



# Reserve Bank of New Zealand Analytical Notes

## Estimated policy rules for different monetary regimes: Flexible inflation targeting versus a dual mandate

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## NON-TECHNICAL SUMMARY

The Reserve Bank of New Zealand (RBNZ) has had a single price-stability mandate for monetary policy since February 1990. This mandate is set to be extended due to the RBNZ (Monetary Policy) Amendment Bill that is currently before parliament and that seeks to add employment to the RBNZ's mandate. The Federal Reserve System in the United States (Federal Reserve) also has a dual mandate for monetary policy.

In this paper we compare the responses of monetary policy to inflation and economic activity in New Zealand and the United States. We estimate how monetary policy in New Zealand responded to inflation and economic activity using the data available to policy makers at each point in time from 2000 through 2017. We then compare these estimates to similar estimates for the United States and assess how monetary policy settings have evolved over time.

We find that, on average, monetary policy in New Zealand and the United States has responded to changes in economic activity and inflation in similar ways. Our findings show that the RBNZ has stabilised measures of economic activity, i.e. the output gap and output growth, to a similar extent to that of the Federal Reserve. This is despite the RBNZ not operating under a dual mandate. A potential explanation for this result is that the flexibility of the RBNZ's inflation targeting strategy over history has allowed it to stabilise economic activity while maintaining the broader emphasis on price stability.

## 1 Introduction

The Reserve Bank of New Zealand (RBNZ) is responsible for conducting monetary policy to maintain price stability and in doing so contribute to New Zealand's economic wellbeing. Going forward, the RBNZ (Monetary Policy) Amendment Bill currently before parliament seeks to add stable employment as an additional primary mandate for monetary policy.<sup>1</sup> This would result in a dual mandate for monetary policy similar to the Federal Reserve System in the United States (Federal Reserve) and the Reserve Bank of Australia.<sup>2</sup> The Federal Reserve is required to conduct monetary policy to promote maximum employment, stable prices, and moderate long-term interest rates.<sup>3</sup>

Wadsworth (2017) found that formal inflation-targeting frameworks differ between advanced-economy inflation targeting central banks, but in practice these central banks operate in a similar manner. To explore this finding empirically, this paper compares monetary policy responses over 2000 to 2017 in New Zealand and the United States by estimating general equilibrium models that feature monetary policy rules. Using these models, we estimate the responses of the policy interest rate to key variables of interest: the inflation gap, the output gap, output growth, and the exchange rate. We use the real-time vintages of data that policymakers at the RBNZ and the Federal Reserve would have had available when making interest rate decisions. Our estimation strategy enables us to study the evolution of the policy rules of the central bank over time for each country.

We find that the estimated average monetary policy rule coefficients for New Zealand and the United States are similar even though the two central banks have had two different formal monetary policy frameworks. It appears that the RBNZ's flexible inflation targeting approach with a single mandate has resulted in monetary policy actions similar to those of the Federal Reserve, which has a dual mandate.

## 2 An overview of the data: New Zealand and the United States

New Zealand and the United States are advanced economies with inflation targets for monetary policy. New Zealand is a small open economy, and in contrast, the United States economy is large and relatively insulated from global economic developments. This section shows the evolution of headline inflation, real GDP and policy rates in the two economies.

Figure 1 shows the deviation of headline inflation from target for the United States and New Zealand over the past three decades. The RBNZ targets an inflation rate between one and three percent with a midpoint of two percent. The target is measured by headline consumer

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<sup>1</sup> In March 2018, the *Policy Targets Agreement* (PTA) between the Reserve Bank Governor and the Minister of Finance added monetary policy should also contribute to supporting maximum sustainable employment. The PTA can be found at <https://www.rbnz.govt.nz/monetary-policy/policy-targets-agreements/pta2018>.

<sup>2</sup> At the time of writing real-time data for Australia was not available to the authors, so it was not excluded from the comparison.

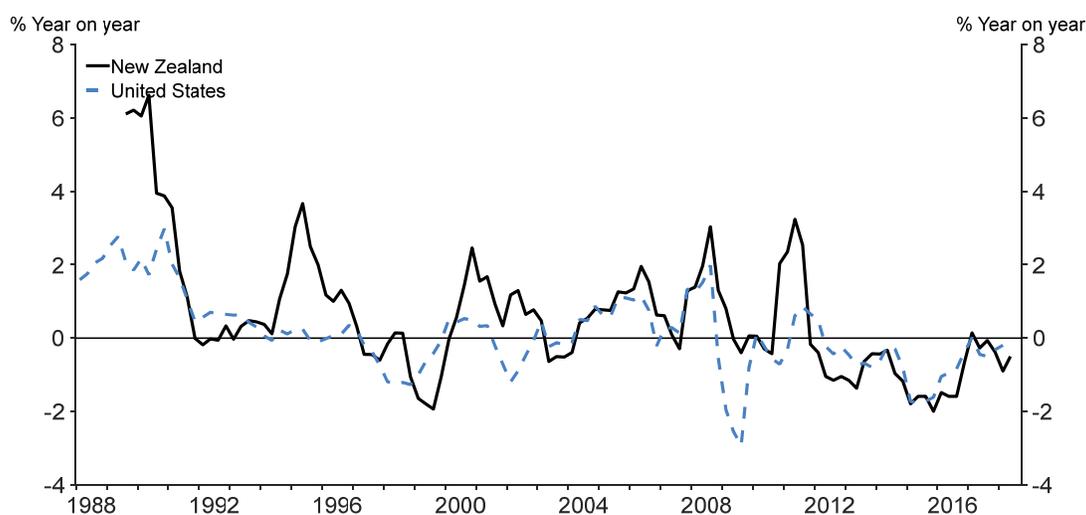
<sup>3</sup> Section 2A of the Federal Reserve Act (1913) states that the Board of Governors of the Federal Reserve System and the Federal Open Market Committee shall maintain long run growth of the monetary and credit aggregates commensurate with the economy's long run potential to increase production, so as to promote effectively the goals of maximum employment, stable prices, and moderate long-term interest rates.

price index (CPI) inflation. The Federal Reserve was given a numerical target for inflation of two percent in 2012, measured by personal consumption expenditure (PCE) inflation.<sup>4</sup>

Figure 2 shows the growth in real GDP for the two countries. New Zealand experienced higher GDP growth in the early 1990s, followed by lower GDP growth in the late 1990s. Both economies experienced a fall in GDP growth after the Global Financial Crisis (GFC). New Zealand's real GDP recovered faster reaching just over four percent year-on-year, whereas the United States' economy recovered more gradually. Both economies had GDP growth at around three percent year-on-year at the end of 2017.

