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**Modelling structural change:  
the case of New Zealand**

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## Modelling structural change: the case of New Zealand

### Abstract<sup>1</sup>

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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## 1 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.<sup>2</sup> Since standard statistical inference relies on the stability of causal relationships, this structural change meant it was not useful to attempt a traditional estimated macroeconomic model at that time. Instead, as in a number of other economies subject to structural change,<sup>3</sup> 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<sup>4</sup> to the Reserve Bank of New Zealand's policy

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<sup>2</sup> New Zealand's reform program is described in some detail in Evans et al (1996).

<sup>3</sup> 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).

<sup>4</sup> 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 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).

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 associated with relying on a single, calibrated model of the economy.

The remainder of this paper is structured as follows. In section 2, 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 third 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 and the prices charged to consumers. In this work, we have put emphasis on the possibility of ongoing structural change, 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 4, we discuss a specific example: how evidence that the neutral real interest rate in New Zealand might have fallen was incorporated into policy. Section 5 concludes.

## 2 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 2.1). Then, in section 2.2, 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.

### 2.1 Identifying and understanding structural change

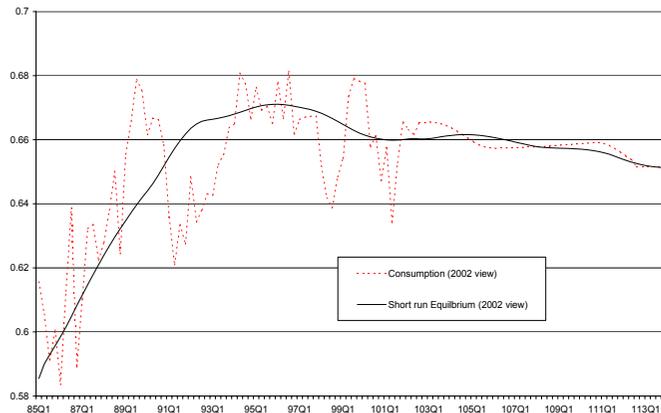
In the early 1990s, the Reserve Bank estimated a cointegration based macro-model of the New Zealand economy, Model XII (see Brookes and Gibbs 1994). This model was used in the forecasting process in the early 1990s, but the structural relationships had broken down by 1994/95, when work began on a new 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 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.<sup>5</sup> 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.

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



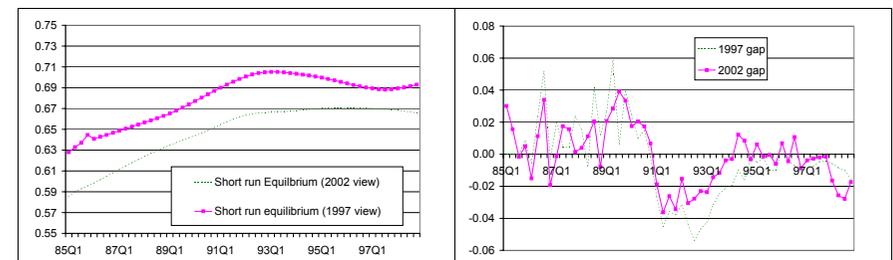
It seems clear from the chart above that the filtering has removed a trend of some description from the consumption to output ratio. Moreover, this trend would not have been well captured using a linear trend – most of the upward drift occurred in the early part of the period. Working with detrended (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

<sup>5</sup> Some variables have equilibria computed using a more complicated process: for example, a multivariate filter determines potential output. Also, some variable's equilibria are determined residually to satisfy standard identities: for example, equilibrium consumption is solved for using the national accounts add-up.

difficult and may not be of primary interest in monetary policy formulation anyway.

The left-hand chart below compares 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<sup>6</sup> 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 revised. 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 we recalibrated accordingly.

<sup>6</sup> See Drew and Hunt (1998) for a more detailed description.

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.<sup>7</sup> 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 3.

## 2.2 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 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 important ones, 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.

