A structural forecasting model for New Zealand: NZSIM *

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Abstract

We describe the underlying structure of the new forecasting model used at the Reserve Bank of New Zealand. The model is a parsimonious, flexible dynamic stochastic general equilibrium model. It is deliberately kept small so that it is easily understood and applied by a range of users. For this reason, we provide both a non-technical overview and a more complete description of the model's micro-foundations. We also outline how the model's parameters are estimated, evaluate its ability to explain New Zealand data and discuss its key transmission channels.

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*The views expressed in this paper are those of the authors, and do not necessarily reflect the views of the Reserve Bank of New Zealand. NZSIM stands for New Zealand Structural Inflation Model. We are grateful to our colleagues at the Reserve Bank for their advice and assistance. Emails: Gunes.Kamber@rbnz.govt.nz, Chris.McDonald@rbnz.govt.nz, Nick.Sander@rbnz.govt.nz, Konstantinos.Theodoridis@bankofengland.co.uk

1 Introduction

The purpose of this paper is to present the underlying structure of NZSIM: the RBNZ's new forecasting model. This paper describes the model's structure and transmission channels, how it is estimated on New Zealand economic data and how it might be used for forecasting and policy analysis.

The RBNZ's mandate is to conduct monetary policy with the goal of maintaining a stable general level of prices. New Zealand – being a small open economy – is affected by economic events that originate both domestically and abroad. Setting monetary policy in this environment can be challenging due to the uncertainty around how these events affect the economy and due to the lagged impact of monetary policy on the economy. As such, the RBNZ needs to have a view on the current and future states of the economy. To assist with this, the RBNZ employs a suite of macroeconomic models. NZSIM replaces KITT (Lees, 2009) as the central structural forecasting model which organises and summarises within a single framework the insights gained from a range of economic data and policy judgment. NZSIM, like KITT, is a dynamic stochastic general equilibrium (DSGE) model based on optimising economic agents who are subject to constraints and market frictions.

In macroeconomic modelling there is a trade-off between simplicity and comprehensiveness. In developing NZSIM, we want to capture important transmission channels while retaining a parsimonious structure. We emphasise simplicity because as models increase in size and complexity, the transparency of transmission channels are lost and resources required to analyse and explain the model's output increase. In addition, as extra variables and features are incorporated systematically into a model's structure, it can become cumbersome for users to adjust the model's forecasts without introducing undesirable movements in the forecasts of other variables.

To address this trade-off, NZSIM contains a sophisticated yet 'bare-bones' design. Instead of providing a richer, more detailed structure to the model, we instead include many structural shocks which – when used individually or in combination – can approximate much of the economic phenomena the RBNZ is interested in incorporating into its forecasts. In addition, where pure micro-foundations impose restrictions in the model that are at odds with the data we adjust these micro-foundations to produce model behaviour that is more consistent with observed data. Two examples of this are adjusting the UIP equation by introducing an endogenous risk premium that is correlated with the exchange rate and adopting a methodology that allows inflation expectations to be formed adaptively rather than rationally (as in Hagedorn, 2011).

The advantage of this framework is that all policy scenarios and forecasts from the model are based on a consistent, (broadly) micro-founded structure where the transmission channels are well understood. By being built largely on micro-foundations, the RBNZ's model makes clear how agents interact to produce observed economic outcomes, how agents' expectations of the future affect their current decisions and how agents are affected by structural shocks.

In terms of its architecture, NZSIM is a small open economy New Keynesian model with both domestic and foreign sectors.[1] The model builds on the already well-established literature on structural models estimated on New Zealand data.[2] Households sell their labour to domestic firms and consume output produced domestically or imported from abroad. Both prices and wages are subject to nominal rigidities. In order to increase the flexibility of the model, one area that we deviate from the existing literature is that households have preferences that can be either separable and non-separable, as introduced by Jaimovich and Rebelo (2009). We extend these preferences to include the possibility of habit formation in both consumption and labour.

New Keynesian models are ideal for monetary policy analysis because of the presence of nominal rigidities. This introduces two important features to the model. Firstly, the central bank can make households better off by reducing the need for firms to change prices (by adjusting the money supply). Secondly, these rigidities encourage firms to set prices depending on what they expect demand and supply to be like in the future. As such, the central bank has an important role in influencing expectations and reducing the costs of rigidities. In NZSIM, nominal rigidities are imposed by assuming that it is costly for firms to change their prices, as in Rotemberg (1982).

It is our intention that rather than remaining in a static form, NZSIM will evolve over time. The version of NZSIM presented here is intended to form the building blocks of the RBNZ central forecasting model as it progresses. As mentioned in Del Negro et al. (2013), an advantage of DSGE models is that, as academic research progresses, they can be adjusted to incorporate new features and procedures. Even now the forecasting version of NZSIM includes adjustments and extensions that for the purposes of brevity are not detailed in this paper. These extensions represent the beginning of an organic process of model improvement that will continue as we increase our understanding of the New Zealand economy. It is our intention to describe these extensions in future work.

The remainder of this paper is as follows. Section 2 provides a non-technical summary of the model structure; Section 3 details the precise optimisation problems that characterise the model; Section 4 details the estimation procedure, the transmission properties of the estimated model, as well as the model's fit and forecasting performance; Section 5 presents examples of alternative policy scenarios that can be produced using NZSIM; Section 6 outlines how one extension we implemented – introducing alternative methods of inflation expectations formation – improves the model's empirical fit and transmission channels; and Section 7 concludes.

[1] Such as Benigno and Thoenissen (2003), Gali and Monacelli (2005), Lubik and Schorfheide (2005), Adolfson et al. (2007), Justiniano and Preston (2010a) and Justiniano and Preston (2010b).

[2] See for example Albertini et al. (2012), Kam et al. (2009), Lees et al. (2011), Lubik and Schorfheide (2007) and Matheson (2010).

2 Non Technical Summary of the Model

The structural elements of the model are based on a typical New Keynesian framework with small open economy extensions. Optimising agents form the foundation of this framework. There are three key agents that we model: households, domestic firms and import distributing firms. While theory provides a starting point in model design, empirical fit remains an important benchmark. To this end, the model contains several features designed to improve its fit to the data - such as flexible household preferences and a modified uncovered interest rate parity condition.

The remainder of this section discusses how the three main types of agents operate, interact and make decisions. The final equations for the model are included in Table 1.

Households

Households aim to maximise their lifetime utility, given their lifetime income. They gain utility from high and stable consumption. While higher consumption is preferred by households, working more decreases their utility. Households are allotted time to either work or enjoy leisure. When they work, they supply labour to firms who pay them a wage in return. Any profits that the firms make are also paid to households.

Households are able to smooth their consumption over time by borrowing and saving. The interest rate represents the cost of borrowing and the return on saving. Households consume based on what they expect to earn over their lifetime (as in the permanent income hypothesis) where the choice of how much to consume in each period depends on, among other things, the interest rate.

As such, households face two decisions: i) how to allocate their consumption over time and ii) how much labour to supply to domestic firms. We choose a specific structure of household utility that is flexible in order to match the observable data. For instance, we assume that households dislike abrupt changes in their consumption making them reluctant to adjust it quickly. In addition we assume that the manner in which households enjoy their consumption depends on how much labour they supply.[3] This results in a consumption equation where the interest rate affects how households decide to allocate their consumption today relative to the future. In addition, previous levels of consumption and the expected change in working hours affect consumption and savings decisions.

Households' consumption baskets are composed of domestic and tradable goods. Demand for each type of consumption good, as a proportion of overall consumption, depends on its price relative to the price of goods in the other sector.

[3] The equations in table 1 show the expected change in output instead of labour. In the subsection discussing domestic firms, we discuss how labour can be written in terms of output.

The wage that households earn is determined by both firms' demand for and households' supply of labour. The labour market is assumed to be monopolistically competitive with sticky wages. In the absence of sticky wages households would set their wage at a constant markup over their marginal rate of substitution (MRS, the marginal cost of working relative to the extra consumption benefits gained).

We assume, however, that it is costly for households to adjust their wages. Specifically, we assume these costs are positively related to the size of the adjustment and that they occur when households adjust wages faster or slower than wage inflation in the previous quarter (referred to as indexation). With this assumption, households prefer to adjust their wages gradually allowing the model to match the persistence in wage inflation data. In addition, if households anticipate that economic events might support future wage increases, they may raise their wages immediately to avoid adjustment costs. As such, households adjust their wages gradually to achieve a constant markup between the real wage and their MRS, but will deviate from this if they expect their MRS to change in the future.

Domestic firms

Domestic firms employ labour (provided by households) to produce domestic goods. We assume they hold a fixed amount of capital at the business cycle frequency. Ignoring the capital accumulation decision simplifies the model structure considerably and allows us to write labour in terms of output. Moreover, general equilibrium models with typical investment adjustment costs perform poorly when explaining investment dynamics without heavily relying on investment specific shocks (Justiniano et al., 2010, Kamber et al., 2012). Therefore, we keep the model structure simple by omitting capital.

We model domestic firms as competing in a monopolistically competitive environment. In this environment firms have some market power and, to maximise profits, they would like to set their prices at the optimal markup over their marginal cost.

Their marginal cost is affected by wages and the level of output. Higher levels of output are costly because of decreasing returns to scale. That is, to increase output domestic firms can only employ more labour, which by assumption becomes increasingly less productive. As such, they require an increasing amount of labour as output rises. Accordingly, domestic firms' marginal costs are a function of both wages and the output gap (the output gap representing the changes in the marginal productivity of labour).

We motivate a role for monetary policy by making it costly for firms to adjust their prices. When firms do not appropriately adjust their prices to economic shocks, inefficient fluctuations in output result. Monetary policy can reduce the size of these inefficient fluctuations by setting interest rates (which affect households' demand for domestic firms' output) so that firms prefer not to adjust their prices.

Like wages, adjustment costs occur when firms adjust prices faster or slower than inflation in the previous quarter (indexation). This is to match the persistence in non-tradable inflation data. As a result, firms are slow to adjust prices at each point in time. Also, because they cannot adjust prices freely, their expectations of future costs and demand conditions affect current pricing decisions.

Due to price rigidities, the markup between each domestic firm's price and their marginal cost is not always optimal for the firm. If markups are less than firms' desired levels, domestic inflation tends to increase as firms restore their desired markup. On the other hand, when markups are large the opposite effect occurs and domestic inflation eases.

Import distributing firms

The import distributing (tradable) firms purchase imports and domestic output to produce tradable goods. The domestic output can be thought of as representing the distribution costs faced by import retailers.

Like domestic firms, import retailers also face imperfect competition and, accordingly, maximise their profits by setting their price at a markup over their marginal cost. For tradable firms, their marginal cost is affected by NZD import prices and the price of domestic goods. Since imports are priced in foreign currency, the NZD exchange rate is an important determinant of these firms' marginal costs and, as such, of tradable inflation. As with domestic inflation, the marginal cost of production relative to tradable goods prices (i.e. their implied markup) appears in the tradable inflation equation. Therefore, when input costs are high, mark-ups are squeezed, causing firms to raise their prices.

Tradable firms also face price adjustment costs. As such, they also adjust their prices gradually and tradable inflation is dependent on not only today's marginal costs and price, but also on expected future marginal costs and prices.

Other structural elements

The other key agent in the model is the central bank. As mentioned above, interest rates can improve welfare when set to achieve economic conditions where firms prefer not to adjust their prices. Rather than imposing an interest rate rule that reflects optimal policy within this model, we specify an empirical policy rule that captures past behaviour by the RBNZ.