Over much of the sample period, the United States tended to have a lower federal funds target rate (FFTR) compared to the policy rates (shown by the overnight cash rate and 90-day bank bill rate) in New Zealand (figure 3).<sup>5</sup> The United States held policy rates at zero (solid blue line) from 2009 through 2015. During this period, the Federal Reserve continued to stimulate the economy through quantitative easing and forward guidance policies. We proxy the implications for the short-term rate during this period by using the the shadow short rate (SSR)<sup>6</sup> (plotted with dashed blue line). The SSR was below zero during this period.

**Figure 1: Headline inflation deviation from target**



<sup>4</sup> Figure 1 assumes an implicit pre-2012 target of two percent for the United States and take into account the changes to the Reserve Bank's numerical target over history.

<sup>5</sup> The 90-day rate is a good measure of the historical monetary policy stance in New Zealand because it typically moved in a consistent manner with the OCR. However, following the GFC, variations in the 90-day rate became inconsistent with the OCR.

<sup>6</sup> The shadow short rate is a proxy for the US short-term market rate, derived from the term structure of interest rates (see Krippner 2011). See detailed description at <https://www.rbnz.govt.nz/research-and-publications/research-programme/additional-research/measures-of-the-stance-of-united-states-monetary-policy/comparison-of-international-monetary-policy-measures>.

Figure 2: Real GDP

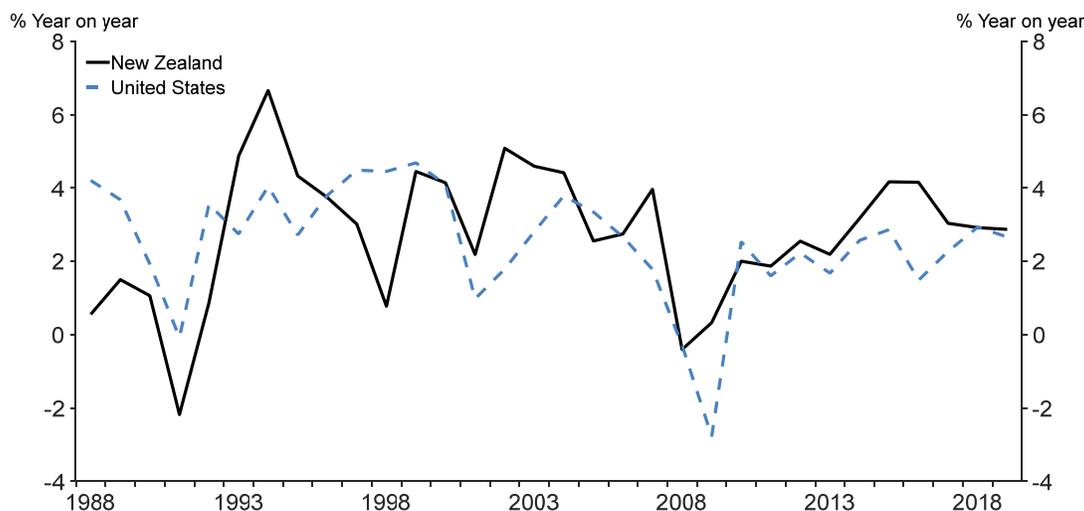
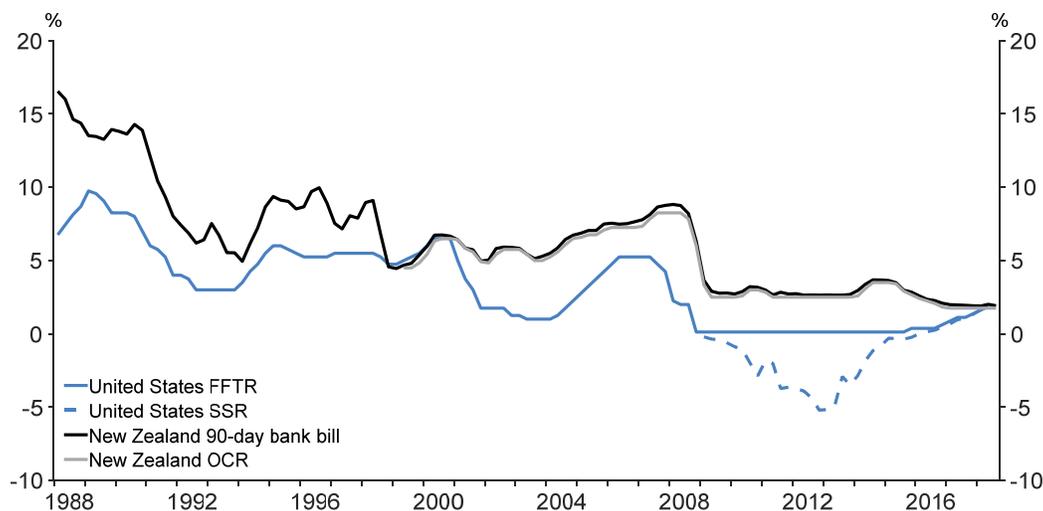


Figure 3: Short-term interest rates



### 3 Using a Taylor Rule to compare monetary policy

The general equilibrium models that we use to estimate policy rules for New Zealand and the United States are much-simplified versions of the New Zealand Structural Inflation Model (NZSIM), which the RBNZ uses for macroeconomic forecasting.<sup>7</sup> The design of the monetary policy rule in our framework is informed by Taylor (1993). Taylor (1993) introduced a simple model of US monetary policy which describes how the interest rate responds to the output gap and deviations in inflation from a central bank's target. This model is now referred to as the Taylor rule and was originally defined as:

$$r_t = r^* + \alpha_\pi \pi_t + \alpha_y y_t + \epsilon_t,$$

<sup>7</sup> NZSIM is an open-economy general equilibrium model, where the central bank follows a rule to stabilise the economy in the face of shocks (Austin and Reid, 2017).

where  $r_t$  is the Taylor rule implied rate;  $r^*$  is the neutral real policy rate,  $\pi_t$  is the deviation of inflation from target, and  $y_t$  is the output gap. The coefficients  $\alpha_\pi$  and  $\alpha_y$  are the central bank responses to inflation and the output gap.  $\epsilon_t$  is an error term. The Taylor rule can be modified by using additional variables. For example, later in this paper, we include the lagged policy rate, output growth and the exchange rate.

