameters were as follows:

$$\text{(16)} \qquad \textit{final estimates} \quad \begin{cases} \alpha_{1,T} = 0.13 \\ \alpha_{2,T} = 1.06 \\ \alpha_{3,T} = 0.03 \end{cases}$$

The patterns of the coefficients were as follows:

figure 4: $\alpha_{1,t}$

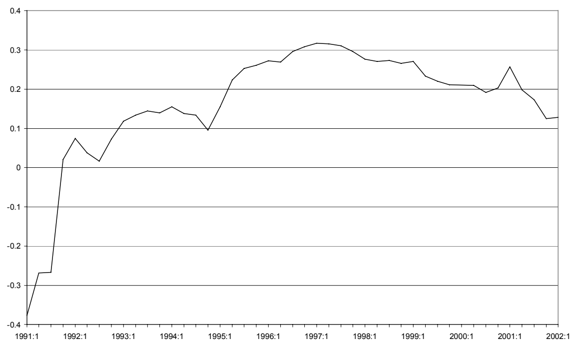


figure 5: $\alpha_{2,t}$

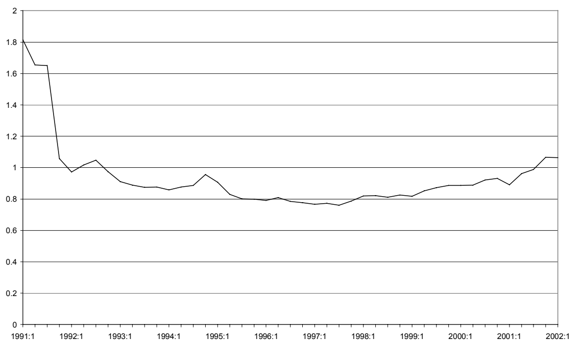
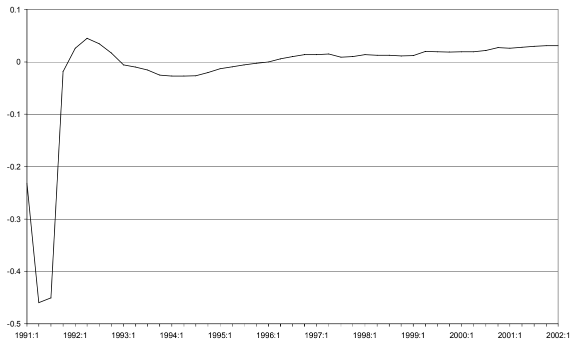


figure 6: $\alpha_{3,t}$



After some initial volatility, the values of the parameters appear to settle fairly near the values predicted under rational expectations, although $\alpha_{1,T}$ remains positive and $\alpha_{3,T}$ is somewhat lower than predicted. Over the last 5 years or so of the estimation, $\alpha_{1,T}$ appears to be falling towards zero and $\alpha_{2,T}$ rising towards 1, which takes the expectations formation process closer to the REE.

Of course the specification we have utilised above is extremely simple. An obvious criticism of the model is that it does not integrate the transmission of shocks from the rest of the world and the exchange rate. We have done some preliminary investigation of the stability of the model with domestically denominated import prices incorporated in the Phillips curve as an exogenous variable, and this does not greatly alter the results. But we would like to consider the robustness of these results to further open economy extensions in the future.

One thing that is somewhat surprising in the specification above is the fact that there does not appear to have been a transition from adaptive expectations towards rational expectations over the estimation period (i.e. . $\alpha_{1,T}$ is never near 1). A possible explanation for this is that we have characterised adaptive expectations too strictly. If inflation outturns exhibit high frequency volatility, a more appropriate adaptive expectations rule may include more than one lag of inflation when formulating expectations. Again, we would like to examine this in further work.

2.2 Domestic inflation

In this section, we look at the possibility of instability in the long run relation between domestic prices, import prices and unit labour cost. In many macroeconomic models, for example the SEM model of Ha and Hampton (2002), a cointegrating relationship between prices and costs is imposed. While this seems reasonable, it is not clear a priori that the parameters of this relationship will be stable. For example, technological changes could mean that the relative importance of labour or imported goods in the production function increases. There could also be structural shifts in the levels of firm's margins as a result of changes in the level of competition. Finally, it is possible that declining inflation will lead firms to be slower to pass cost shocks on. This last point has been investigated (in different contexts) in work such as that of Barassi et al. (2000, 2001), who examine the possibility of a time-varying error correction parameter.