We assume the central bank follows a policy rule in which interest rates respond to one quarter ahead inflation expectations, the output gap, the nominal exchange rate and output gap growth. We also allow for interest rate smoothing to reflect that interest rates respond gradually to economic shocks.

As New Zealand is a small open economy, NZSIM includes two channels that allow events occurring in the rest of the world to affect New Zealand: the terms of trade and exports demand. Changes in the terms of trade can have significant effects on aggregate demand and pricing in the tradable sector. In addition, the rest of the world purchases exports from New Zealand exporting firms – who in turn purchase goods from the domestic firm. Therefore, NZSIM implies that international events can have considerable implications for the domestic economy.

Due to the assumption of nominal rigidities, movements in the exchange rate can affect the terms of trade and, therefore, aggregate demand and inflation in the domestic economy. The TWI exchange rate is modelled using a modified uncovered interest parity condition (UIP).[4] Similar to the standard UIP condition, the expected change in the exchange rate responds to changes in domestic or foreign interest rates.

3 Technical description of the model

The previous section outlined the structure of the model without the technical details. This section provides these details and includes a description of the optimisation problems faced by the agents in this economy. The first order conditions of these problems describe the evolution of the model's variables. The baseline version of this model assumes that agents in this economy have full information about the structure and the state of the economy (Rational Expectation Hypothesis).

3.1 Households

3.1.1 Utility Function

In each period, households consume (C_t), save via a financial intermediary issuing a bond $\left(B_t^h\right)$ and supply labour (n_t). They pay a transfer overseas ($Trans_t$) and a lump-sum tax to the government (T_t). We assume that each household has an identical utility function and supplies differentiated labour. Investment is not modelled as a choice variable of the household. Capital letters (with tildes) denote nominal variables. The utility function is defined as

$$U\left(C_{t+s}\left(j\right), n_{t+s}\left(j\right)\right) = E_t \sum_{s=0}^{\infty} \beta^s \omega_{t+s}^c \left\{ \frac{1}{1-\sigma} \left(\left(C_{t+s}\left(j\right) - \chi_c C_{t+s-1}\right) - \frac{\omega_{t+s}^n z_{t+s}(j)}{1+\sigma_n} \left(\frac{n_{t+s}(j)}{n_{t+s-1}^{\chi n}}\right)^{1+\sigma_n} \right)^{1-\sigma} \right\}$$

where n_t is labour and z_t is a preference shifter that evolves according to

$$z_{t+s}\left(j\right) = z_{t+s-1}^{1-\upsilon}\left(j\right)\left(C_{t+s}\left(j\right) - \chi_c C_{t+s-1}\right)^{\upsilon} \left(\frac{tfp_{t+s}}{\widetilde{tfp}_{t+s-1}}\right)^{1-\upsilon} \qquad \upsilon \in [0, 1]$$

Our utility function specification nests the one proposed by Jaimovich and Rebelo (2009), where the parameter υ controls the importance of the wealth effect in households' labour supply curve. When υ

[4] The precise modifications are detailed in the technical appendix and are based on Adolfson et al. (2008).

is set to 0, preferences become non-separable as in Greenwood et al. (1988) (henceforth referred to as GHH). When υ is set to one, preferences are of the same class as King et al. (1988). Here we allow households to form habits not only in terms of consumption (as in Christiano et al., 2005; Smets and Wouters, 2007; Adolfson et al., 2007) but also in terms of working hours. As it is explained by Schmitt-Grohe and Uribe (2008) and Kamber (2010), habit formation in hours worked adds persistence to the labour market even when wages are fully flexible. This device can be viewed as an approximation of capturing search and matching type frictions in the labour market.

The household budget constraint is

$$\begin{aligned} & R^h_{t-1}\frac{B_{t-1}(j)}{\tilde{P}_t} + \left(1-\Psi_W\left(\frac{W^h_t(j)}{W^h_{t-1}(j)}\right)\right)\frac{W^h_t(j)}{P_t}n_t(j) + \frac{\Xi_t(j)}{P_t} + \frac{Trans_t(j)}{P_t} \\ = & \frac{B_t(j)}{P_t} + \left(1+\tau^C_t\right)\frac{C_t(j)}{P_t} + \frac{T_t(j)}{P_t} \end{aligned}$$

where W^h_t is the nominal wage, R^h_t is the nominal interest rate and P_t is the aggregate price level. $\Psi_W\left(\frac{W^h_t}{W^h_{t-1}}\right)$ captures the cost of resetting wages and Ξ_t denotes the profits made by monopolistic firms.

Aggregate consumption is a function of domestic ($C_{D,t}$) and tradable ($C_{T,t}$) goods. It is described by

$$C_t(j)^{\frac{\eta-1}{\eta}} = (1-\omega_C)^{\frac{1}{\eta}}C_{D,t}(j)^{\frac{\eta-1}{\eta}} + \omega_C^{\frac{1}{\eta}}C_{T,t}(j)^{\frac{\eta-1}{\eta}}$$

where η is the elasticity of substitution between domestic and tradable goods and ω_C measures the trade openness. Optimal consumption and debt are derived by maximising the utility function subject to the budget constraint.

3.1.2 Labour Supply

Households are monopolistic suppliers of their own differentiated labour (denoted by j). They set their nominal wage W^h_t and supply any amount of labour demanded at that wage. They face a quadratic adjustment cost, measured in terms of the total nominal wage bill. This prevents agents from being able to change nominal wages rapidly. The specification of the adjustment cost function,

$$\Psi_W\left(\frac{W^h_t(j)}{W^h_{t-1}(j)}\right) = \frac{\psi_W}{2}\left(\frac{W^h_t(j)}{W^h_{t-1}(j)\left(\Delta tfp\ \pi\right)^{1-\gamma_W}\left(\frac{W^h_{t-1}}{W^h_{t-2}}\right)^{\gamma_W}} - 1\right)^2$$

ensures that $\Psi_W(\cdot) = 0$ in the steady state.

There exists a 'labour packager' that costlessly transforms heterogenous household labour into a homogenous labour bundle, which is hired by firms. The labour packager, which operates under perfect competition, combines labour from both optimal and non-optimal households to create the labour bundle. Aggregate labour is given by

$$n_t = \left[\int_0^1 (n_t(j))^{\frac{1}{\lambda_{w,t}}} \, dj \right]^{\lambda_{w,t}}$$

The per capita demand for labour of type j is given by

$$n_t(j) = \left(\frac{w_t^h(j)}{w_t^h} \right)^{-\frac{\lambda_{w,t}}{\lambda_{w,t}-1}} n_t$$

The aggregate wage is given by

$$W_t^h = \left[\int_0^1 W_t^h(j)^{\frac{1}{1-\lambda_{w,t}}} \, dj \right]^{1-\lambda_{w,t}}$$

Households decide how much labour to supply by maximising the utility function subject to the budget constraint and the per capita demand for labour equation.

3.2 Financial Intermediary

Bonds issued by the financial intermediary and held by the household at the beginning of period $\frac{B_t(j)}{P_t}$ pay an interest rate R_t^h. Households can only take positions in the bond market via a financial intermediary. The intermediary receives households' savings and invests these into domestic and foreign bonds. The price of these bonds are subject to a risk premium that depends on the overall debt in the economy expressed as ratio to GDP. The intermediary is operated under perfect competition, where their objective is to

$$\max_{\frac{B_t^d(f)}{P_t},\, \frac{B_t^f(f)}{S_t P_t}} E_t \left[\begin{array}{c} R_t \frac{B_t^d}{P_t} \Psi_{B^b}\left(\frac{B_t}{P_t}, \omega_t^R\right) + R_t^* \frac{S_t}{S_{t+1}} \frac{B_t^f(f)}{S_t P_t} \Psi_{B^f}\left(\frac{B_t}{P_t}, \omega_t^R, \omega_t^S, \frac{R_{t-1}}{R_{t-1}^*}, \Delta S_t\right) \\ -R_t^h \frac{B_t(f)}{P_t} \end{array} \right]$$

subject to

$$\frac{B_t(f)}{P_t} = \frac{B_t^d(f)}{P_t} + \frac{B_t^f(f)}{S_t P_t}$$

where $\frac{B_t^d(f)}{P_t}$ and $\frac{B_t^f(f)}{S_t P_t}$ represent each financial intermediary's real domestic dollar holdings of domestic and foreign bonds respectively. The real exchange rate is defined as $Q_t = \frac{S_t P_t}{P_t^*}$ and S_t is the nominal exchange rate defined so that a rise corresponds to an appreciation.

In real terms, the maximisation problem becomes

$$\max_{B_t^d(f),\, B_t^f(f)} E_t \left[\begin{array}{c} R_t B_t^d(f) \Psi_{B^b}\left(b_t, \omega_t^R\right) + R_t^* \frac{Q_t}{Q_{t+1}} \frac{\pi_{t+1}}{\pi_{t+1}^*} \frac{B_t^f(f)}{Q_t} \Psi_{B^f}\left(B_t, \omega_t^R, \omega_t^S, \frac{R_{t-1}}{R_{t-1}^*}, \frac{Q_t}{Q_{t+1}} \frac{\pi_{t+1}}{\pi_{t+1}^*}\right) \\ -R_t^h B_t(f) \end{array} \right]$$

where

$$\Psi_{B^b}\left(B_t, \omega_t^R\right) = \exp\left\{ -\psi_B \left(\frac{B_t}{y} - \frac{b}{y} \right) + \omega_t^R \right\}$$

$$\Psi_{B^f}\left(B_t, \omega_t^R, \omega_t^S, \frac{R_{t-1}}{R_{t-1}^*}, \frac{Q_t}{Q_{t+1}} \frac{\pi_{t+1}}{\pi_{t+1}^*}\right) = \exp\left\{ \begin{array}{c} -\psi_B \left(\frac{B_t}{y} - \frac{b}{y} \right) \\ -\psi_{uip} \left(\frac{R_{t-1}}{R_{t-1}^* \left(\frac{Q_t}{Q_{t+1}} \frac{\pi_{t+1}}{\pi_{t+1}^*} \right)} - 1 \right) + \omega_t^R + \omega_t^S \end{array} \right\}$$

The first risk premium function $\Psi_{B^b}\left(b_t, \omega_t^R\right)$ is one of the methods suggested by Schmitt-Grohe and Uribe (2003) to close the model. This device ensures that the net foreign asset position does not become explosive (see Adolfson et al., 2007; Harrison and Oomen, 2010; Justiniano and Preston, 2010b; Christiano et al., 2011; Mumtaz and Theodoridis, 2012). Following the literature, the elasticity parameter ψ_B is set to a very small number minimising the contribution of this term in the overall dynamics of the model.

The second risk premium function $\Psi_{B^f}\left(b_t, \omega_t^R, \omega_t^S, \frac{R_{t-1}}{R_{t-1}^*}, \frac{Q_t}{Q_{t+1}} \frac{\pi_{t+1}}{\pi_{t+1}^*}\right)$ is not a standard modelling feature and it has been added to capture persistent deviations of the exchange from the UIP condition. Our UIP modification, similar to K.I.T.T (Lees, 2009), shares common features with the those employed by Christiano et al. (2011) and Adolfson et al. (2008).

The modification is motivated by the observation that the standard UIP implies a purely forward looking exchange rate. With this structure, the response of the exchange rate is in general too immediate to economic shocks, causing the exchange rate to be more volatile than in the data. In our modification, the parameter ψ_{uip} controls for the smoothness of the exchange rate movements, by making the contemporaneous exchange rate depend on the past values of exchange rates and interest rates. In the empirical section 4, we evaluate whether the New Zealand data supports non-zero values of this parameter.