Firstly, we discuss alternative models that run 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.
- The fact that the dynamic equations are written in gap terms, making the model reliant on assumptions about de-trending.

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<sup>7</sup> Another example is the discussion of the Phillips curve in Drew and Hunter (2000).

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 Keynesian 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 such as money and credit. An additional example is the Small Estimated Model (SEM) constructed by Ha and Hampton (2002), which uses many of the functional forms employed in 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 place higher priority on diversifying our frames of reference, rather than concentrating 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.

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 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 Monetary Policy Committee with simulations showing the implications of alternative assumptions about the feed through from the spike in CPI inflation into inflationary expectations.

These "alternative scenarios" are likely to be 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, so we look for those alternative economic interpretations. 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.

### 3 Evolution of key nominal relationships

A key robustness issue for policymakers is the possibility that parameters in important relationships have changed. Analysing a range of models (as discussed in section 2.2) 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.<sup>8</sup>

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 (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 should be time-varying. It may be that a variable can represent the structural change and lead to a new, stable, time-invariant equation.

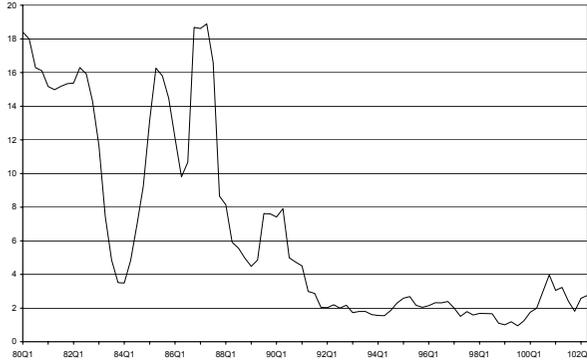
In this section, we develop some analysis of possible time-varying relationships between nominal variables. Two particular issues are analysed:

- Firstly, we estimate a mark-up model of inflation and consider possible sources of instability in that relationship (see section 3.1).
- Secondly, we look at how the stage one passthrough of exchange rate movements into domestic import prices has changed (see section 3.2).

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<sup>8</sup> The basic theory behind the Kalman filter is described in the Annex to this paper. See Harvey (1989) for an exhaustive presentation.

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



We have focused 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<sup>9</sup>. 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 that it greatly changes the optimal conduct of policy.

<sup>9</sup> Which is likely to increase the case for pricing to market (ie less passthrough of small exchange rate movements into the domestic currency price).

### 3.1 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:

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

where  $p^d$  is the domestic price,  $p$  the import price,  $gap$  the output gap and  $ulc$  the unit labour cost. This is a fairly standard markup relationship where the margin between consumer prices and producer costs (composed of import prices and unit labour costs) adjusts to an equilibrium level over time.

**Table 1: General specification**

Dependent Variable: $\Delta p^d$				
	Coefficient	Std. Error	t-Statistic	Prob.
$C$	-0.004663	0.001906	-2.446804	0.0165
$\Delta p$	0.062464	0.014019	4.455674	0.0000
$\Delta p_{-2}$	0.036438	0.014959	2.435808	0.0170
$Gap$	0.150168	0.032044	4.686345	0.0000
$\Delta p^d_{-1}$	0.359710	0.065859	5.461841	0.0000
$\Delta ulc$	0.091177	0.019850	4.593330	0.0000
$\Delta ulc_{-1}$	0.084584	0.021910	3.860606	0.0002
$\lambda$	-0.103368	0.023215	-4.452583	0.0000
$\alpha$	-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