The general specification of the equation we used was as follows:

(17)
$$\begin{aligned}\Delta p^d &= c + \gamma_1 \Delta p + \gamma_2 \Delta p_{-2} + \gamma_3 gap + \gamma_4 \Delta_4 p^d_{-1} + \gamma_5 \Delta ulc \\ &+ \gamma_6 \Delta ulc_{-1} + \lambda\left(p^d_{-1} + \alpha p_{-1} - (1+\alpha) ulc_{-1}\right) + \varepsilon\end{aligned}$$

where p^d is the domestic price, p the import price, gap the output gap and ulc the unit labour cost.

Table 1: general specification

Dependent Variable: Δp^d

	Coefficient	Std. Error	t-Statistic	Prob.
c	-0.004663	0.001906	-2.446804	0.0165
Δp	0.062464	0.014019	4.455674	0.0000
Δp_{-2}	0.036438	0.014959	2.435808	0.0170
Gap	0.150168	0.032044	4.686345	0.0000
Δp^d_{-1}	0.359710	0.065859	5.461841	0.0000
Δulc	0.091177	0.019850	4.593330	0.0000
Δulc_{-1}	0.084584	0.021910	3.860606	0.0002
λ	-0.103368	0.023215	-4.452583	0.0000
α	-0.270315	0.054659	-4.945452	0.0000
R-squared	0.896088	Mean dependent var		0.015100
Adjusted R-squared	0.886192	S.D. dependent var		0.013394

S.E. of regression	0.004519	Akaike info criterion	-7.869440
Sum squared resid	0.001715	Schwarz criterion	-7.624350
Log likelihood	374.9290	Durbin-Watson stat	2.077361

The equation exhibits a bit of instability diagnosed by cumulated-sum tests:

Figure 7

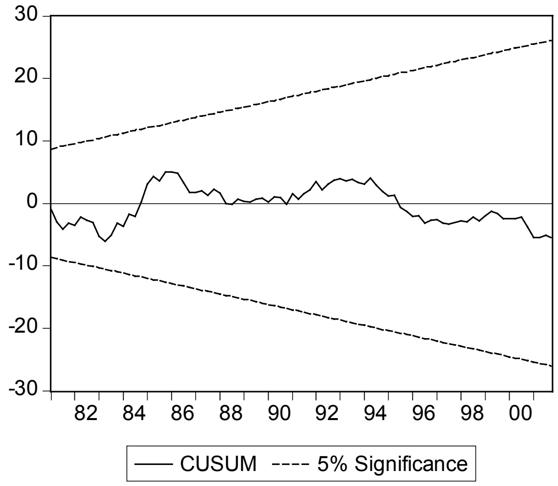
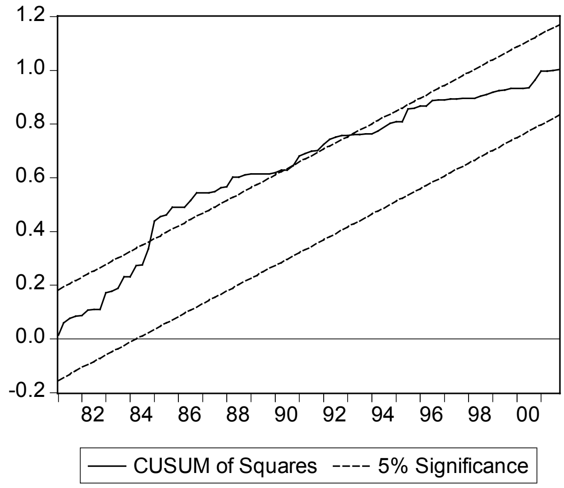


Figure 8



We went on to examine two possible sources of instability: a time-varying share of import prices in the long-run relation (which was rejected by the data) and a time-varying speed of adjustment. In essence the last specification is drawn from the recent contributions of Barassi et al. (2000, 2001) who claim that a changing speed of adjustment to the long run relation can capture a wide range of structural changes. Those authors also emphasise that when there are several breaks and when the breakpoints are unknown it can be more feasible to use time-varying parameters estimated with a Kalman filter.

More precisely the speed of adjustment was modelled as follows:

(18) $$\lambda = \lambda_{-1} + \nu$$

(19) $$Var(\varepsilon) = k_1 e^{\mu} \text{ and } Var(\nu) = k_2 e^{\mu}$$

where k_1 and k_2 were calibrated as the variance of coefficients obtained with an OLS estimation, and the parameter μ estimated within the state-space model.

The resulting specification did not exhibit residual autocorrelation, and implied a reduction in the speed of adjustment over the recent period.