3.3 Domestic Producers

There is a continuum (denoted by i) of monopolistically competitive firms producing domestic goods. Monopolistic competition provides an environment where firms can act as price setters and face price adjustment costs. Price adjustment costs are a desirable modelling feature as they motivate a role for monetary policy to stabilise prices. Domestic firms employ labour $(n_t\,(i))$ and are subject to both permanent (tfp_t) and temporary (ω_t^y) TFP shocks. The production function is given by

$$y_t\,(i) = \omega_t^y tfp_t n_t\,(i)^\alpha - F_D tfp_t$$

where F_N is a fixed cost associated with the production process.

Firms maximise their discounted future stream of profits including both production costs and menu costs,

$$\max_{P_{D,t}(i)} E_t \left[\begin{array}{c} \sum_{s=0}^{\infty} \beta^s \frac{\omega_{t+s}^c \lambda_{t+s}}{\omega_t^c \lambda_t} \frac{P_{D,t+s}}{P_{t+s}} \left\{ \left(\frac{P_{D,t+s}(i)}{P_{D,t+s}} - mc_{D,t+s} - \Psi_{P_D}\left(\frac{P_{D,t+s}(i)}{P_{D,t+s-1}(i)}\right)\right) y_{t+s}\,(i) \right\} \\ -F_D tfp_{t+s} \end{array} \right]$$

where λ_t represents the marginal utility of consumption, $P_{D,t}$ is the domestic price level and $mc_{D,t}$ is the domestic firms' marginal cost.[5]

[5]The marginal utility of consumption is obtained from the first order conditions of the households' utility maximisation problem.

Firms sell differentiated goods to the final output aggregator with firm i facing demand

$$y_t(i) = \left(\frac{P_{D,t}(i)}{P_{D,t}}\right)^{-\frac{\lambda_{D,t}}{\lambda_{D,t}-1}} y_t$$

The combined quantity of output is given by the CES aggregator

$$y_t = \left[\int_0^1 y_t(i)^{\frac{1}{\lambda_{D,t}}} di\right]^{\lambda_{D,t}}$$

The price adjustment cost for firm i is measured in terms of output and is given by

$$\Psi_{P_D}\left(\frac{P_{D,t}(i)}{P_{D,t-1}(i)}\right) = \frac{\psi_N}{2}\left(\frac{P_{D,t}(i)}{P_{D,t-1}(i)(\pi_D)^{1-\gamma_N}\left(\frac{P_{D,t-1}}{P_{D,t-2}}\right)^{\gamma_N}} - 1\right)^2 y_t$$

and

$$\lambda_{D,t} = (1-\rho_{\lambda_D})\lambda_D + \rho_{\lambda_D}\lambda_{D,t-1} + \sigma_{\lambda_D}\omega_t^{\lambda_D}$$

is a stochastic process that describes the evolution of domestic firms' markups.

3.4 Imports

The tradable and domestic sectors are modelled in similar ways. The tradable aggregation firm combines differentiated tradable goods which are produced from imports. Imports are differentiated by intermediate producers (retailers) that also incur some (domestic) distribution costs. Let $y_{T,t}(\kappa)$ be the tradable output produced by retailer κ. The final import good is a CES composite of individual retail goods

$$y_{T,t} = \left[\int_0^1 y_{T,t}(\kappa)^{\frac{1}{\lambda_{T,t}}} d\kappa\right]^{\lambda_{T,t}}$$

Cost minimisation implies that each retailer faces an isoelastic demand for its output, given by

$$y_{T,t}(\kappa) = \left(\frac{P_{T,t}(\kappa)}{P_{T,t}}\right)^{-\frac{\lambda_{T,t}}{\lambda_{T,t}-1}} m_t$$

where $P_{T,t}$ is the tradable price level and m_t represents the quantity of imports used in production.

Each retailer faces a quadratic cost of adjusting prices measured in terms of the differentiated import good

$$\Psi_{P_T}\left(\frac{P_{T,t}(\kappa)}{P_{T,t-1}(\kappa)}\right) = \frac{\psi_T}{2}\left(\frac{P_{T,t}(\kappa)}{P_{T,t-1}(\kappa)(\pi_T)^{1-\gamma_T}\left(\frac{P_{T,t-1}}{P_{T,t-2}}\right)^{\gamma_T}} - 1\right)^2 y_{T,t}(\kappa)$$

and solves the following maximisation problem

$$\max_{P_{T,t}(\kappa)} E_t\left[\begin{array}{c}\sum_{s=0}^{\infty}\beta^s \frac{\omega_{t+s}^c \lambda_{t+s}}{\omega_t^c \lambda_t}\frac{P_{T,t+s}}{P_{t+s}}\left\{\left(\frac{P_{T,t+s}(\kappa)}{P_{T,t+s}} - mc_{T,t+s} - \Psi_{P_T}\left(\frac{P_{T,t+s}(\kappa)}{P_{T,t+s-1}(\kappa)}\right)\right)m_{t+s}(\kappa)\right\} \\ -\varsigma^T tfp_t\end{array}\right]$$

where $mc_{T,t}$ is the marginal cost faced by the tradable firm.

Note that firms have to pay an import licensing fee to the government, which ensures that the firm makes zero profits in the steady state.

Each firm's production function is given by

$$y_{T,t} = \left[\tau^{\frac{1}{\eta_T}} m_t^{\frac{\eta_T - 1}{\eta_T}} + (1-\tau)^{\frac{1}{\eta_T}} \left(Y_{D,t}^{T}\right)^{\frac{\eta_T - 1}{\eta_T}} \right]^{\frac{\eta_T}{\eta_T - 1}}$$

where m_t are imports and $Y_{D,t}^{T}$ represents the amount of domestic production used for the distribution of imports.

3.5 Exports

There is a continuum of exporting firms indexed by h on the unit interval. Each firm h buys a homogenous domestic good from a domestic retailer for the price $P_{D,t}$ and differentiates it. They then sell these differentiated goods to the foreign economy, facing the following demand schedule,

$$C_{X,t}(h) = \left(\frac{P_{X,t}^{*}(h)}{P_{X,t}^{*}} \right)^{-\frac{\lambda_{X,t}}{\lambda_{X,t}-1}} c_{X,t}$$

where $P_{X,t}^{*}$ is the price of the export goods in foreign currency and $c_{X,t}$ is the quantity of exports sold.

Similar to Gali and Monacelli (2005), Justiniano and Preston (2010b) and Adolfson et al. (2007), we assume that the foreign demand for exports is given by

$$C_{X,t} = \varpi \left(\frac{P_{X,t}^{*}}{P_t^{*}} \right)^{-v_f} y_t^{*}$$

where y_t^{*} and P_t^{*} denote the foreign demand and foreign price level respectively.

Each exporter faces a quadratic cost of adjusting their prices as set in the export market currency. The cost for firm i is proportional to the volume of exports, with the cost per unit given by

$$\Psi_{P_X}\left(\frac{P_{X,t}^{*}(h)}{P_{X,t-1}^{*}(h)} \right) = \frac{\psi_X}{2} \left(\frac{P_{X,t}^{*}(h)}{P_{X,t-1}^{*}(h) \left(\pi_X\right)^{1-\gamma_X} \left(\frac{P_{X,t-1}^{*}}{P_{X,t-2}^{*}} \right)^{\gamma_X}} - 1 \right)^2$$

and the firm selects its price in order to maximise lifetime profits

$$\max_{P_{X,t}^{*}(h)} E_t \left[\begin{array}{c} \sum_{s=0}^{\infty} \beta^s \frac{\omega_{t+s}^{c} \lambda_{t+s}}{\omega_t^{c} \lambda_t} \frac{P_{X,t+s}^{*}}{P_{t+s} Q_{t+s}} \left\{ \left(\frac{P_{X,t+s}^{*}(h)}{P_{X,t+s}^{*}} - mc_{X,t+s} - \Psi_{P_X}\left(\frac{P_{X,t+s}^{*}(h)}{P_{X,t+s-1}^{*}(h)} \right) \right) C_{X,t+s}(h) \right\} \\ -\varsigma^X tfp_t \end{array} \right]$$

Note that the exporting firm must pay an exporting licensing fee τ^X to the government.

3.6 Net Foreign Asset Position

It is shown in the appendix that the evolution of foreign debt $\left(b_t^f\right)$ is given by

$$b_t^f = \frac{R_{t-1}^{*}}{\pi_t^{*} \widetilde{\Delta tfp_t}} \frac{Q_{t-1}}{Q_t} \pi_t \Psi_{B^f}(\cdot)\, b_{t-1}^f + \frac{p_{M,t}^{*}}{Q_t} \left(\frac{p_{X,t}^{*}}{p_{M,t}^{*}} c_{X,t} - m_t \right)$$

where $P_{M,t}$ is the wholesale price of imports in foreign currency.

3.7 Policy

In the model, the central bank sets the nominal interest rate. At this stage, we assume the interest rate decisions of the central bank are guided by a policy rule rather than by optimal policy, which would seek to maximise a model-based welfare criterion. The policy rule (in log deviations from steady state) is given by

$$\hat{r}_t = \rho_r \hat{r}_{t-1} + (1 - \rho_r) \left[\phi_\pi \hat{\pi}_{t+1} + \phi_y \hat{y}_t + \phi_{\Delta y} \Delta \hat{y}_t - \phi_s \Delta \hat{s}_t + \omega_t^r \right]$$

The specification of the policy rule is flexible and can be seen as a generalised Taylor rule. The parameter ρ_r governs the degree of interest rate smoothing. The monetary authority is assumed to respond to inflation expectations at time t+1 and the long run response to inflation is measured by the parameter ρ_π. The policy rule also allows the interest rate to respond to movements in the level and growth rate of the output gap. Our definition of output gap is derived within the model. It is defined as the difference between actual output and the level of output that would prevail in the absence of nominal rigidities. Moreover, following Lubik and Schorfheide (2007), we allow exchange rate fluctuations to directly affect interest rates by introducing a term that depends on nominal exchange rate growth. Finally, ω_t^r is a monetary policy shock representing deviations from the monetary policy rule.

The particular choice of the policy rule, and the existence of additional macroeconomic variables, are motivated by our desire to have an empirical rule that describes the RBNZ's underlying policy rule. The RBNZ is tasked with ensuring the price stability in New Zealand. In particular, the Policy Targets Agreement between the Minister of Finance and the Governor of the RBNZ requires the Reserve Bank to "keep future CPI inflation outcomes between 1 per cent and 3 per cent on average over the medium term, with a focus on keeping future average inflation near the 2 per cent target midpoint" and "in pursuing its price stability objective, the Bank shall implement monetary policy in a sustainable, consistent and transparent manner, have regard to the efficiency and soundness of the financial system, and seek to avoid unnecessary instability in output, interest rates and the exchange rate."[6]

Given the price stability objective of the RBNZ, an option would be to specify the interest rate rule as a function of inflation expectations alone. However, the model-based expectations may not capture the RBNZ's forecasts of inflation at that point in time. Furthermore, we do not employ a measure of observed households' or firms' inflation expectations in the empirical section as there is no perfect measure of these expectations. Instead by allowing for additional terms in the policy rule, we aim to capture the effects of output gap and exchange rate movements (both directly and via households'

[6] The full PTA can be accessed from http://www.rbnz.govt.nz/monetary_policy/policy_targets_agreement/.

and firms' inflation expectations) on the RBNZ's inflation forecasts. Moreover, a more generic rule may also reduce the effect of model misspecification in estimating the model's structural parameters.