Several authors have estimated Taylor rules for New Zealand to assess the response of monetary policy to inflation and the output gap. Kendall and Ng (2013), RBNZ (2007), Huang (2002), and Plantier and Scrimgeour (2002) use the original single equation approach of Taylor (1993), which models interest rates as being dependent on inflation and economic slack. In particular, Kendall and Ng (2013), RBNZ (2007) and Huang (2002) find that monetary policy responses to inflation and output are broadly similar between New Zealand, the United States and Australia. However, the single equation approach used in the papers means they cannot account for the feedback effects from the interest rate to the broader economy. For this reason, the models estimated could potentially suffer from endogeneity and the coefficient estimates may be biased. However, other authors, notably, Kam, Lees and Liu (2009) and Lubik and Schorfheide (2007) use general equilibrium models to estimate monetary policy rules for small open developed economies, including New Zealand.<sup>8</sup> This paper takes a similar approach to these authors.<sup>9</sup>

#### 4 A system estimation framework

Our general equilibrium framework estimates a system of interdependent equations to find the response of monetary policy to economic activity and inflation in New Zealand and the United States. A structural model avoids the issues of endogeneity between variables that can occur in single equation models. In particular, our model explicitly allows interest rates, inflation and economic activity to influence each other through a system of general equilibrium relationships, not unlike the approach of NZSIM. For example, household demand responds to the real interest rate through the aggregate demand relation, firms respond to demand pressures by adjusting prices, and the central bank sets the interest rate to stabilise inflationary pressures and economic activity.

All variables in the model are defined in terms of deviations from their long-run values. In any period  $t$ , the interest rate gap  $\hat{r}_t$  (from the neutral rate) depends on its own lagged value, the price inflation gap from target ( $\hat{\pi}_t$ ), the output gap ( $\hat{y}_t$ ), output growth ( $\Delta\hat{y}_t$ ) and the depreciation ( $\Delta\hat{ner}_t$ ) of the New Zealand dollar. Formally, the monetary policy rule for New Zealand is represented by the following equation:

$$\hat{r}_t = \alpha_r \hat{r}_{t-1} + \alpha_\pi \hat{\pi}_t + \alpha_y \hat{y}_t + \alpha_{\Delta y} \Delta\hat{y}_t + \alpha_{\Delta ner} \Delta\hat{ner}_t + \eta_t^r.$$

<sup>9</sup> In contrast to this paper and the aforementioned literature, Karagedikli and Lees (2007) consider non-linear monetary policy rules.

The coefficients,  $\alpha_r$ ,  $\alpha_\pi$ ,  $\alpha_y$ ,  $\alpha_{\Delta y}$  and  $\alpha_{\Delta ner}$  indicate the short-run responses of the interest rate to the lagged interest rate, inflation, output gap, output growth and nominal exchange rate depreciation.<sup>10</sup>  $\eta_t^r$  is a deviation from the monetary policy rule, commonly known as the monetary policy shock. It is assumed to be independent and normally distributed.

For the United States, we use a closed-economy model, which is nested within the open-economy model designed for New Zealand. We eliminate the exchange rate from the monetary policy rule for the United States which is given as:

$$\hat{r}_t = \alpha_r \hat{r}_{t-1} + \alpha_\pi \hat{\pi}_t + \alpha_y \hat{y}_t + \alpha_{\Delta y} \Delta \hat{y}_t + \eta_t^r.$$

Both models are estimated using real-time vintages of data, beginning in 2000Q1.<sup>11</sup> All samples start in 1993Q4 while the sample for the final vintage ends in 2017Q4. The use of real-time data ensures that our estimates for the monetary policy rule parameters are based on the data sets available to the policy makers at the time of the interest rate decisions. As shown in figure 3, the United States reached a zero lower bound on policy rates after the GFC. This poses a challenge for our estimation exercise, since a linear monetary policy rule is less suitable to model the policy rate for several years after the GFC. To estimate the United States model, we proxy the policy rate using the SSR, which is a metric for the stance of monetary policy when the policy rate is at zero. The SSR is derived from the term structure of interest rates and can be thought of as a next-best (although not perfect) substitute for the short-term policy rate. However, as we will see in the following section, the conclusions of this paper are relevant even for our results based on the pre-GFC data vintages in the first half of the sample.

Two more caveats are in order before we present the results. Firstly, dual mandates are typically specified in terms of employment and not output. Despite this, it is common to estimate monetary policy rules for the United States in terms of output because employment is highly correlated to economic activity. In line with the correlations observed in the data, many structural macroeconomic models, including the RBNZ's official model NZSIM, assume a tight relationship between output and employment. Structural models with a more detailed labour market structure would be necessary to assess policy reactions if output and employment deviated significantly from one another. Secondly, estimated policy rule coefficients are influenced not merely by how the central bank values the stabilisation of economic activity relative to inflation stabilisation, but also by other supply and demand relationships in the macro-economy. Therefore, these estimates should be viewed as representing observed monetary policy behaviour—a combination of central bank preferences and the impacts of macroeconomic relationships (see also Kam, Lees and Liu, 2009).

## 5 Results

In figures 4 through 8, we present the estimates of various coefficients in the policy rules for New Zealand and the United States. The vertical axes measure the magnitudes of the estimated parameters while the horizontal axes plot the sequence of real-time data vintages. As we move to the right along the horizontal axes, each new data vintage in the sequence

<sup>10</sup> The implied long-run responses to inflation, output-gap, output growth and currency depreciation can be obtained by dividing the respective coefficients by  $(1 - \alpha_r)$ .