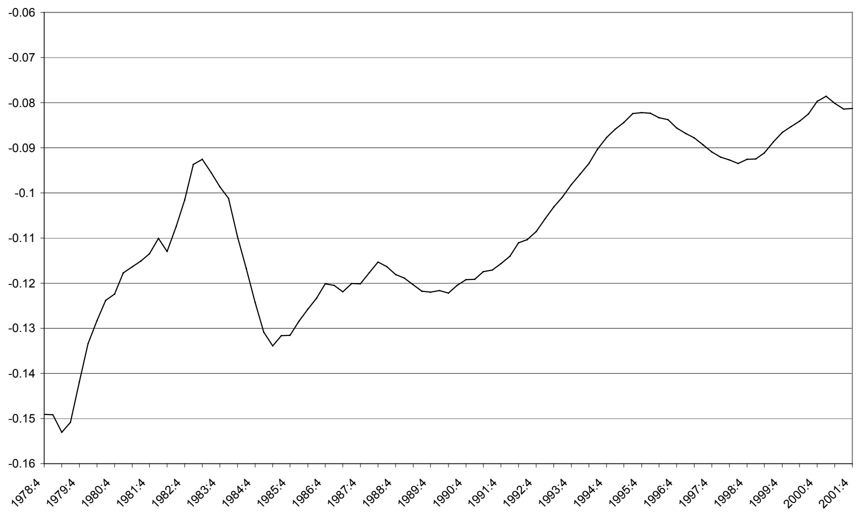
Table 2

Dependent Variable: Δp^d
Method: Maximum likelihood (Marquardt)
Convergence achieved after 18 iterations

	Coefficient	Std. Error	z-Statistic	Prob.
c	-0.003973	0.004012	-0.990165	0.3221
Δp	0.059032	0.014729	4.007970	0.0001
Δp_{-2}	0.037439	0.014732	2.541288	0.0110
Gap	0.161253	0.029625	5.443147	0.0000
Δp^d_{-1}	0.254265	0.077276	3.290342	0.0010
Δulc	0.075358	0.025757	2.925781	0.0034
Δulc_{-1}	0.072840	0.021416	3.401181	0.0007
α	-0.281016	0.064165	-4.379593	0.0000
μ	0.003265	0.000610	5.354463	0.0000
	Final State	Root MSE	z-Statistic	Prob.
λ	-0.081249	0.021123	-3.846515	0.0001

Log likelihood	364.1951	Akaike info criterion	-7.638604
Parameters	9	Schwarz criterion	-7.393514
Diffuse priors	1	Hannan-Quinn criter.	-7.539644

Figure 9: time-varying speed of adjustment



This appears quite consistent with our hypothesis that the transition to a low inflation environment, as shown earlier in Figure 3, has made firms slower to pass on wage and cost shocks. Interestingly, the gradual decline in the speed of adjustment parameter begins at almost exactly the point where inflation was stabilised near the target (around 1991). This provides circumstantial evidence that the slowing of passthrough is related to a gradual increase in the credibility of the inflation targeting regime.

2.3 Import price and exchange rate passthrough

We started our investigation of exchange rate passthrough with a rather basic specification, based on a error correction framework with long run pricing consistent with the law of one price (LOOP), and cyclical pricing to market behaviour (with the New Zealand output gap depicting the business cycle) also incorporated. We began with a rather detailed lag structure:

$$\Delta p = \gamma_0 + \sum_{i=0}^{k} \gamma_{1,i} \Delta e_{-i} + \sum_{i=0}^{k} \gamma_{2,i} \Delta p^*_{-i} + \sum_{i=1}^{k} \gamma_{3,i} \Delta p_{-i} + \sum_{i=0}^{k} \gamma_{4,i} gap_{-i} + \gamma_5 p_{-1} + \gamma_6 p^*_{-1} \quad (20)$$

where p is the import price, e the exchange rate, p^* the foreign price and gap the output gap[16]. The equation was estimated and thereafter tested in order to reduce the number of parameters in the short-run dynamics. The accepted specification was as follows:

$$\Delta p = \gamma_0 + \gamma_1 \Delta e + \gamma_2 gap + \gamma_3 p_{-1} + \gamma_4 \left(p^*_{-1} - e_{-1}\right) + \gamma_5 \left(p^m_{-1} - e_{-1}\right) + \gamma_6 \left(p^o_{-1} - e_{-1}\right) + \varepsilon \quad (21)$$

where p^m is the price of minerals and p^o the oil price (both in foreign currency terms).