In terms of fiscal policy, the government collects license fees $\left(\tau^X \text{ and } \tau^M\right)$, issues new debt $\left(B_t^d\right)$ and finances government spending (g_t). Lump sum taxes (τ_t) adjust to ensure that the government's budget is always balanced (i.e. $b_t^d = 0$).

3.8 Log-linear model

The dynamics of the model are fully characterised by the first order conditions from the optimisation problems presented in this section together with the market clearing conditions. The presence of permanent TFP shocks introduces a stochastic trend in real variables. In an online appendix, we first write the model in terms of stationary variables and solve for the deterministic steady state. We then log-linearise the model around this steady state. The resulting log-linear equations are summarised in Table 1. These equations are used in the following empirical sections.

4 Empirical Analysis

In this section, the model's parameters are estimated on New Zealand economic data. This section discusses the Bayesian estimation procedure, the data and priors used in estimation, the empirical fit and a selection of the resulting impulse responses.

4.1 Data and Estimation

We use Bayesian techniques to estimate the model's parameters.[7] Our estimation uses quarterly data for New Zealand from the period 1993Q2 to 2013Q1, which covers most of New Zealand's inflation targeting era. Over this sample the monetary regime has remained largely unchanged and has focused on price stability. Although the monetary policy mandate has emphasised price stability since 1989, actual price stability was not achieved until 1992. We select 1993Q2 as the starting point of our sample as we believe that by this point the RBNZ had credibly convinced the public of its mandate of price stability.

The data series that we observe are: output growth, consumption growth, export growth, the nominal interest rate, nominal wage inflation, headline inflation, domestic inflation, nominal exchange rate growth and terms of trade growth. Output is defined as real gross domestic product (GDP). Consumption and exports are in real terms and come from the national accounts. Our interest rate

[7] We do not describe the details of the estimation approach here. Further details are available in An and Schorfheide (2007) and Del Negro and Schorfheide (2011).

measure is the New Zealand 90-day bank bill rate. Nominal wage inflation is constructed as the percent change in average hourly earnings (ordinary time, private sector) from the Quarterly Employment Survey. Headline and domestic inflation are percent change in headline consumer price index and in non-tradable goods prices, both excluding the goods and services tax (GST) changes in 2010. The nominal exchange rate is the New Zealand dollar trade weighted index and, lastly, terms of trade are the ratio of export to import prices from the Overseas Trade Index (OTI). Output, consumption and exports data are transformed to per capita terms using working age population from Household Labour Force Survey. All the data are seasonally adjusted, except the exchange rate and the interest rate. Interest rate and exchange rate data are produced by the RBNZ. All other data are produced by Statistics New Zealand.

The measurement equations that relate the model variables to the observable variables are outlined in table 2. Figure 1 plots all the data that we use in the estimation. Note that our observable set of variables does not include a measure of demand for New Zealand's exports. This is motivated by the fact that it is hard to construct a measure reflecting the total demand addressed to the New Zealand economy. In particular, our model places a tight constraint on the relationship between foreign demand and total exports. However, typical measures of foreign demand, such as trade weighted aggregates of trading partner's GDP, have very weak correlation with export data. The same observation applies to measures of foreign interest rates and prices. This is possibly one of the reasons why estimated small open economy models typically predict a low share of foreign shocks in the domestic variables variance decomposition (Justiniano and Preston, 2010a). Our strategy consists of treating foreign variables as latent variables and inferring their dynamics using information contained in domestic variables, exchange rates and terms of trade.

We estimate the posterior mode, by maximising the log posterior density function (a combination of prior information and the likelihood of the data). Then, we estimate the full posterior distribution using the Metropolis Hastings algorithm. In the remaining part of this section, we discuss the calibration and choice of priors for the estimated parameters.

The model allows for a rich structure with many frictions. However, we do not use all features in our baseline version. We set the intertemporal elasticity of substitution parameter to 1 and the preference shifter to 0, collapsing the model to the GHH utility function. Further, we turn off habit formation in hours worked. We relax these assumptions and discuss the results in section 4.2.

Before estimating, we calibrate some parameters to be consistent with the mean values in the data. We set the discount factor (β) to 0.99, which gives an annual steady state real interest rate around 4 per cent. We assume households work for 20 percent of their allocated time in the steady state, as in Jaimovich and Rebelo (2009). The share of tradable goods in the consumption basket (ω_C) is assumed to be the share of tradable goods in the CPI, which is 0.44 in New Zealand. The share of imported goods in the production of tradable goods (τ) is set to 0.8 to match the average share of total imports over GDP. Following Schmitt-Grohe and Uribe (2003), we ensure the stationarity of the model by setting the elasticity of the risk premium to the level of debt (Ψ_B) to 0.001.

Priors

The third column of table 3 details the priors used in estimation of the model's parameters. We discuss a subset of these priors below.

We assume the consumption habit parameter comes from a beta distribution, with a mean of 0.4 and a standard deviation 0.05. Our prior mean (0.4) is lower than similar estimated models for other economies. This low value is motivated by the fact that the persistence of consumption growth in New Zealand is much lower than in many other countries. Several authors who estimated DSGE models on NZ data (Justiniano and Preston, 2010a) have found low values for habit persistence. Obviously, our choice of prior has some effect on the posterior distribution. We have experimented by setting the mean of the prior for the habit persistence to a higher value. That left us, however, with unrealistically long delays in the transmission of transitory nominal shocks.

On the price setting side, we estimate the inverse of the price adjustment cost parameters. The priors for the inverse of these parameters are from a gamma distribution, with means of 1/200 and standard deviations of 1/800.[8] It is not straightforward to provide an economic interpretation of the size of this parameter. But, given the other calibrated parameters, the equivalent of this parameter in a Calvo (1983) type price setting framework would be 0.8, implying that prices are changed on average every 5 quarters.

We have three parameters governing the demand elasticities in the model: the consumer's elasticity of substitution between domestic and tradable goods (η), tradable firms' elasticity of substitution between domestic and imports (η_T) and export demand elasticity (η_X). There is no direct evidence on what these elasticities should be at the macroeconomic level in New Zealand. We impose diffuse priors for η, η_T and η_X centered on a mean of 1.5, 1.5 and 1 respectively. These demand elasticity priors come from a gamma distribution.

We center our prior for the parameter governing the interest rate response to inflation movements to 2. We assume that the priors for the parameters in the interest rate equation are normally distributed with a mean of 0.15 and standard deviation 0.1. Finally, the prior on the interest rate smoothing parameter ρ_r is beta distributed with mean 0.75 and standard deviation 0.05.

[8] The standard deviation for the prior on the tradable adjustment cost parameter is slightly larger than the other parameters (1/600). We did this because the volatility of tradable inflation is considerably smaller than the volatility of import prices, implying larger nominal rigidities.

All the exogenous disturbances follow independent AR(1) processes. The prior means for the persistence of shocks are set to 0.5. The priors for standard deviations of the shocks are from the inverse gamma distribution with a mean of 0.2.

Posterior Inference

The last two columns in table 3 present the posterior mean and 90% probability intervals for the estimated parameters. We have also plotted the posterior distributions along with the prior distributions in figure 2. Most parameter distributions are shifted by our estimation procedure indicating that information in the data can be linked to our structural parameters.

We find that the largest nominal rigidities are in the tradable goods sector. The adjustment cost ψ_T for the tradable prices is around 769, compared to domestic prices, export prices and wages all of which range from 200 to 250. This reflects that import prices are volatile, as a result of exchange rate movements, but tradable prices respond only moderately.

Households appear to view tradable and non-tradable goods as substitutes with an elasticity of ($\eta = 1.65$). However, tradable firms, when using imports and domestic output as inputs in the production of tradable goods view these inputs as complements ($\eta_t = 0.52$). This is consistent with the view that tradable retailers incur domestic distribution costs in bringing imports to market.

In terms of the policy rule, our parameter estimates suggest that interest rates have a substantial degree of persistence. The posterior mean of the interest rate smoothing parameter is 0.81, in line with previous estimates on New Zealand data and above our prior. The interest response to inflation remains near our prior of 2. The interest rate responses to the output gap and output growth are both positive. This is consistent with the view that the RBNZ may use the output gap as a proxy for future domestic inflation. The mean response of interest rates to the exchange rate is essentially zero. This is similar to what Lubik and Schorfheide (2007) and Kam et al. (2009) found in their cross-country study of the small open economy central banks policy functions.

In the remainder of this section, we focus on the empirical performance of the model.

4.2 Empirical fit

There are four aspects that we consider regarding the empirical fit of the model. These are the second order moments, the marginal likelihood and the out-of-sample forecast performance.

Second order moments

An intuitive method to evaluate a model's empirical fit is to compare second order moments (the correlations and standard deviations) of the data to those implied by the model. Table 5 presents the standard deviations of the observed variables and figure 3 displays their cross-correlations with up to eight lags. Model based moments are computed by taking 100 draws from the posterior parameter estimates and simulating 100 artificial datasets composed of 84 observations – the length of our sample – for each variable. In these results, we report the median and 90 per cent probability intervals of both the model and data. The moments of the data in table 5 and the associated confidence bands are obtained from estimating a Bayesian VAR with all the observable data used in the estimation of the model. In table 5 we label the moments obtained from simulating the BVAR 'data' because, apart from interest rates (which has a standard deviation in the data of 2.12 instead of the 2.04 shown in table 5), the mean second moments from the BVAR are very similar to those observed in the data.

There is a reasonable overlap between the empirical and model-implied confidence intervals for the standard deviations of the observable data. Although the model somewhat overestimates the volatilities of some variables, overall the model is able to replicate the second moments of the data well. In addition, the estimated model is able to reproduce the rankings of the volatilities. The model-implied standard deviations for all the inflation variables are lower than output, and wage inflation is more volatile than tradable and non-tradable inflation. Further, the volatilities of the interest rate, export growth and the exchange rate are all higher than the volatility of output, which is in line with the data.

In terms of the cross correlations, the model performs similarly to a BVAR in replicating the correlation in the data. The model is not able to capture all the cross correlations in the data, but it does capture most of the reduced form lead-lag dynamics in the data. Given that an empirical BVAR model does no better than NZSIM, we see empirical fit as a strong feature of the model.

Marginal likelihoods

An alternative method of evaluating the model fit is to formally evaluate the marginal likelihood of the model given the observed data. Unless used to compare models, marginal likelihoods hold little information, so we examine which of the model's features are important by removing a selection of features one at a time and re-estimating the model. We consider the importance of features included within the baseline such as removing habit persistence in consumption (χ_c), the UIP smoother (ψ_{uip}), wage adjustment costs, domestic goods price adjustment costs and the tradable goods price adjustment costs. In addition, we consider adding features that are excluded from the baseline such as estimating habit persistence in hours worked (χ_n) and allowing the preference shifter (v) to be different from 0. In table 6, we present the posterior modes for each parameter when turning on and off different features of our model. We also show the marginal likelihoods for each model including the baseline with larger numbers indicating improved empirical fit. For comparison, the log of the marginal likelihood of the baseline model is -772.

We find that habit persistence in consumption is important to fit the data well. When we set $\chi_c = 0$, we find that the log of the marginal likelihood falls to -804. This suggests that consumption and GDP tend to respond to shocks in a hump-shaped or gradual manner. This is consistent with previous studies of consumption and GDP responses in New Zealand, see for example Buckle et al. (2007), Haug and Smith (2012) and Bloor and Matheson (2008). In a similar manner, the smoothing term in the UIP equation helps to fit the data. When we set $\psi_{uip} = 0$ the log marginal likelihood falls to -787. This likely occurs because the pure UIP equation does a poor job in explaining movements in the exchange rate.