Cumulated sum tests suggested this initial specification was not totally stable. Consequently, 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:

$$\lambda = \lambda_{-1} + \nu \quad (2)$$

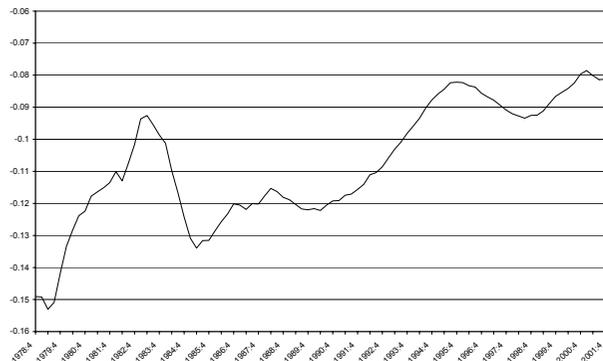
$$Var(\varepsilon) = k_1 e^{\mu} \text{ and } Var(\nu) = k_2 e^{\mu} \quad (3)$$

where  $k_1$  and  $k_2$  were calibrated as the variance of coefficients obtained with an OLS estimation, and the parameter  $\mu$  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: Time varying estimates**

Dependent Variable: $\Delta p^d$				
Method: Maximum likelihood (Marquardt)				
Convergence achieved after 18 iterations				
	Coefficient	Std. Error	z-Statistic	Prob.
$C$	-0.003973	0.004012	-0.990165	0.3221
$\Delta p$	0.059032	0.014729	4.007970	0.0001
$\Delta p_{-2}$	0.037439	0.014732	2.541288	0.0110
$Gap$	0.161253	0.029625	5.443147	0.0000
$\Delta p^d_{-1}$	0.254265	0.077276	3.290342	0.0010
$\Delta ulc$	0.075358	0.025757	2.925781	0.0034
$\Delta ulc_{-1}$	0.072840	0.021416	3.401181	0.0007
$\alpha$	-0.281016	0.064165	-4.379593	0.0000
$\mu$	0.003265	0.000610	5.354463	0.0000
	Final State	Root MSE	z-Statistic	Prob.
$\lambda$	-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 4: Time-varying speed of adjustment**

This appears quite consistent with our hypothesis that the transition to a low inflation environment has made firms slower to pass on wage and cost shocks. Interestingly, the gradual decline in the speed of adjustment parameter begins around the point where inflation was stabilised near the target (from 1991). This provides circumstantial evidence that the slowing of passthrough is related to a gradual increase in the credibility of the inflation targeting regime. The estimation suggests the current speed of adjustment (around 0.08) is about 20 per cent slower than the one estimated over the entire period (around 0.10).

### 3.2 Import price and exchange rate passthrough

The responsiveness of the CPI to shifts in the exchange rate depends on the first stage passthrough from an exchange rate shift to domestically denominated import prices, and the second stage passthrough from domestically denominated import prices to the CPI. We analyse first stage passthrough in this section, having already implicitly analysed the speed and degree of second stage passthrough in the previous section. A priori, we might expect to see a similar result to that in the previous section, where price stability has led to a reduction in the speed of passthrough of exchange rate shifts to domestically denominated import prices.

The logic relates to how the behaviour of the nominal exchange rate changes when prices are stable. Until the mid 1980s, exchange rate depreciations in New Zealand led to increases in domestically denominated import prices that were almost always permanent responses to inflation differentials. Recently, nominal exchange rate fluctuations have tended to be much more temporary. This makes it reasonable for firms that want to stabilise domestic prices (perhaps for market share or pricing to market reasons) to wait longer before passing exchange rate fluctuations on. After an exchange rate shift, the assumptions about passthrough embedded into FPS play a pivotal role in forecasting inflation, which makes this an important area of research, although the influence of exchange rate fluctuations on prices is generally temporary and “looked through” by policy makers (see Orr, Scott and White (1998)).

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 detailed lag structure:

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

where  $p$  is the import price,  $e$  the exchange rate,  $p^*$  the foreign price and  $gap$  the output gap.<sup>10</sup>

<sup>10</sup> The variable  $gap$  was introduced directly in levels, as theory clearly suggests it should be stationary and standard tests confirmed this.