Table 3: results

Dependent Variable: Δp
Method: Least Squares
Sample(adjusted): 1990:2 2001:4
Included observations: 47 after adjusting endpoints

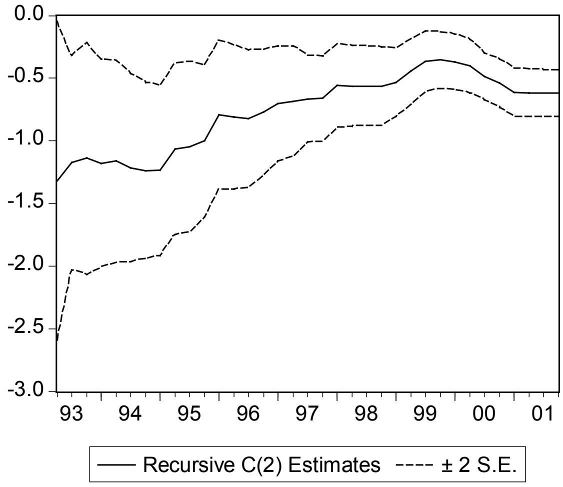
Variable	Coefficient	Std. Error	t-Statistic	Prob.
c	7.119018	1.162172	6.125613	0.0000
Δe	-0.616956	0.093041	-6.630992	0.0000
gap	0.433650	0.130760	3.316386	0.0019
$p(-1)$	-0.760706	0.125850	-6.044520	0.0000
$p^*(-1) - e(-1)$	0.437523	0.071982	6.078218	0.0000
$p^m(-1) - e(-1)$	0.056195	0.023529	2.388324	0.0217
$p^o(-1) - e(-1)$	0.051668	0.014605	3.537696	0.0010

R-squared	0.754427	Mean dependent var	0.004950
Adjusted R-squared	0.717591	S.D. dependent var	0.027216
S.E. of regression	0.014463	Akaike info criterion	-5.497823
Sum squared resid	0.008367	Schwarz criterion	-5.222269
Log likelihood	136.1988	F-statistic	20.48075
Durbin-Watson stat	2.131742	Prob(F-statistic)	0.000000

The coefficients give plausible values, and the residuals do not exhibit significant auto-correlation. Full passthrough in the long run was rejected, while a Wald test accepted that the elasticity of foreign prices as a whole (i.e. for p^*, p^m and p^o) is equal to the elasticity of the exchange rate. This equation passed all tests on serial correlation (LM test, Box-Pierce, Durbin-Watson), heteroscedasticity (ARCH and white tests) and specification test (RESET test). We then performed some recursive estimations, and both CUSUM and CUSUM of square residuals suggested that the equation was stable. Nevertheless, the recursive estimation suggested the coefficient on the short term effect of the exchange rate seemed to be relatively unstable:

[16] The variable *gap* was introduced directly in levels as it should be (and was found to be) stationary.

Figure 10: coefficient on the exchange rate



Although the major tests suggest that the equation is well specified and stable, the potential instability of this coefficient suggests a need for further investigation. We used recursive estimation, and found results which suggested that the exchange rate passthrough has decreased until 1999 and increased since. We investigated this further using a state space model.

The estimated state-space model was composed of the following measurement equation:

(22) $$\Delta p = \gamma_0 + \gamma_{1,t}\Delta e + \gamma_2 gap + \gamma_3 p_{-1} + \gamma_4\left(p^*_{-1} - e_{-1}\right) + \gamma_5\left(p^m_{-1} - e_{-1}\right) + \gamma_6\left(p^o_{-1} - e_{-1}\right) + \varepsilon$$

where $\gamma_{1,t}$ is a time-varying parameter, i.e. a state variable that is modelled as follows:

(23) $$\gamma_{1,t} = \gamma_{1,t-1} + \nu_t$$

with $\varepsilon_t \sim N\left(0, k_1 e^{\mu}\right)$ and $\nu_t \sim N\left(0, k_2 e^{\mu}\right)$, where k_1 and k_2 are the respective variances estimated in the equation estimated with fixed coefficients. The hyper-parameter μ is estimated within the Kalman filter using maximum likelihood.