Tradable price rigidities have dramatically improve the marginal likelihood of the model relative to rigidities in domestic goods prices or wages. This reflects the extra degree of volatility in the real marginal cost of tradable goods relative to these other sectors. Without tradable rigidities, the price of tradable goods would be extremely volatile. Any change in the exchange rate would have an immediate one-to-one effect on their prices. Hampton (2001) shows, however, that a 10 percent depreciation in the NZD exchange rate results in only a 0.5 percent rise in New Zealand tradable goods prices in the short run. This small pass-through is consistent with strong nominal rigidities in our model. For the domestic or non-tradable firms, their marginal cost is determined by the output gap and the real wage. These are far less volatile and more persistent. As such, the model does not need a large amount of nominal rigidities in the domestic goods sector.

Moving to extensions to our baseline, allowing habit persistence in hours worked reduces the log marginal likelihood of the model to -791. While our chosen data set sees no increase in fit from this feature, this may change if we were to include some measure of labour hours worked in our set of observable variables.

Finally, we activate the flexible preferences discussed earlier by allowing υ to be different from zero (relative to the baseline where preferences are GHH). This version of the model has a slightly higher log marginal likelihood of -771. This suggests that more generic household preferences can improve the model's ability to describe the New Zealand business cycle. We plan to analyse the implications of these preferences on model dynamics in future research.

4.3 Impulse Response Analysis

In general, the model can replicate the basic features of the data. An additional important feature of the model is its transmission channels. When constructing the RBNZ's official forecasts, the model-based forecasts represent a starting point from which 'off-model' information is added. When incorporating off-model information, the direct information pertaining to the value of a model variable is not sufficient to predict the effects on other variables. To process the information fully, it is also important to assess why the value of a particular model variable has changed. Once an appropriate event has been decided upon, the forecasts are adjusted by selecting one or more structural shocks to impose the value of the model variable identified by off-model information. The impulse responses are essential in this process because they describe how the chosen shocks will affect the model variables. For brevity, here we discuss two impulse responses: a monetary policy shock and an exchange rate shock.

Monetary Policy Shock

The first shock that we consider is a monetary policy shock that temporarily raises the interest rate by 1 percent (figure 4). This shock represents an event where the central bank in the model deviates from its policy rule. In this case, economic conditions do not warrant the interest rate increase. In the charts, the solid blue line is from the posterior mode and the confidence bands show the 5th and 95th percentiles of 1000 draws from the MCMC chain. The interest rate and the inflation responses have been annualised and the exchange rate is defined so that an increase represents an appreciation.

Monetary policy achieves its targets in this model through three channels: i) the demand channel, ii) the exchange rate channel and iii) the expectations channel. Interest rates can have a powerful impact on aggregate demand in the economy through their impact on household spending decisions. In NZSIM, households select how much to consume and save based on their expectation of the entire path of interest rates.[9] While the equations presented in subsection 3.1 detail how households optimise between consumption in the current and subsequent periods, this logic holds in all future periods. Therefore, monetary policy can have a powerful effect on households' consumption, both through affecting current interest rates and influencing households' expectations of interest rates in the future. This channel is reflected in figure 4 by the hump-shaped fall in consumption when households face higher interest rates. Because households all choose to increase their savings in the current period and there is no investment in NZSIM, domestic demand falls which lowers domestic GDP.

In addition to the demand channel, monetary policy has a considerable impact on the exchange rate. The modified UIP equation predicts large and persistent movements in the exchange rate when

[9] In NZSIM, the term structure of interest rates reflects market participants' beliefs about short term rates.

domestic monetary policy is adjusted relative to foreign monetary policy. The exchange rate affects inflation directly by lowering the cost of production in the tradable sector. Tradable firms face lower importing costs and pass on some of this to households. This results in lower CPI inflation. In addition, the exchange rate affects economic activity through exports demand and two substitution effects: a production substitution effect in the tradable sector toward imports as an input into production, and a consumption substitution effect as households choose to consume more of the tradable good. Both the lower exports and the substitution effects result in lower demand for domestic production which, as production is reduced, lowers marginal costs in the domestic sector and therefore inflation.

The expectations channel amplifies the demand and exchange rate channels. As mentioned above, households' consumption decisions are determined by households' expectations of future interest rates. In addition, the modified UIP arbitrage condition provides a role for future interest rate differentials to affect the current value of the exchange rate. If the central bank is able to affect these expectations, households will adjust their consumption and speculators will move the exchange rate without any need for the central bank to adjust interest rates in the current period. In NZSIM, the central bank commits to (on average) follow the policy rule specified in section 3.7. The particular type of interest rate rule – via these expectations – can have strong impacts on the path of inflation and output.

Exchange rate shock

Here we consider the impact of a 1 percent appreciation of the NZD TWI that cannot be explained by interest rate differentials (detailed in figure 5). While this shock is modelled as changes in the risk premium required to hold foreign bonds, this shock can be thought of as representing changes in international investors' preferences for investing in New Zealand.

The higher TWI reduces the NZD price of both import and exports. Lower imports prices reduce the cost of production for the import distributing firms. This decline in their marginal cost is partially passed on to households who increase their demand for tradable output and in doing so are able to increase their total consumption. While total consumption increases, the expenditure switching toward imports is sufficiently large that domestic consumption falls. This contributes to a reduction in GDP. In addition, the high exchange rate reduces export receipts and as firms raise prices to contain their losses, export volumes fall. This reduction in exports leads to a further reduction in GDP. Lower GDP leads to lower domestic marginal costs and reduces domestic inflation. As tradable and non-tradable inflation are lower, the central bank reduces interest rates which slowly brings the exchange rate back to its pre-shock level.

5 Alternative policy scenarios

The RBNZ, in preparing its official forecasts, extracts information from more variables than are practical to include in a structural model. In addition, not all information is able to be summarised in terms of a quantitative variable. Given that this 'off-model' information is relevant to the likely paths of variables in the model, the RBNZ uses conditional forecasting methods to adjust the model-based forecast to reflect the insights gained from the available off-model information.

When information suggests that a particular variable is likely to be different to the model's forecast, this is usually due to some economic event. The qualitative nature of this event is important for forecasting in order to predict the effect on other variables from, for example, information suggesting higher GDP. If the information suggesting higher GDP was related to productivity changes, then the higher GDP should suggest lower CPI inflation (as the increased productivity lowers the cost of production). If however, the higher GDP was driven by an increase in households' demand for consumption, this this extra demand should raise CPI inflation. Without identifying the event leading to the increase in GDP, it is not clear what the inflationary implications are.

Structural models articulate the effects of a variety of economic events in terms of shocks affecting economic agents and their interactions. This is a useful property of a model when incorporating off-model information. By having a range of events to select, forecasters can select shocks to best match the particular economic event the off-model information indicates. Often the information contained in the indicators may reflect changes in seemingly different areas of the economy. For instance, a rise in the exchange rate may indicate an expected increase in export prices (see Chen et al., 2010). The structure of NZSIM and the RBNZ's conditional forecasting toolkit allows for the exchange rate forecasts to be adjusted with an event representing a rise in the demand for exports as well as a range of other possible events.

In this section, we detail some scenarios in which interest rates are held constant by the central bank for a given period of time. Each scenario starts with model-based forecasts produced using data up to March 2013. We then construct conditional or judgementally adjusted forecast by holding interest rates constant for eight quarters. In each of the scenarios, the reason for interest rate being held constant is different.[10]

In the first scenario, displayed in figure 6, we impose a constant interest rate forecast using monetary policy shocks only. The interest rate path starts diverging after mid-2013 as in the baseline scenario the interest rate starts to increase. Accordingly, the dynamics of other variables are different after that point. As a result of interest rates being persistently lower due to the monetary policy shocks,

[10] Throughout the scenarios we assume that shocks are unanticipated. Del Negro et al. (2012) discusses ways to implement conditional interest rate forecasts using anticipated shocks.

households are induced to reduce their savings and consume more. This yields higher output and imports. To increase production, domestic firms increase their demand for labour, generating higher wages. This raises their marginal cost of production and results in higher prices. Overall, the model predicts higher output in the near term and a persistent rise in inflation.

In the second scenario, we use preference shocks to generate a constant interest rate scenario. In the model, preference shocks can be seen as exogenous fluctuations in domestic demand. In this case, the scenario consists of finding the (negative) demand shocks that would make the central bank keep interest rates constant until 2015. The forecasts under this scenario are displayed in figure 7.

According to the interest rate rule in the model, in order for the central bank to keep interest rate low, it has to forecast either low inflation or subdued output dynamics. Therefore we need a series of negative consumption shocks to generate the same constant interest rate scenario. As a result demand is much lower than in the baseline resulting in consumption growth being negative. The persistent decline in real activity is associated with low domestic inflation and therefore low headline inflation.

While interest rates are the same in these first two scenarios, because we use different structural shocks, the dynamics of real activity and the movements in inflation are markedly different. For instance, in the first scenario output and inflation both increased, whereas in the second they both fall.

In the final scenario, we do not take a stand on what causes interest rates to remain constant, other than excluding monetary policy shocks. We interpret this scenario as representing the most likely set of economic events that, consistent with the estimated policy rule would result in the central bank leaving policy unchanged. However, as described in Benes et al. (2008), the set of shocks to deliver a constant interest rate track are not uniquely determined, as the path of only one variable is imposed with multiple shocks selected to explain this. We overcome this issue using the algorithm outlined by Waggoner and Zha (1999). This algorithm finds, given the estimated shocks' persistence and standard deviations, the statistically most likely combination of shocks that delivers the target interest rate track.

The forecasts under this scenario are displayed in figure 8. Because we do not allow monetary policy shocks to explain the lower interest rates, the results in multiple shocks scenario show a weakening in inflation that is qualitatively similar to the consumption shock scenario. Key differences are that in the multiple shocks scenario, the responses of output, consumption, imports and tradable inflation are less pronounced than in the consumption shock scenario. Overall, allowing for multiple shocks tends to results in less dramatic movements in most model variables while delivering the same interest rate path because the shocks can be smaller when there are more of them.

These scenarios show how a structural model can give forecasters a powerful and flexible framework for implementing off-model information. Not only can forecasters adjust the values of variables in the model, but they can select from a wide range of different economic events to produce the desired adjustments to model variables. This allows for the effect of incorporating off-model information to have clear economic content which can aid forecasters in explaining their forecasts. In addition, the Waggoner and Zha (1999) algorithm, by selecting multiple shocks, allows for forecasters to take an agnostic view if necessary on the economic events driving new off-model information.

6 Extensions - Adaptive inflation expectations

In the baseline model, inflation expectations are model consistent (rational). There is a large literature investigating the ability of DSGE models to capture the observed inflation expectations dynamics.[11] In this section, we assume a more flexible inflation expectation formation and investigate how this modification affects the model's dynamics. The expectation formation is allowed to be intrinsically persistent and backward (instead of forward) looking. The equation below describes how inflation expectations are formed:

$$\pi_t^e = \rho_1^{pe}\pi_{t-1}^e + (1-\rho_1^{pe})[\rho_2^{pe}\pi_{t+1} + (1-\rho_2^{pe})\pi_{t-1}]$$

ρ_1^{pe} is the weight on past inflation expectations and ρ_2^{pe} is the relative weight on rational expectations and last period's observed inflation. When $\rho_1^{pe} = 0$ and $\rho_2^{pe} = 1$ expectations are rational, as in the baseline model. Expectations of domestic, tradable, and wage inflation all follow this process with sector-specific expectations variables, but the same values for ρ_1^{pe} and ρ_2^{pe}.