<sup>11</sup> More specific details on the modelling approach as well as the data are given in the Appendix.

includes an additional data point, so that the sample window keeps expanding. The median (thick solid lines) and 90 percent probability intervals (thin solid lines) for New Zealand are indicated in black while the corresponding estimates for the United States are presented in blue dashed lines.

Figure 4 presents the estimates of the monetary policy response to inflation. Over the data vintages, New Zealand's coefficient appears to drift downwards towards to about 0.3. The estimates exhibit some volatility for the vintages adjacent to the period of the GFC. The magnitude of the median estimate is quite similar to the median estimate for the United States. The probability intervals are fairly wide for both countries and the intervals intersect for most vintages. These patterns are also observed in the remaining policy rule coefficients. Figure 5 presents the estimates for the monetary policy smoothing parameter. Through all the vintages, the estimates for both countries are very high suggesting that interest rates are extremely slow moving.

The estimated coefficients on economic activity are smaller than the coefficients on inflation and lagged policy rates in line with the results in the literature. We find that New Zealand's policy response to the output gap (figure 6) is significantly above zero through much of history while the corresponding estimate for the United States is not. In contrast, in figure 7, the New Zealand coefficient on output growth is not always significantly different from zero in the earlier vintages, whereas the estimate for the United States stays significantly positive throughout all the vintages. The size of the coefficient on output growth increases over time for New Zealand, particularly post-GFC. In contrast, the size of the coefficient on output growth is relatively steady for the United States. Towards the end of the estimation horizon, the median estimates on the coefficient on output growth hover around the 0.15 mark for both countries. New Zealand's monetary policy response to output growth could be explained by the RBNZ's actions during the GFC. Notably, the RBNZ cut the policy rate by about 575 basis points to support economic activity through 2008 and 2009. Our results for the United States are influenced by the use of the SSR as a proxy for the short-term policy rate in the post-GFC data vintages. However, the sensitivities of the policy rate to the output gap and output growth in both countries are in the same ballpark even for the pre-GFC period.

Overall, the similarity in the estimates for the coefficients on the output gap and output growth in both economies is particularly interesting given that the RBNZ has had a single price stability mandate since 1989, while the Federal Reserve has operated under a dual mandate since the late 1970s. This suggests the flexibility in the RBNZ's inflation-targeting strategy has allowed it to offset volatility in economic activity over history. It appears the RBNZ has stabilised economy activity in sample period to a similar extent as that of the Federal Reserve.

Finally, figure 8 shows the estimate for the coefficient on the depreciation of the New Zealand dollar.<sup>12</sup> For most of the vintages, we do not find a coefficient that is significantly different from zero, suggesting monetary policy did not respond materially to the exchange rate. However, for the first few vintages, we find a significantly positive response, which

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<sup>12</sup> Note that we do not have an analogue for the United States, as we have used a closed-economy model for the corresponding estimation.

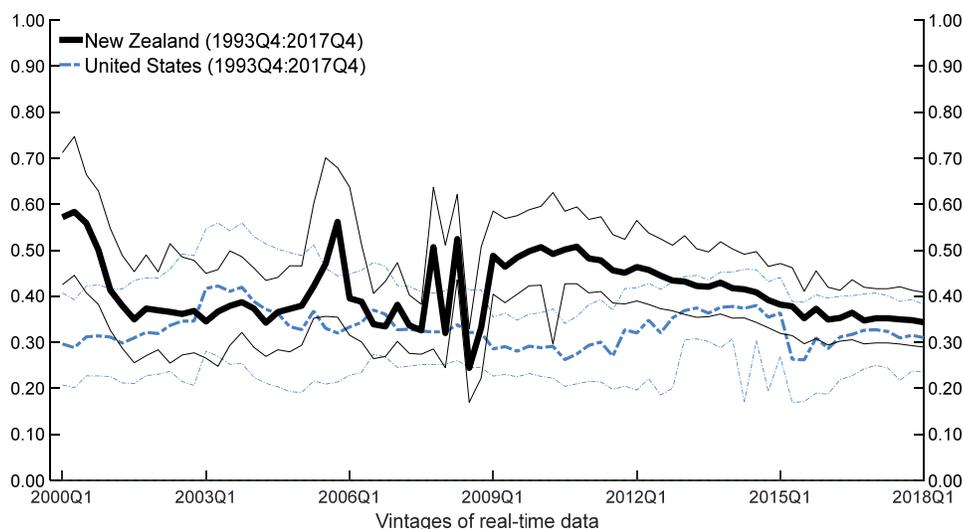
could reflect the period when the RBNZ used a Monetary Conditions Index (a weighted average of the exchange rate and short-term interest rates) as its policy tool.<sup>13</sup> However, these results should be treated with some caution as the sample size is small for the early data vintages.

Kendall and Ng (2013), RBNZ (2007), and Huang (2002) also found that monetary policy in New Zealand and the United States respond similarly to inflation and economic activity despite the limitations imposed by the single-equation estimation strategies.

The magnitudes of the (comparable) New Zealand policy rule coefficients are also in the ballpark of those found by Kam, Lees and Liu (2009) and Lubik and Schorfheide (2007) using general equilibrium models. Similarly, the coefficients obtained for the United States, particularly for the pre-GFC vintages, are similar to corresponding estimates obtained in other studies, e.g. Smets and Wouters (2007).

**Figure 4: Monetary policy response to inflation  $\alpha_\pi$  (Medians, 90 percent probability intervals)**

$$\hat{r}_t = \alpha_r \hat{r}_{t-1} + \alpha_\pi \hat{\pi}_t + \alpha_y \hat{y}_t + \alpha_{\Delta y} \Delta \hat{y}_t + \alpha_{\Delta ner} \Delta \hat{ner}_t + \eta_t^r$$



<sup>13</sup> See Hunt (1999).