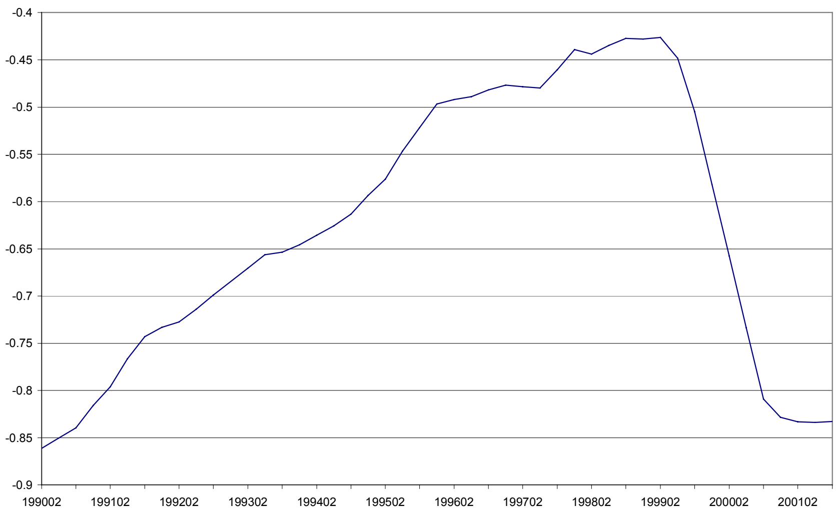
The table below summarises the results obtained, and is followed by a plot of the smoothed values of the time-varying parameter.

Table 4: results from Kalman filter

Dependent Variable: Δp
Method: Maximum likelihood (Marquardt)
Included observations: 47

	Coefficient	Std. Error	z-Statistic	Prob.
c	7.116812	0.037369	190.4474	0.0000
gap	0.404663	0.141417	2.861498	0.0042
$p(-1)$	-0.760486	0.015759	-48.25769	0.0000
$p^{*}(-1) - e(-1)$	0.438221	0.021757	20.14144	0.0000
$p^{m}(-1) - e(-1)$	0.055763	0.025710	2.168939	0.0301
$p^{o}(-1) - e(-1)$	0.048753	0.013141	3.710146	0.0002
μ	0.701493	0.177217	3.958392	0.0001
	Final State	Root MSE	z-Statistic	Prob.
$\gamma_{1,T}$	-0.832792	0.196796	-4.231758	0.0000
Log likelihood	129.3210	Akaike info criterion		-5.205147
Parameters	7	Schwarz criterion		-4.929593
Diffuse priors	1	Hannan-Quinn criter.		-5.101454

Figure 11: time-varying coefficient, exchange rate



Basically the estimation confirms the results obtained with recursive estimations: the coefficient of the exchange rate has increased before falling sharply during the recent period. The magnitude of the change is also in line with the most recent study on the exchange rate passthrough in New Zealand of Kochhar et al. (2002), as they find that the passthrough has declined from 0.65 in early nineties to 0.50 in 1999 before going back to 0.60. In this study we go a step further as we did not impose price homogeneity on the long run (while Kochhar et al. do) and we reject the hypothesis that the passthrough is complete in the long run. This hypothesis is also rejected by Campa and Goldberg (2002) who find relatively similar results (they find a short term passthrough elasticity of 0.47 and long term elasticity of .62, while the OLS regression gave 0.62 and 0.71).

The results appears similar (at least until the final couple of years) to those uncovered in the previous section looking at consumer prices, and can again be plausibly related to the reduced volatility of New Zealand inflation. Increases in domestically denominated import prices caused by nominal exchange rate depreciations were almost always permanent until the mid 1980s, but have tended to be temporary more recently (figure 3). Thus, it seems plausible that the speed with which first-stage passthrough occurs could have fallen as the proportion of import cost shocks that proved temporary rose over time. On this basis, the recent increase in passthrough reflects the fact that the 1999-2001 depreciation was sustained for longer than firms initially expected, and they were eventually forced to pass the cost shock through.

3 Using and communicating evidence of structural change

In this section, we briefly summarise the results of some recent internal investigations of the neutral real rate (NRR). We think this provides an interesting example of how the search for structural change described in section two can interact with the policymaking and forecasting process described in section one.