Hagedorn (2011) uses a similar approach.[12] He finds that adaptive expectations reduce the strength of the expectations channel when implementing a disinflationary policy. As such, the central bank in the model has to be more proactive with interest rates in order to achieve its inflation target.

We re-estimate the model with two additional parameters: ρ_1^{pe} and ρ_2^{pe}. Our priors for these parameters are beta distributions with a mean of 0.5 and a standard deviation of 0.1.[13] We find that the posterior mode for ρ_1^{pe} is around 0.9 and for ρ_2^{pe} is around 0.5. This produces markedly more persistent model-implied inflation expectations - as shown in figure 9. The high value for ρ_1^{pe} suggests that having a persistent expectations process improves model fit. Indeed, the marginal likelihood of the adaptive expectations version of the model is higher than the baseline (-761 versus 772), suggesting that allowing persistence in inflation expectations improves the in-sample fit of the model. One caveat however, is

[11]See for example Del Negro and Eusepi (2011) who explore the role of time-varying inflation target and Milani (2011) for the role of adaptive learning in inflation expectations formation

[12]Hagedorn's original specification had π_t instead of π_{t-1}. We have tried both and the results are similar.

[13]We adjust the priors for Ψ_N, Ψ_T and Ψ_W to a mean of 100 and standard deviation of 20. With adaptive expectations adding persistence to inflation, price adjustment costs do not need to be as high.

that the estimate of the weight on rational versus backward looking expectations (ρ_2^{pe}) is not well identified.

Figure 10 compares the impulse responses of the baseline model and the adaptive expectations extension to a monetary policy shock. Real variables and interest rates show similar dynamics, with price variables – particularly domestic inflation – being markedly more persistent. This increase in persistence occurs because the adaptive expectations changes the Phillips curve. These changes emphasise *past expectations of* future marginal costs rather than simply future marginal costs. This makes the responses of prices and wages more sluggish. As Figure 10 shows, monetary policy shocks in the rational expectations model have their peak effect on non-tradable, tradable and wage inflation after several quarters. By contrast, in the adaptive expectations model the additional persistence delays further the peak response of inflation variables – in particular, non-tradable inflation and wage inflation. This additional intrinsic source of persistence is likely to be the reason why the adaptive expectations version of the model better matches the data.

Although we imposed the alternative expectation formation rule in an ad hoc manner, this modelling device is a shortcut to approximating learning about inflation behaviour. This 'learning' through the adaptive expectations device introduces additional complexity to inflation stabilisation, as expectations - once raised - are slow to fall.

Overall, we see this specification as a useful first step towards improving the modeling of inflation expectations in New Zealand and in small open economy models. As described in Milani (2012), there are many alternative formal ways of introducing departures from rational expectation hypothesis into structural dynamic macroeconomic models. We hope our findings will serve as a base for future studies in that direction.

7 Conclusion

We have outlined the underlying structure of NZSIM, the RBNZ's forecasting model. The model is a parsimonious, structural small open economy model driven by a number of economic shocks. The model is deliberately kept small so that it can be easily understood and applied in the policy environment.

We have shown that the model is able to match the salient features of New Zealand macroeconomic data relatively successfully. To this end, we have presented the model's ability to match the volatilities and correlations in the data. In addition, the transmission mechanisms of economic shocks implied by the estimated model are consistent with empirical evidence. The cost of using a simple model is that it does not include all the factors that might be relevant for constructing a macroeconomic forecast. The model is, however, rich enough to implement alternative economic and policy scenarios. We have illustrated an example of this by introducing off-model information into the model forecast. Finally, we have presented an extension to the model that allows for a more flexible specification of inflation expectations formation and analysed its effects on the monetary transmission mechanism.

The model presented here is a snapshot of the current macroeconomic model at the RBNZ. We continue to consider alternative models and additional extensions when creating forecasts and alternative policy scenarios. In the near future, we intend to present some of these extensions and further evaluation of the model's empirical performance. Such work includes analysing housing market dynamics and their relationship to consumption, evaluating the real-time forecast performance and producing model-consistent forecasts of non-modelled variables.

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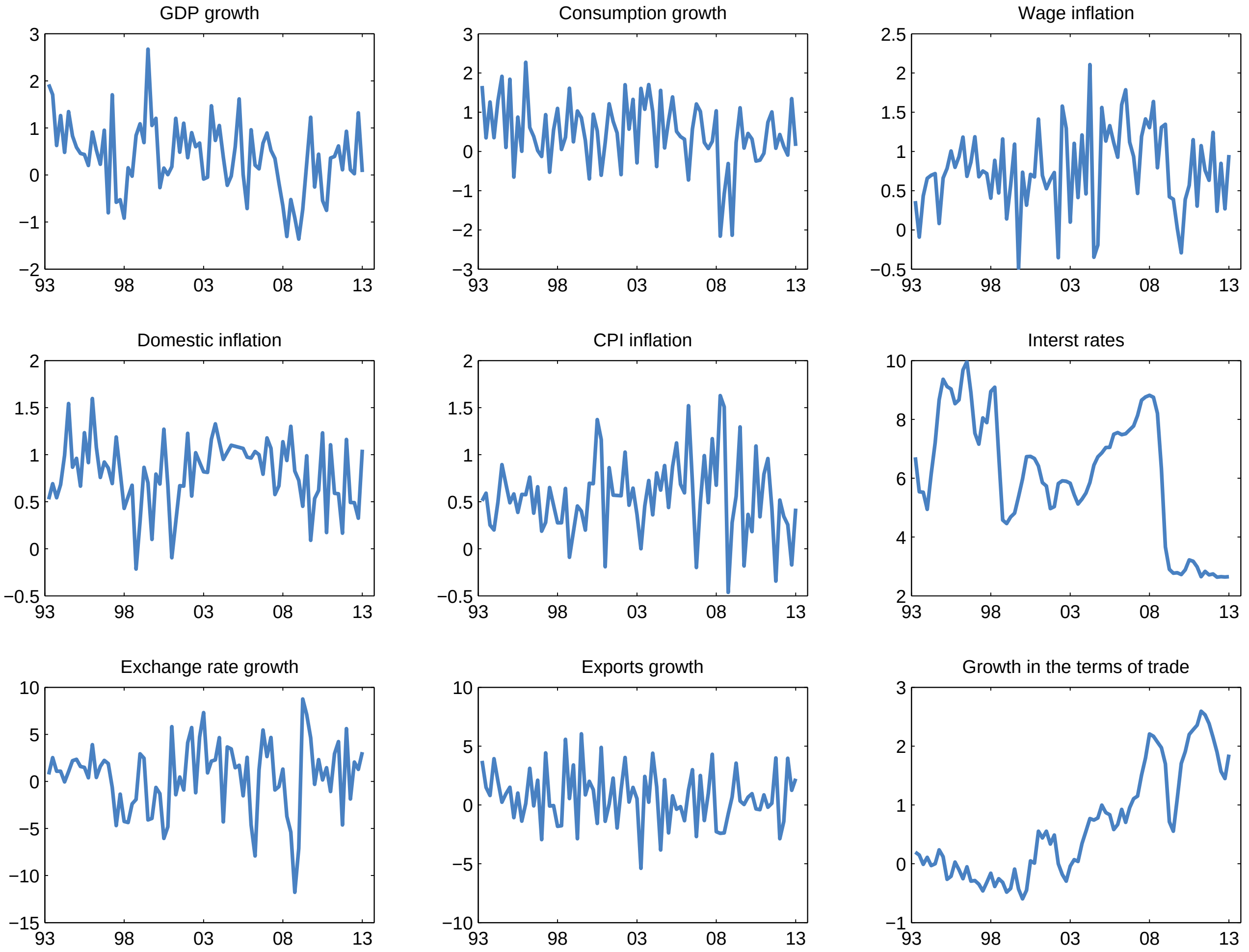
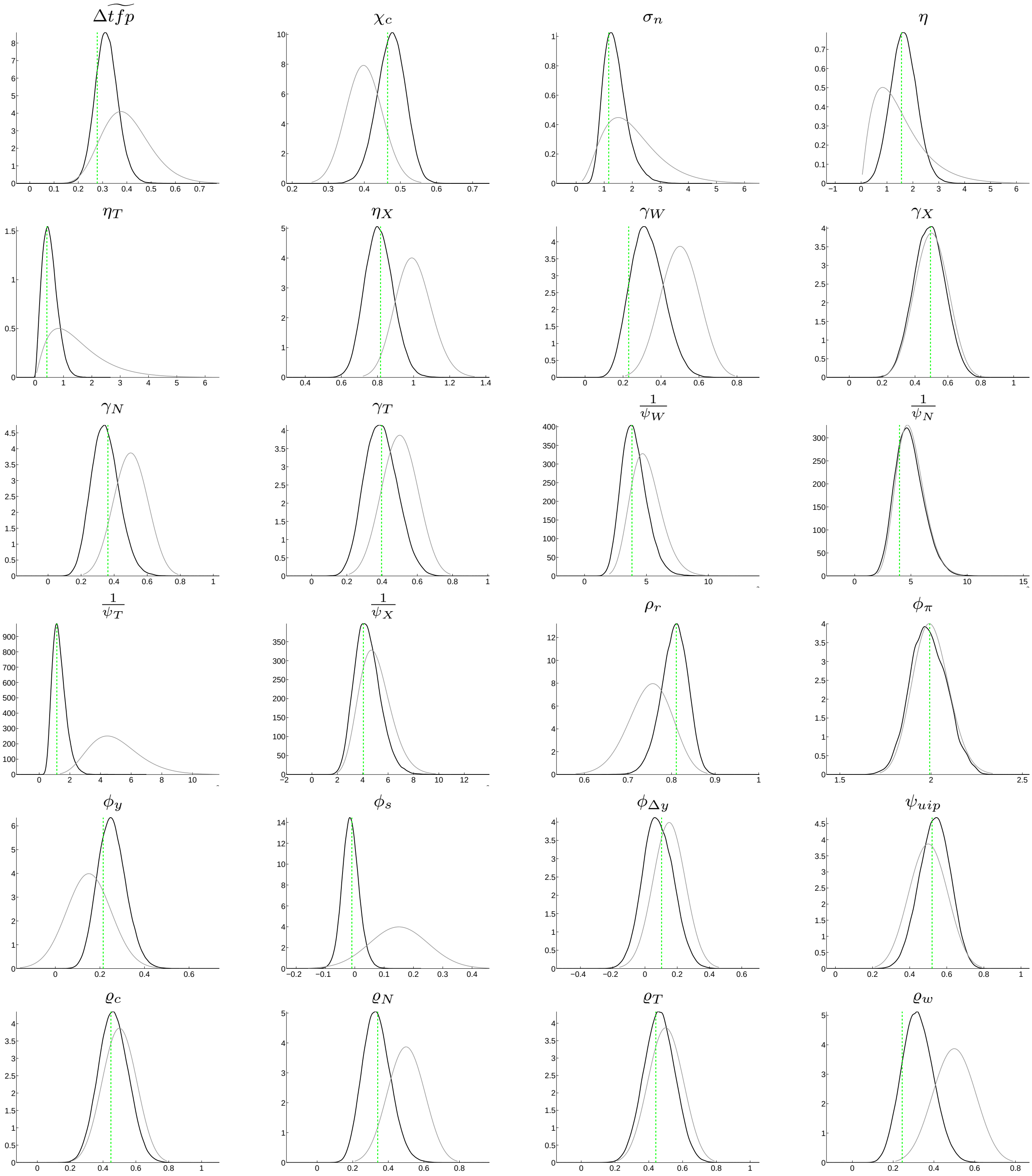
8 Figures