Figure 5: Monetary policy rule smoothing parameter  $\alpha_r$  (Medians, 90 percent probability intervals)

$$\hat{r}_t = \alpha_r \hat{r}_{t-1} + \alpha_\pi \hat{\pi}_t + \alpha_y \hat{y}_t + \alpha_{\Delta y} \Delta \hat{y}_t + \alpha_{\Delta ner} \Delta \hat{ner}_t + \eta_t^r$$

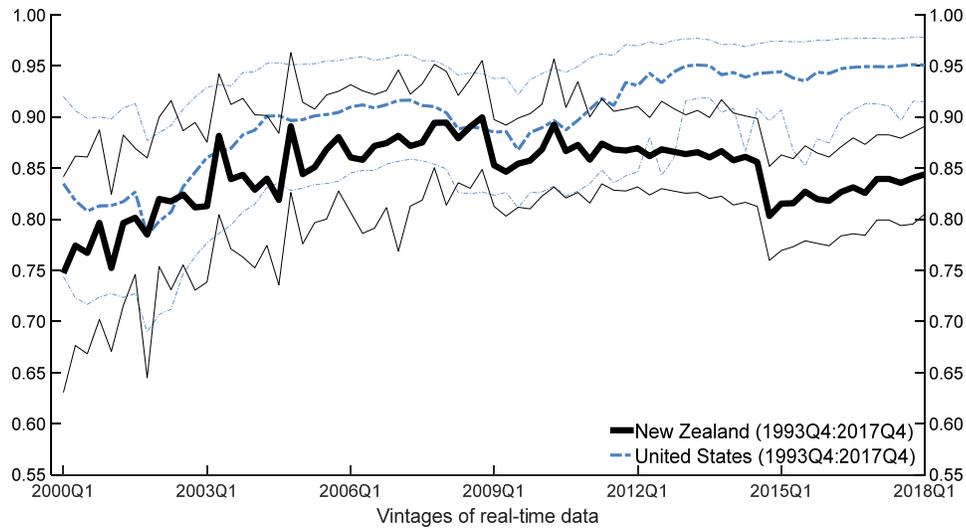


Figure 6: Monetary policy response to output gap  $\alpha_y$  (Medians, 90 percent probability intervals)

$$\hat{r}_t = \alpha_r \hat{r}_{t-1} + \alpha_\pi \hat{\pi}_t + \alpha_y \hat{y}_t + \alpha_{\Delta y} \Delta \hat{y}_t + \alpha_{\Delta ner} \Delta \hat{ner}_t + \eta_t^r.$$

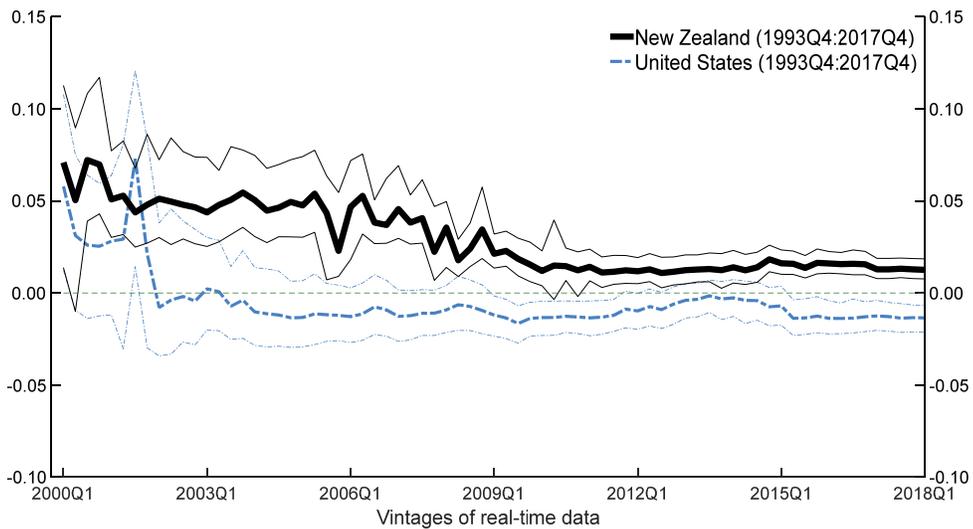


Figure 7: Monetary policy response to output growth  $\alpha_{\Delta y}$  (Medians, 90 percent probability intervals)

$$\hat{r}_t = \alpha_r \hat{r}_{t-1} + \alpha_\pi \hat{\pi}_t + \alpha_y \hat{y}_t + \alpha_{\Delta y} \Delta \hat{y}_t + \alpha_{\Delta ner} \Delta \hat{ner}_t + \eta_t^r.$$