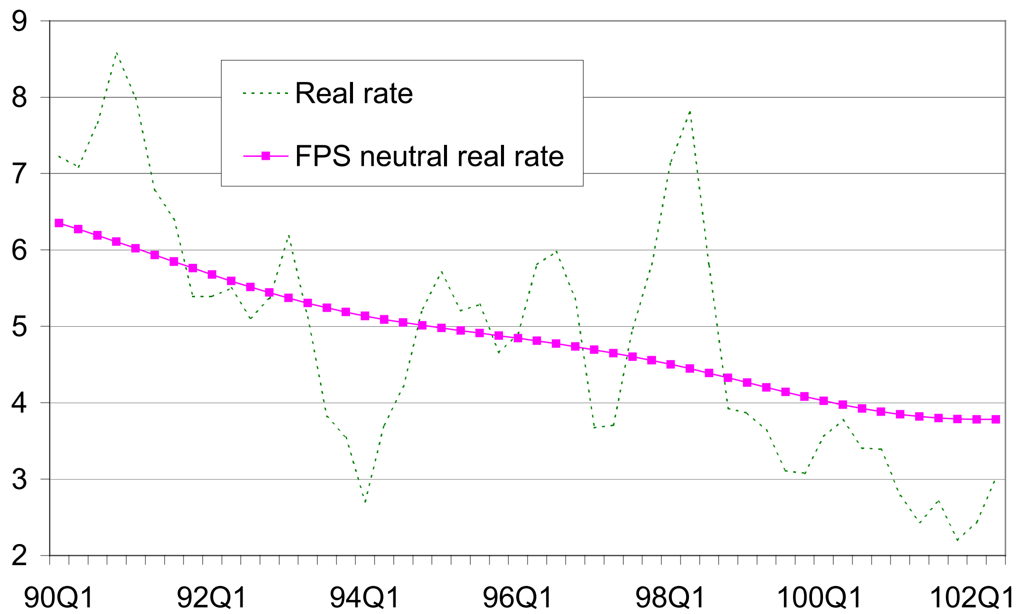
A parameter like the NRR clearly has direct implications for any framework where monetary policy is characterised as the shifting of rates from neutral levels in order to counteract inflationary and demand pressures in the economy. Hence, it is important that the parameter is not changed arbitrarily, and policy makers are unlikely to react positively to a changed NRR as an explanation for a counterintuitive shift in the policy track. But it is plausible that the neutral real rate can vary over time. For example, a decline in the risk premium attached to New Zealand assets by overseas investors could plausibly lower the equilibrium cost of capital here, and that would ultimately lead to a decline in our neutral real rate.

Policy makers expressed concern about the neutral real rate (then 4.5 percent per annum)[17] incorporated into FPS during 2001. This concern led to a couple of pieces of published analysis. Archibald and Hunter (2001) outlined a number of ways to calculate the neutral real rate and their implications. Plantier and Scrimgeour (2002) presented some circumstantial evidence that the real interest rate may have been falling over the 1990s, based on a specification of the Taylor rule where the neutral real rate is allowed to shift over time.

Initial analysis in the paper by Archibald and Hunter considered how we might think about the NRR from a monetary policy perspective, and suggested points of difference between thinking about the NRR as a short-run, medium-run, or long-run equilibrium concept. The medium-run concept was identified as the relevant concept for NZ's policy framework, and reasons why this NRR concept might change over time were considered. The paper also investigated international evidence on the NRR in other countries (based on the idea that risk free interest rates in an open capital market like New Zealand's would be related to equivalent returns in other open economies). Later work derived further evidence was derived from inflation indexed bond data, and long-term survey data on inflation expectations (combined with nominal yields).

This analysis was subsequently supported by Plantier and Scrimgeour's work, in which the NRR was determined residually: a persistent fall in the residuals from a Taylor rule was interpreted by their state space model as a fall in the neutral real rate. There are obviously other possible explanations for a persistent shift in the residuals, and ideally we would have proceeded from there to a model where the NRR was explicitly modelled (an ambitious task, but one we hope to attempt in the future).

Figure 12: Historical real interest rates and FPS estimate of neutral real rate



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[17] See Archibald and Hunter (2001) for a description of how this parameter was arrived at.

When we engaged with the policy makers and made a decision about the calibration of the model, this economic evidence provided an intuitive corroboration of their intuition that FPS was producing policy rates that were too high. It was this combination of state space based estimation, economic analysis, and policy maker intuition pointing in the same direction that led us to recalibrate down the steady state level of the neutral real rate (currently 4 percent in the long run, with some variation over time as shown in the chart above). This is a practical example of the sorts of issues relating to time-varying parameters we describe in section one: they can provide a starting point for further investigation or corroborate other economic evidence, but shouldn't be viewed as conclusive in themselves.

4 Conclusions

In this paper, we have described how the major structural changes seen in the New Zealand economy over the 1980s have informed the modelling approaches adopted at the Reserve Bank of New Zealand, by leading to the development of a model that was calibrated rather than estimated on historic relationships and the diversification and validation agenda that has evolved since.