Figure 1: Data used to estimate the model



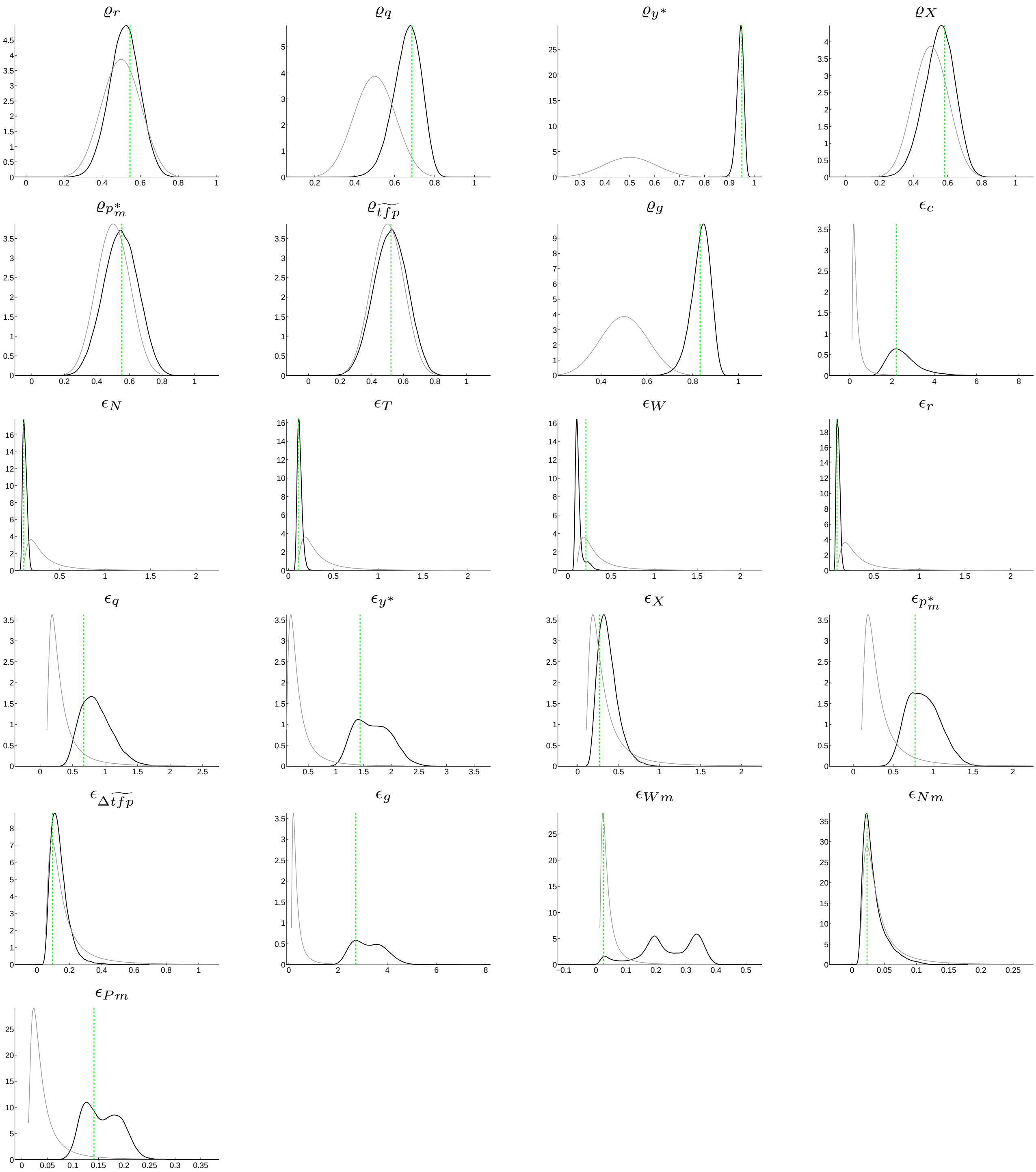
Note: This figure details the data used in the estimation of NZSIM. For details on how to obtain this data refer to subsection 4.1.

Figure 2: Prior and Posterior distribution of the estimated parameters



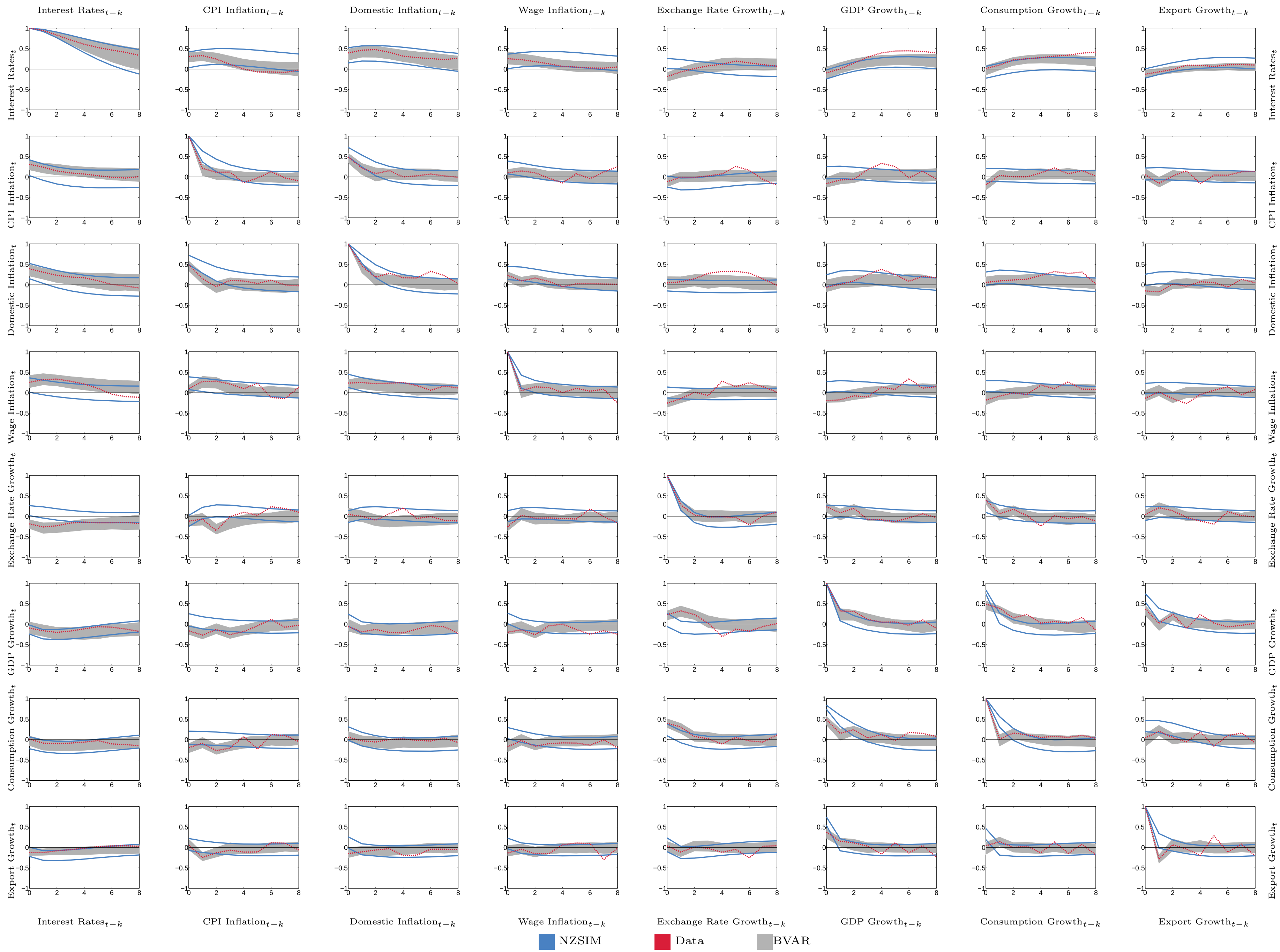
Note: This figure shows the prior (grey distribution), the estimate of the posterior mode (green) and the posterior distribution (black) from 500,000 draws from a Markov chain Monte Carlo procedure.

Figure 2: *continued*



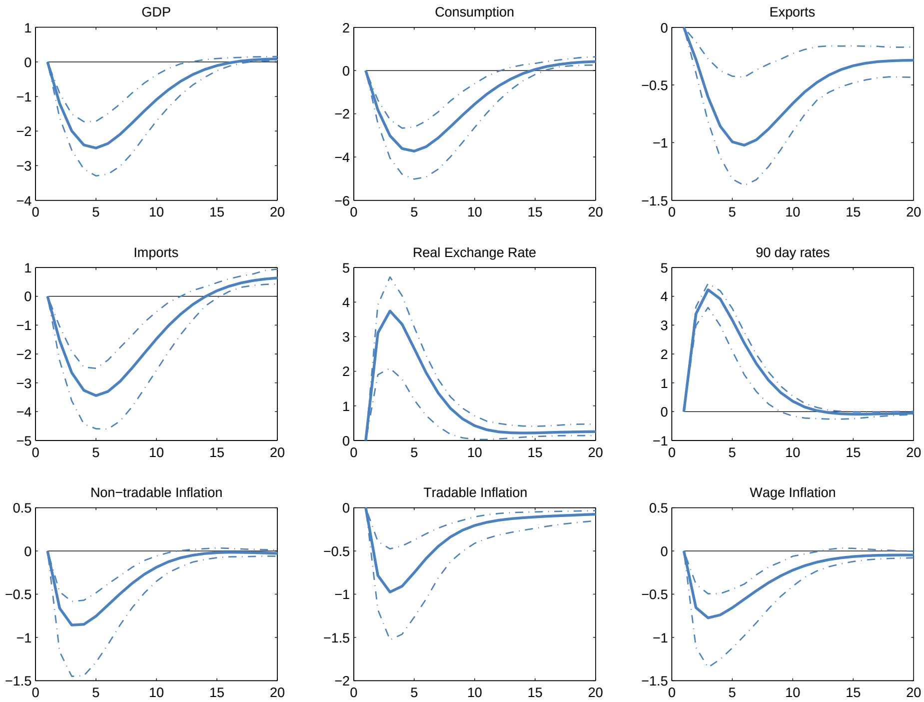
Note: This figure shows the prior (grey distribution), the estimate of the posterior mode (green) and the posterior distribution (black) from 500,000 draws from a Markov chain Monte Carlo procedure.