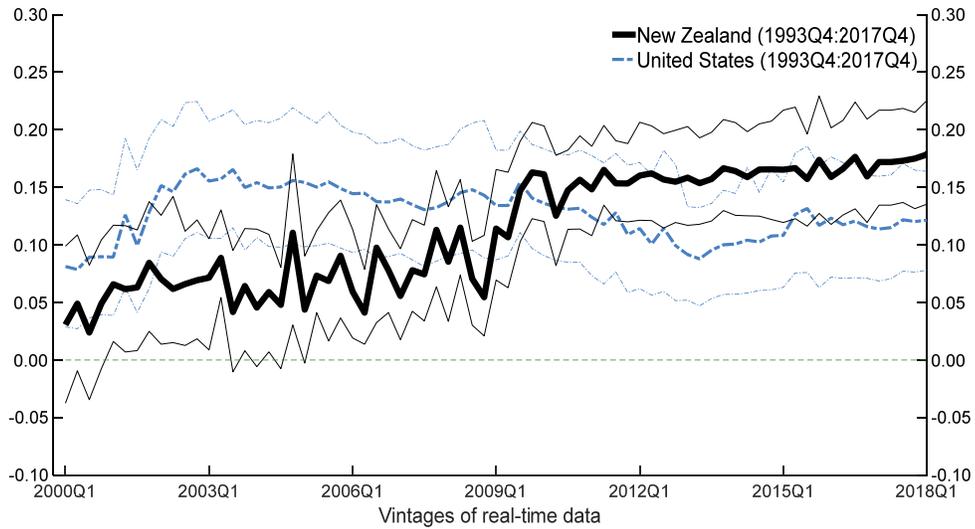
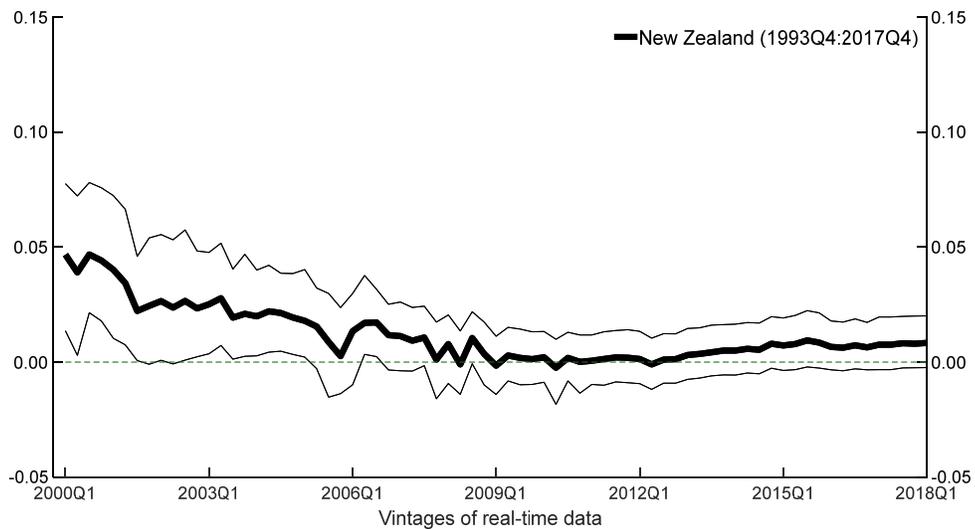


Figure 8: Monetary policy response to NZD exchange rate depreciation  $\alpha_{\Delta ner}$  (Medians, 90 percent probability intervals)

$$\hat{r}_t = \alpha_r \hat{r}_{t-1} + \alpha_\pi \hat{\pi}_t + \alpha_y \hat{y}_t + \alpha_{\Delta y} \Delta \hat{y}_t + \alpha_{\Delta ner} \Delta \hat{ner}_t + \varepsilon_t^r.$$



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## 6 Conclusion

This paper estimates general equilibrium models of monetary policy for New Zealand and the United States, using real-time data over the past three decades. Our results indicate that the responses of monetary policy to inflation and measures of economic activity in the two economies have been quite similar. This is despite the fact that the RBNZ has operated under a single price stability mandate over this period, in contrast to the Federal Reserve, which has operated under a dual mandate since the late 1970s. A potential explanation for this result is that the flexibility of the RBNZ's inflation targeting approach has resulted in the stabilisation of economy activity to an extent comparable to that of the Federal Reserve.

We emphasise that our estimates of policy rule coefficients are based on historical data, and do not shed light on how the introduction of a dual mandate might change the RBNZ's monetary policy settings. The RBNZ's new dual mandate opens up avenues for further research that rigorously explores potential changes in monetary policy formulation.

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## APPENDIX

### A1. Model equations

A formal description of the model equations follows. In our notation, a deviation of a variable during period  $t$ , from its long-run trend value, is indicated by an upper hat. The symbol  $E$  represents rational expectations of the future.  $\Delta$  indicates a change in a model variable. All shocks are assumed to be normally distributed.

The only endogenous source of aggregate demand in the small open economy model we use for New Zealand is consumption ( $\hat{c}_t$ ). Aggregate absorption of goods ( $\hat{a}_t$ ) is defined as the sum of consumption demand and a demand shock. Formally,

$$\hat{a}_t = \hat{c}_t + \varepsilon_t^{dem},$$

where  $\varepsilon_t^{dem} = \rho_{dem}\varepsilon_{t-1}^{dem} + \eta_t^{dem}$ ,  $\eta_t^{dem} \sim N(0, \sigma_{dem})$ .

We define  $p_d$ ,  $p_m$ , and  $p_x$  to be the prices of the domestically-sold goods, imported goods and exported goods respectively. If  $\bar{m} \in [0,1]$  indicates the share of imports in aggregate demand, the demand for domestically sold output ( $\hat{a}_{d,t}$ ) and imported goods ( $\hat{a}_{m,t}$ ) are given by:

$$\hat{a}_{d,t} = \hat{a}_t + \bar{m}(\hat{p}_{m,t} - \hat{p}_{d,t}) \text{ and}$$

$$\hat{a}_{m,t} - \hat{a}_{d,t} = -(\hat{p}_{m,t} - \hat{p}_{d,t}).$$

The aggregate price level is given by  $\hat{p}_t = \bar{m}\hat{p}_{m,t} + (1 - \bar{m})\hat{p}_{d,t}$ . Goods produced ( $\hat{y}_t$ ) in the small open economy are sold domestically ( $\hat{a}_{d,t}$ ) or exported ( $\hat{y}_{x,t}$ ):

$$\hat{y}_t = \bar{m}\hat{y}_{x,t} + (1 - \bar{m})\hat{a}_{d,t}.$$

Export volumes co-vary positively with the output gap in the rest of the world ( $\hat{y}_t^*$ ), and negatively with the differential between the price of exports and the foreign price level ( $\hat{p}_t^*$ ):

$$\hat{y}_{x,t} = \hat{y}_t^* - (\hat{p}_{x,t} - \hat{p}_t^*).$$

The consumption gap  $\hat{c}_t$  in the small open economy is negatively related to the excess of the nominal short-term interest rate ( $\hat{r}_t$ ) over the expected inflation rate ( $\hat{\pi}_t^{pe}$ ) in the aggregate price level, given the expected path as well as past realisations of the consumption gap:

$$\hat{c}_t - h\hat{c}_{t-1} = (E_t\hat{c}_{t+1} - h\hat{c}_t) - (1 - h)(\hat{r}_t - \hat{\pi}_t^{pe}).$$