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:

$$\Delta p = \gamma_0 + \gamma_1 \Delta e + \gamma_2 gap + \gamma_3 p_{-1} + \gamma_4 (p_{-1}^* - e_{-1}) + \gamma_5 (p_{-1}^m - e_{-1}) + \gamma_6 (p_{-1}^o - e_{-1}) + \varepsilon \quad (5)$$

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

### Table 3: Results

Dependent Variable:  $\Delta p$

Method: Least Squares

Sample(adjusted): 1990:2 2001:4

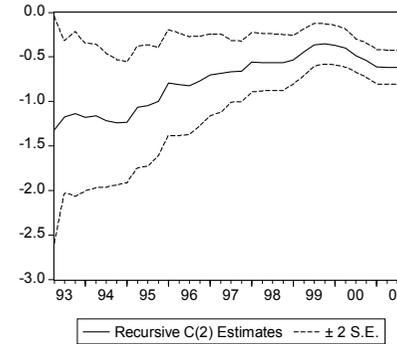
Included observations: 47 after adjusting endpoints

Variable	Coefficient	Std. Error	t-Statistic	Prob.
$C$	7.119018	1.162172	6.125613	0.0000
$\Delta e$	-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 (ie 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:

### Figure 5: 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 decreased until 1999 and has increased since. We investigated this further using a state space model.

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

$$\Delta p = \gamma_0 + \gamma_{1,t} \Delta e + \gamma_2 gap + \gamma_3 p_{-1} + \gamma_4 (p_{-1}^* - e_{-1}) + \gamma_5 (p_{-1}^m - e_{-1}) + \gamma_6 (p_{-1}^o - e_{-1}) + \varepsilon \quad (6)$$

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

$$\gamma_{1,t} = \gamma_{1,t-1} + v_t \quad (7)$$

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

Table 4 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**

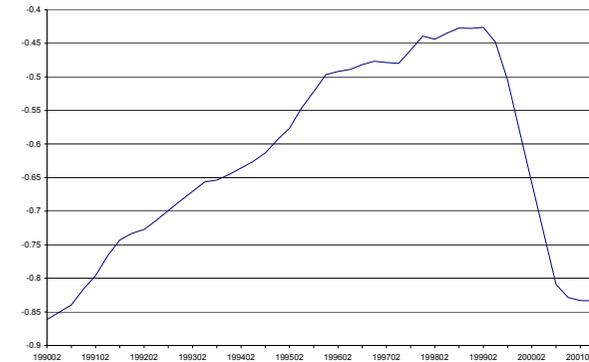
Dependent Variable:  $\Delta p$

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
$\mu$	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 6: 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 0.62, while the OLS regression gave 0.62 and 0.71).

In a sense, this result highlights the difficulty of interpreting structural change in reduced form parameters. The Reserve Bank was aware in 1999 and 2000 that import price inflation was remaining surprisingly weak, given the extent of exchange rate depreciation that had occurred. However, there was then a surprising spike in tradables inflation, which took the headline CPI to around 4 per cent briefly during 2000. Our results interpret this as a decline in the passthrough followed by an abrupt increase after 2000: the underlying lesson appears to be that firms are willing to delay passthrough during short exchange rate cycles, but

passthrough will become more rapid when the exchange rate cycle is persisting longer than initially expected.

#### 4 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 interest 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. However, 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.

During 2001, the declining trend of world interest rates throughout the 1990s led to consideration of whether the neutral real rate (then 4.5 per cent per annum)<sup>11</sup> incorporated into FPS might be a little high. In resulting work, Archibald and Hunter (2001) outlined a number of ways to calculate the neutral real rate, and presented some results. 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.