We then went on to look for structural change in several different aspects of the nominal side of the economy (expectations formation, exchange rate passthrough, and the setting of consumer prices). Our analysis of each of these areas provides some evidence that, following the achievement of low and stable inflation, the behaviour of the nominal side of the New Zealand economy has evolved in a manner consistent with the predictions of economic theory. This tends to validate the choice made in the mid 1990s to work with a calibrated model, rather than a model estimated on relationships that were still evolving. However, it also suggests that empirical testing of the relationships embedded into that calibrated model may be increasingly feasible, given the increasing size of New Zealand's post reform dataset, and the ability of Kalman filter based methods to allow for time-varying parameters.

5 Annexes

5.1 The Kalman filter and the smoothed estimates

For simplicity let us consider a measurement equation that has no fixed coefficients:

(24) $$Y_t = \Gamma_t X_t + \varepsilon_t$$

where Y_t is a vector of measured variables, Γ_t is the state vector of unobserved variables, X_t is a matrix of parameters and $\varepsilon_t \sim N(0, H)$. The state equation is given as:

(25) $$\Gamma_t = \Gamma_{t-1} + \eta_t$$

where $\eta_t \sim N(0, Q)$[18].

Let γ_t be the optimal estimator of Γ_t based on the observations up to and including Y_t, $\gamma_{t|t-1}$ the estimator based on the information available in $t-1$, and $\gamma_{t|T}$ the estimator based on the whole sample.

We define the covariance matrix P of the state variable as follows:

(26) $$P_{t-1} = E\Big((\Gamma_{t-1} - \gamma_{t-1})(\Gamma_{t-1} - \gamma_{t-1})' \Big)$$

The predicted estimate of the state variable in period t is defined as the optimal estimator based on information up to the period $t-1$, which is given by:

(27) $$\gamma_{t|t-1} = \gamma_{t-1}$$

while the covariance matrix of the estimator is:

(28) $$P_{t|t-1} = E\Big((\Gamma_t - \gamma_{t|t-1})(\Gamma_t - \gamma_{t|t-1})' \Big) = P_{t-1} + Q$$

The filtered estimate of the state variable in period t is defined as the optimal estimator based on information up to period t and is derived from the updating formulas of the Kalman filter[19]:

---

[18] Q and H are referred to as the hyper-parameters of the model, to distinguish them from the other parameters.

[19] This estimator minimises the mean square errors when the expectation is taken over all the variables in the information set rather than being conditional on a particular set of values (see Harvey 1989 for a detailed discussion). Thus the conditional mean estimator, γ_t, is the minimum mean square estimator of Γ_t. This estimator is unconditionally unbiased and the unconditional covariance matrix of the estimator is the P_t matrix given by the Kalman filter.

(29) $$\gamma_t = \gamma_{t|t-1} + P_{t|t-1} X_t' \left(X_t P_{t|t-1} X_t' + H \right)^{-1} \left(Y_t - X_t a_{t|t-1} \right)$$

and

(30) $$P_t = P_{t|t-1} - P_{t|t-1} X_t' \left(X_t P_{t|t-1} X_t' + H \right)^{-1} X_t P_{t|t-1}$$

The smoothed estimate of the state variable in period t is defined as the optimal estimator based on the whole set of information, i.e. on information up to period T (the last point of the sample). It is computed backwards from the last value of the earlier estimate $\gamma_{T|T}=\gamma_T$, $P_{T|T}=P_T$ with the following updating relations:

(31) $$\gamma_{t|T} = \gamma_t + P_t^* \left(\gamma_{t+1|T} + \gamma_t \right)$$

(32) $$P_{t|T} = P_t + P_t^* \left(P_{t+1|T} + P_{t+1|t} \right) P_t^{*\prime}$$

where $P_t^* = P_t P_{t+1|t}^{-1}$.

Depending on the problem studied one can be either interested in one of those three estimates. In our particular case looking at smoothed values are more appropriate, as the point is not to use the Kalman filter to produce forecasts but to give the most accurate information about the path followed by the time-varying coefficients. Therefore it is more informative to use the whole data set to derive each value of the state variables.

5.2 The dynamic under rational expectations

The system given by equations (4) and (5) can be reformulated in a matrix format:

(33) $$X_t = AX_{t-1} + E_t$$

where $X_t = \begin{pmatrix} y_t & \pi_t - \overline{\pi} \end{pmatrix}'$ and $E_t = \begin{pmatrix} \varepsilon_t & \nu_t \end{pmatrix}'$. This dynamic can be explicitly determined by analysing the eigenvalues of the matrix A, but given the backward looking nature of y_t and the forward looking nature of π_t the configuration of this dynamic is the one of a saddle point. Let γ_1 be the eigenvalue outside the unit circle, γ_2 the one inside the unit circle and P the matrix of eigenvectors the system can be written as follows:

(34) $$PX_t = \begin{pmatrix} \gamma_1 & 0 \\ 0 & \gamma_2 \end{pmatrix} PX_{t-1}$$

There is a unique trajectory that converges towards the equilibrium (given by $\pi_t = \overline{\pi}$ and $y_t=0$). What rational expectations imply is that agents will co-ordinate their expectation to rule out the unstable dynamic. Along this path the dynamic of expected inflation would be stable, monotonic and of the form:

(35) $$E(\pi_{t+1} \mid t) - \overline{\pi} = \lambda_1(\pi_t - \overline{\pi}) + \lambda_2 y_t$$

The dynamic of y_t should be dependent on the first lags of inflation and the output gap and also be stable. In the following we identify the parameters λ_1 and λ_2, and restrict the solutions to the stable dynamic.

Thus, replacing this expression in equation (6) giving the rational expectation:

(36) $$\pi_{t+1} - \overline{\pi} = \lambda_1(\pi_t - \overline{\pi}) + \lambda_2 y_t + e_{t+1}$$

With $0<\lambda_1<1$ and $0<\lambda_2<1$.

Let us define the values of λ_1 and λ_2.

Equations (5) and (36) can be re-written as follows:

(37) $$\pi_t - \overline{\pi} = \lambda_1(\pi_t - \overline{\pi}) + (\lambda_2 + \phi)y_t + \nu_t$$

Re-arranging the terms leads to:

(38) $$\pi_t - \overline{\pi} = \tfrac{\lambda_2+\phi}{1-\lambda_1} y_t + \tfrac{1}{1-\lambda_1}\nu_t$$

Introducing this equation in equation (4) leads to:

(39) $$y_t = -\theta \tfrac{\lambda_2+\phi}{1-\lambda_1} y_t - \tfrac{\theta}{1-\lambda_1}\nu_t + \beta y_{t-1} + \varepsilon_t$$

And after re-arranging the terms:

(40) $$y_t = \tfrac{\beta(1-\lambda_1)}{1-\lambda_1+\theta(\lambda_2+\phi)} y_{t-1} + \tfrac{1-\lambda_1}{1-\lambda_1+\theta(\lambda_2+\phi)}\varepsilon_t - \tfrac{\theta}{1-\lambda_1+\theta(\lambda_2+\phi)}\nu_t$$

The dynamic followed by y_t is obviously stable, as well as the dynamic of π_t as it follows the same dynamic.

To obtain the dynamic followed by inflation we can combine equations (38) and (40):

(41) $$\pi_t - \overline{\pi} = \tfrac{\beta(\lambda_2+\phi)}{1-\lambda_1+\theta(\lambda_2+\phi)} y_{t-1} + \tfrac{\lambda_2+\phi}{1-\lambda_1+\theta(\lambda_2+\phi)}\varepsilon_t + \tfrac{1}{(1-\lambda_1)(1-\lambda_1+\theta(\lambda_2+\phi))}\nu_t$$

Applying this relation in period $t+1$ and taking the rational expectation based on information in period t leads to the following:

(42) $$E(\pi_{t+1} \mid t) - \overline{\pi} = \tfrac{\beta(\lambda_2+\phi)}{1-\lambda_1+\theta(\lambda_2+\phi)} y_t$$

By identification between equations (35) and (42) we can derive the values of λ_1 and λ_2:

(43) $$\lambda_1 = 0$$

(44) $$\lambda_2 = \frac{\beta(\lambda_2 + \phi)}{1 + \theta(\lambda_2 + \phi)}$$

λ_2 is solution of:

(45) $$\theta(\lambda_2)^2 + (1 + \phi - \beta)\lambda_2 - \beta\phi = 0$$

There is one positive solution (the only acceptable otherwise the dynamic would not be monotonic):

(46) $$\lambda_2 = \tfrac{1}{2\theta}\left(-(1 + \phi - \beta) + \sqrt{(1 + \phi - \beta)^2 + 4\beta\phi\theta}\right)$$

Thus the system can be written as follows (omitting the error terms for simplicity):

(47) $$y_t = \Gamma y_{t-1}$$

(48) $$\pi_t - \overline{\pi} = \Lambda y_{t-1}$$

with:

(49) $$\Gamma = \frac{\beta}{1 + \theta(\lambda_2 + \phi)} < 1$$

(50) $$\Lambda = \tfrac{1}{2\theta}\left(-(1 + \phi - \beta) + \sqrt{(1 + \phi - \beta)^2 + 4\beta\phi\theta}\right)$$

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