The parameter  $h \in [0,1]$  influences the history-dependence of aggregate demand due to habit formation. The process for price inflation expectation formation is adapted from Kamber et al. (2015). Inflation expectations are specified as a combination of past expectations ( $\hat{\pi}_{t-1}^{pe}$ ), past inflation outturns ( $\hat{\pi}_{t-1}$ ), and the rational expectations forecast ( $E_t\hat{\pi}_{t+1}$ ):

$$\hat{\pi}_t^{pe} = \alpha_{pe} \hat{\pi}_{t-1}^{pe} + (1 - \alpha_{pe})(e_{pe} E_t \hat{\pi}_{t+1} + (1 - e_{pe}) \hat{\pi}_{t-1}) + \varepsilon_t^{pe},$$

where  $\varepsilon_t^{pe} = \rho_{pe} \varepsilon_{t-1}^{pe} + \eta_t^{pe}$ ,  $e_{pe} \in [0,1]$ ,  $\alpha_{pe} \in [0,1]$ ,  $\rho_{pe} \in [0,1]$ ,  $\eta_t^{pe} \sim N(0, \sigma_{pe})$ .

The domestic component of price inflation ( $\hat{\pi}_{d,t}$ ), for any given path of expectations, is positively related to the real wage ( $\hat{w}_t - \hat{p}_{d,t}$ ):

$$\hat{\pi}_{d,t} - \iota_d \hat{\pi}_{d,t-1} = \beta(E_t \hat{\pi}_{d,t+1} - \iota_d \hat{\pi}_{d,t}) + \frac{\bar{\mu}_{pd} - 1}{\varphi_{pd}} (\hat{w}_t - \hat{p}_{d,t}) + \eta_t^{pd}, \quad \eta_t^{pd} \sim N(0, \sigma_{pd}).$$

The price elasticity of demand  $\bar{\mu}_{p,d} > 1$  and the price stickiness parameter  $\varphi_{p,d} > 0$  influence the response of inflation to the real wage.  $\beta \in (0,1)$  is the economy's discount factor.

The imported component of price inflation, for a given path of expectations, increases with a rise in the foreign-currency price of the import ( $\hat{p}_t^*$ ) as well as a depreciation of the home currency (i.e. a rise in  $\widehat{ner}_t$ ):

$$\hat{\pi}_{m,t} - \iota_m \hat{\pi}_{m,t-1} = \beta(E_t \hat{\pi}_{m,t+1} - \iota_m \hat{\pi}_{m,t}) + \frac{\bar{\mu}_{pm} - 1}{\varphi_{pm}} (\hat{p}_t^* + \widehat{ner}_t - \hat{p}_{m,t}) + \eta_t^{pm}, \quad \eta_t^{pm} \sim N(0, \sigma_{pm}).$$

Exports are priced in foreign currency. For a given path of expectations, export price inflation increases, if the home currency price of the good rises or the home currency appreciates in value.

$$\hat{\pi}_{x,t} - \iota_x \hat{\pi}_{x,t-1} = \beta(E_t \hat{\pi}_{x,t+1} - \iota_x \hat{\pi}_{x,t}) + \frac{\bar{\mu}_{px} - 1}{\varphi_{px}} (\hat{p}_{d,t} - \widehat{ner}_t - \hat{p}_{x,t})$$

Nominal wage inflation ( $\hat{\pi}_t^w$ ), for any given path of expectations ( $\hat{\pi}_t^{we}$ ), co-varies positively with the consumption gap. The wage elasticity of labour demand  $\bar{\mu}_n > 1$  and the nominal wage stickiness parameter  $\varphi_w > 0$  influence the response of wage inflation to the consumption gap:

$$\hat{\pi}_t^w - \iota_w \hat{\pi}_{t-1}^w = \beta(\hat{\pi}_t^{we} - \iota_w \hat{\pi}_{t-1}^w) + \frac{\bar{\mu}_w - 1}{\varphi_w} \left( \hat{c}_t + \frac{h}{1-h} \Delta \hat{c}_t \right) + \eta_t^w, \quad \eta_t^w \sim N(0, \sigma_w).$$

Wage inflation expectations are assigned a law of motion similar to that of aggregate price inflation expectations:

$$\hat{\pi}_t^{we} = \alpha_{we} \hat{\pi}_{t-1}^{we} + (1 - \alpha_{we})(e_{we} E_t \hat{\pi}_{t+1}^w + (1 - e_{we}) \hat{\pi}_{t-1}^w) + \varepsilon_t^{we},$$

where  $\varepsilon_t^{we} = \rho_{we} \varepsilon_{t-1}^{we} + \eta_t^{we}$ ,  $e_{we} \in [0,1]$ ,  $\alpha_{we} \in [0,1]$ ,  $\rho_{we} \in [0,1]$ ,  $\eta_t^{we} \sim N(0, \sigma_{we})$ .

The monetary policy authority follows an empirical rule to set the interest rate, in response to expected CPI inflation, the level and changes in the output gap and to changes in the nominal exchange rate.

$$\hat{r}_t = \alpha_r \hat{r}_{t-1} + \alpha_\pi \hat{\pi}_t + \alpha_y \hat{y}_t + \alpha_{\Delta y} \Delta \hat{y}_t + \alpha_{\Delta ner} \Delta \widehat{ner}_t + \eta_t^r,$$

where  $\alpha_r \in [0,1)$ ,  $\eta_t^r \sim N(0, \sigma_r)$ .

The expected depreciation of the home currency depends on the differential in the interest rates between the home economy and the rest of the world, adjusted for a risk premium that depends on the net foreign financial asset position ( $\widehat{nfa}_t$ ) of the small open economy:

$$E_t \widehat{ner}_{t+1} - \widehat{ner}_t = \hat{r}_t - (\hat{r}_t^* - \kappa \widehat{nfa}_t) + \varepsilon_t^{ex},$$

where  $\varepsilon_t^{ex} = \rho_{ex} \varepsilon_{t-1}^{ex} + \eta_t^{ex}$ ,  $\rho_{ex} \in [0,1)$ ,  $\eta_t^{ex} \sim N(0, \sigma_{ex})$ .