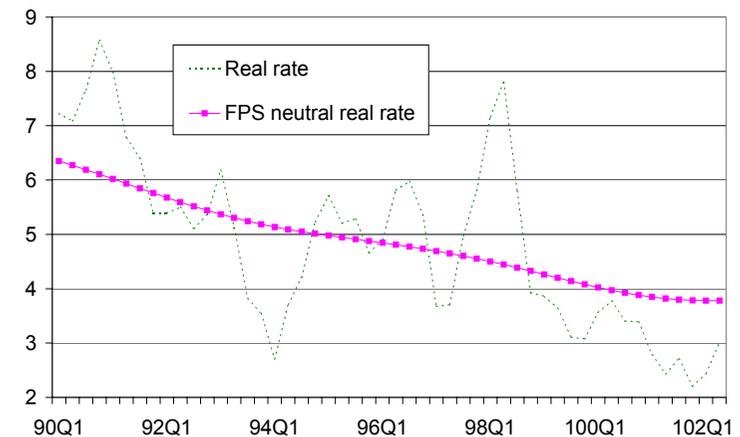
Initial analysis in the paper by Archibald and Hunter considered how we might think about the NRR from a monetary policy perspective, and suggested points of difference between thinking about the NRR as a short-run, medium-run, or long-run equilibrium concept. The medium-run concept was identified as the relevant concept for NZ's

<sup>11</sup> See Archibald and Hunter (2001) for a description of how this parameter was arrived at.

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 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 7:**  
**Historical real interest rates and FPS estimate of neutral real rate**



This economic evidence provided a corroboration of our suspicion that the neutral real rate may have fallen. It was this combination of state space based estimation, economic analysis, and intuition

pointing in the same direction that led us to recalibrate down the steady state level of the neutral real rate (currently 4 per cent 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.

## 5 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. This structural change led the Bank to decide to develop of a model that was calibrated rather than estimated on historic relationships, and has also influenced the diversification and validation agenda that has evolved since.

We then went on to look for structural change in a couple of different aspects of the nominal side of the economy (exchange rate passthrough, and the setting of consumer prices). Our analysis of both 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 recent development of improved econometric methods for dealing with time-varying parameters.

## Annex: The Kalman filter and the smoothed estimates

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

$$Y_t = \Gamma_t X_t + \varepsilon_t \quad (8)$$

where  $Y_t$  is a vector of measured variables,  $I_t$  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:

$$\Gamma_t = \Gamma_{t-1} + \eta_t \quad (9)$$

where  $\eta_t \sim N(0, Q)$ .<sup>12</sup>

Let  $\gamma_t$  be the optimal estimator of  $I_t$  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:

$$P_{t-1} = E\left((\Gamma_{t-1} - \gamma_{t-1})(\Gamma_{t-1} - \gamma_{t-1})'\right) \quad (10)$$

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:

$$\gamma_{t|t-1} = \gamma_{t-1} \quad (11)$$

while the covariance matrix of the estimator is:

$$P_{t|t-1} = E\left((\Gamma_t - \gamma_{t|t-1})(\Gamma_t - \gamma_{t|t-1})'\right) = P_{t-1} + Q \quad (12)$$

<sup>12</sup>  $Q$  and  $H$  are referred to as the hyper-parameters of the model, to distinguish them from the other parameters.

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:<sup>13</sup>

$$\gamma_t = \gamma_{t|t-1} + P_{t|t-1} X_t' (X_t P_{t|t-1} X_t' + H)^{-1} (Y_t - X_t a_{t|t-1}) \quad (13)$$

and

$$P_t = P_{t|t-1} - P_{t|t-1} X_t' (X_t P_{t|t-1} X_t' + H)^{-1} X_t P_{t|t-1} \quad (14)$$

The smoothed estimate of the state variable in period  $t$  is defined as the optimal estimator based on the whole set of information, ie 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:

$$\gamma_{t|T} = \gamma_t + P_t^* (\gamma_{t+1|T} + \gamma_t) \quad (15)$$

$$P_{t|T} = P_t + P_t^* (P_{t+1|T} + P_{t+1|T}) P_t^{*'} \quad (16)$$

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.

<sup>13</sup> 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,  $\gamma_t$ , is the minimum mean square estimator of  $I_t$ . This estimator is unconditionally unbiased and the unconditional covariance matrix of the estimator is the  $P_t$  matrix given by the Kalman filter.

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