The flow of net foreign assets is balanced by the excess of export revenue over import costs:

$$\widehat{nfa}_t - \frac{1}{\beta} \widehat{nfa}_{t-1} = \bar{\vartheta}_{px} \bar{m}(\widehat{ner}_t + \hat{p}_{x,t} + \hat{y}_{x,t}) - \bar{m}(\widehat{ner}_t + \hat{p}_t^* + \hat{y}_{m,t}),$$

where  $\bar{\vartheta}_{px}$  is the export price mark-up in the long run.

The small open economy has no influence on the rest of the world, which is modelled as a closed-economy New Keynesian model. The foreign economy coefficients are assumed to be the same as the analogues in the small open economy.

$$\hat{r}_t^* = \alpha_r \hat{r}_{t-1}^* + \alpha_\pi \hat{\pi}_t^*$$

$$\hat{y}_t^* = E_t \hat{y}_{t+1}^* - (\hat{r}_t^* - E_t \hat{\pi}_{t+1}^*)$$

$$\hat{\pi}_t^* = \beta E_t \hat{\pi}_{t+1}^* + \frac{\bar{\mu}_{pd} - 1}{\varphi_{pd}} \hat{y}_t^*$$

To obtain the model that we use for the United States, we abstract from international trade and financial assets. There is, hence, no role for the exchange rate in the monetary policy rule used for the United States. We choose rational expectations instead of the adaptive laws of motion for price and wage expectation formation. While the assumption of adaptive expectations is in line with the assumption in the RBNZ's NZSIM model, the assumption of rational expectations is consistent with DSGE models used at the Federal Reserve such as versions of the FRB-US or FRB/MCM (see Brayton et al, 1997).

## A2. Data and estimation methodology

The real-time data series for New Zealand are obtained from the RBNZ's in-house database while those for the United States are obtained from the website of the Federal Reserve Bank of Philadelphia. The small open economy model for New Zealand is fitted on real-time vintages of eight quarterly data series: (1) the official RBNZ output gap estimate (2) the CPI inflation gap from target (3) Labour Cost Index nominal wage inflation (4) the 90-day interest rate gap from the real-time RBNZ estimate of the neutral rate (5) changes in the trade-weighted exchange rate (6) import price inflation (7) the RBNZ Survey of Expectations 2-year ahead expected CPI inflation and (8) the RBNZ 2-year ahead wage growth expectations.

For the United States, the model is smaller and is hence fitted on fewer series: (1) A short-term interest rate, which is composed of the Treasury bill rate till 2008 and the shadow short rate, available on the RBNZ website, post-2008 (2) per capita output growth (3) inflation in the personal consumption expenditures deflator and (4) real wage inflation (real non-farm compensation per hour). The estimates of the neutral interest rate, inflation target and potential output growth are model-generated.

We estimate the models using Bayesian methods. Herbst and Schorfheide (2016) provide a formal introduction to the methodology and a less technical overview is available in Jacob and Munro (2017). In a nutshell, the Bayesian approach involves supplementing the likelihood function of the data with prior information about the parameters to formulate the posterior distribution of the parameters. The posterior distribution is then simulated by Markov Chain Monte Carlo methods to obtain a large set of potential parameter values. For each estimation, we use 250,000 draws from the posterior distribution. The estimation is implemented in the Matlab-based toolbox Dynare Version 4.5.6 (Adjemian et al. 2011).

As a robustness check, we also estimated a specification of the New Zealand model using unfiltered data instead of the official RBNZ gaps, and allowed the model to generate the cyclical gaps of the different variables just as we did for the United States. As seen below, the coefficients obtained for the policy rate responses to the output gap and output growth are in similar territory as that of the United States, just as we observed in the baseline New Zealand model results presented in the main text.

**Figure A1: Monetary policy response to output gap  $\alpha_y$  (Medians, 90 percent probability intervals) in the alternative New Zealand model specification**

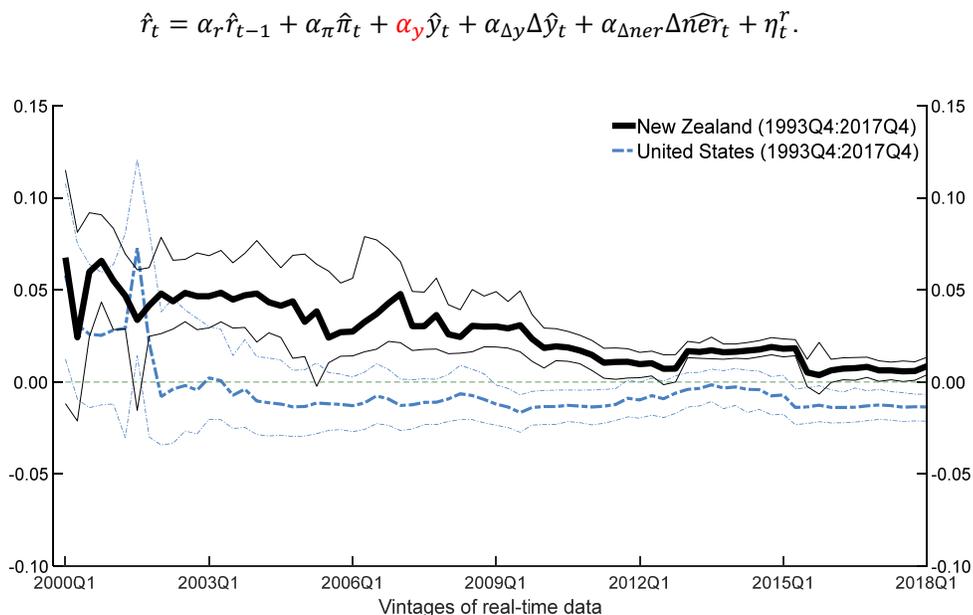


Figure A2: Monetary policy response to output growth  $\alpha_{\Delta y}$  (Medians, 90 percent probability intervals) in the alternative New Zealand model specification

$$\hat{r}_t = \alpha_r \hat{r}_{t-1} + \alpha_\pi \hat{\pi}_t + \alpha_y \hat{y}_t + \alpha_{\Delta y} \Delta \hat{y}_t + \alpha_{\Delta ner} \Delta \hat{ner}_t + \eta_t^r.$$