Figure 3: Correlations



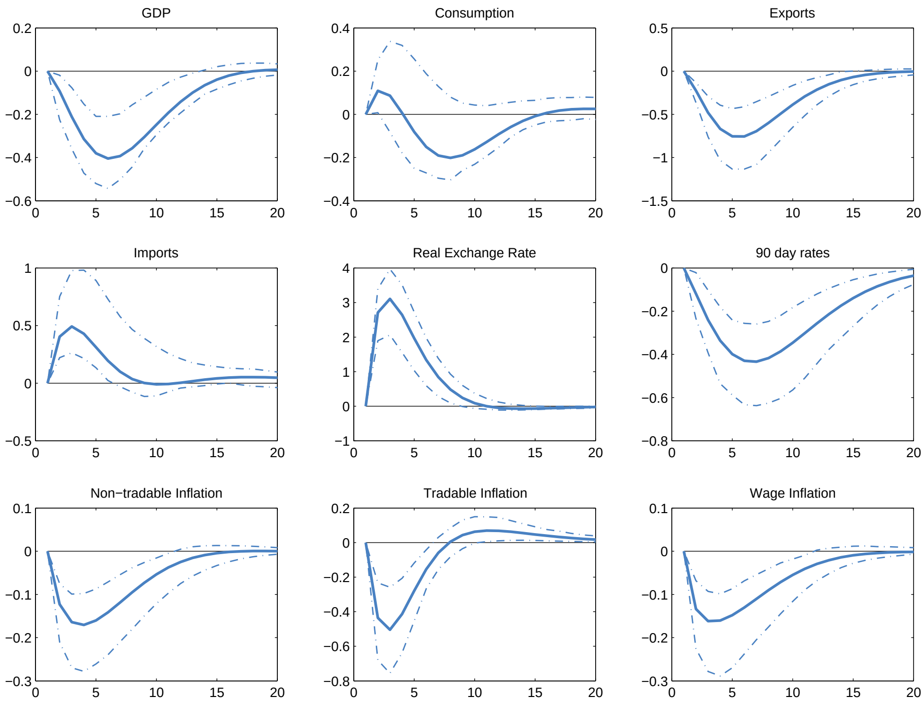
Note: This figure shows the autocorrelations and cross correlations of NZSIM, a BVAR and the data. Diagonal plots show autocorrelations of variables and the off-diagonal plots show the correlations of the variables labelled in the rows against the kth lag of the variables labelled in the columns.

Figure 4: Monetary Policy Shock



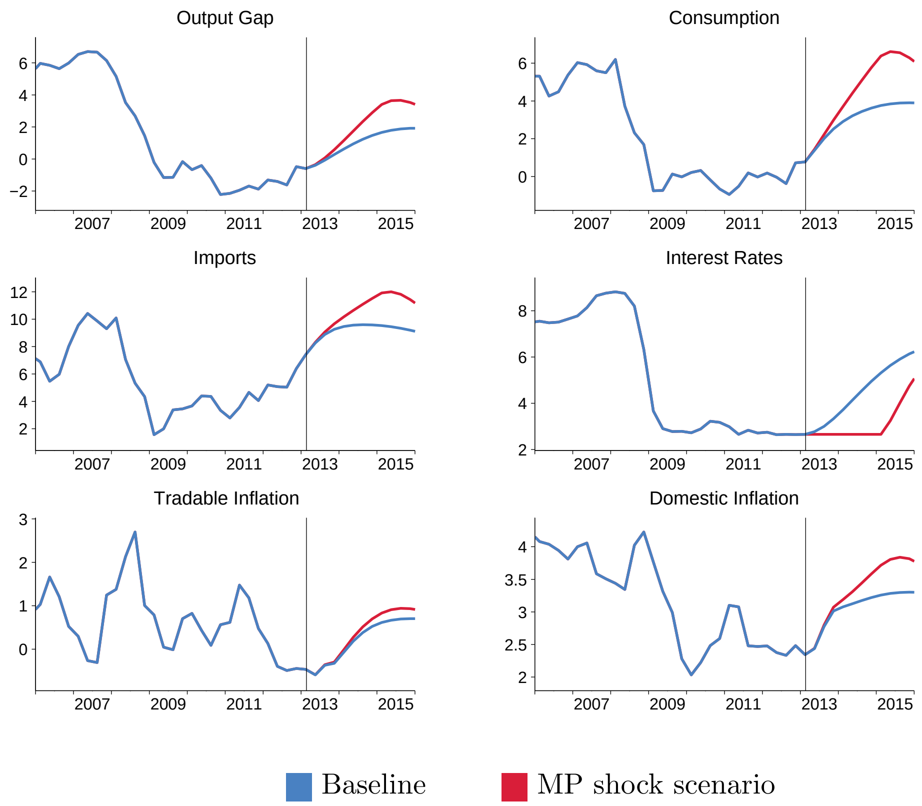
Note: This figure shows the impulse responses form a 1% annualised monetary policy shock. The bands come from 1000 draws randomly selected from the estimated MCMC draws. The thick blue line comes from a single model with parameters from the estimate of the posterior mode.

Figure 5: Exchange Rate Shock



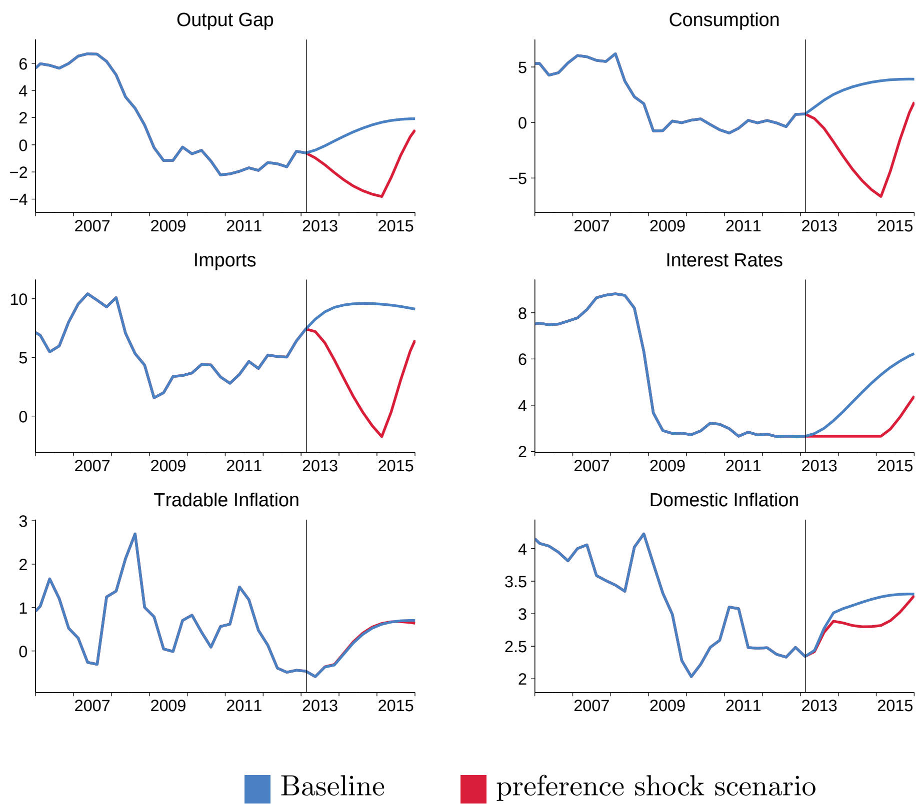
Note: This figure shows the impulse responses form a 1% exchange rate shock. The bands come from 1000 draws randomly selected from the estimated MCMC draws. The thick blue line comes from a single model with parameters from the estimate of the posterior mode.

Figure 6: Alternative interest rate scenario - monetary policy shock



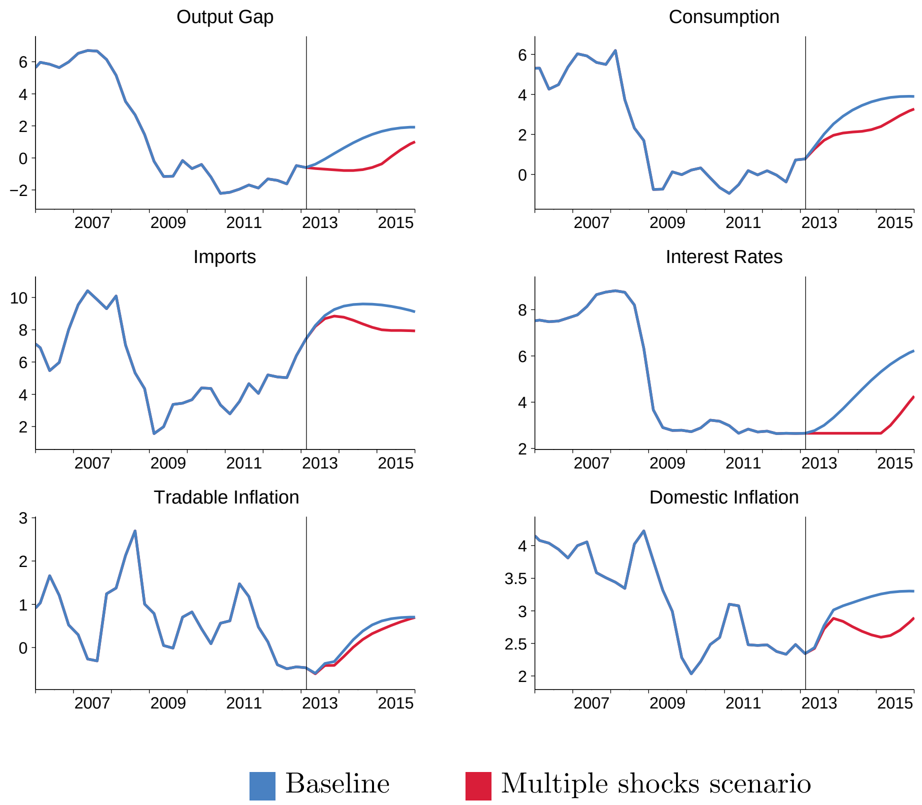
Note: This figure compares the model based forecast to an alternative scenario where interest rates are held constant. Refer to section 5 for details.

Figure 7: Alternative interest rate scenario - preference shock



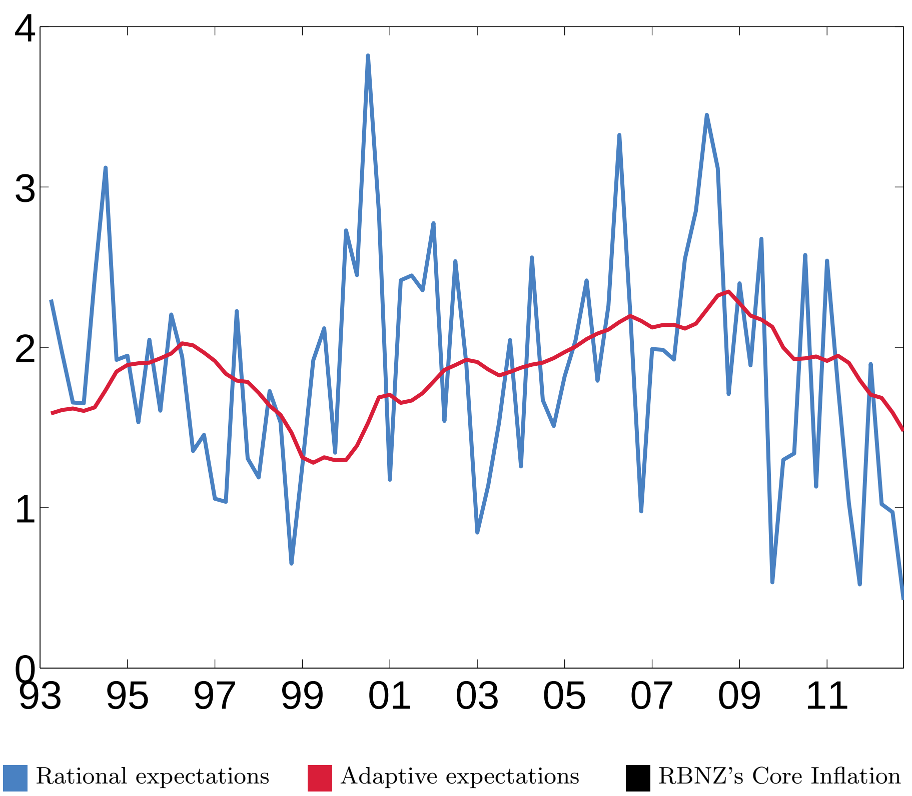
Note: This figure compares the model based forecast to an alternative scenario where interest rates are held constant. Refer to section 5 for details.

Figure 8: Alternative interest rate scenario - multiple shocks



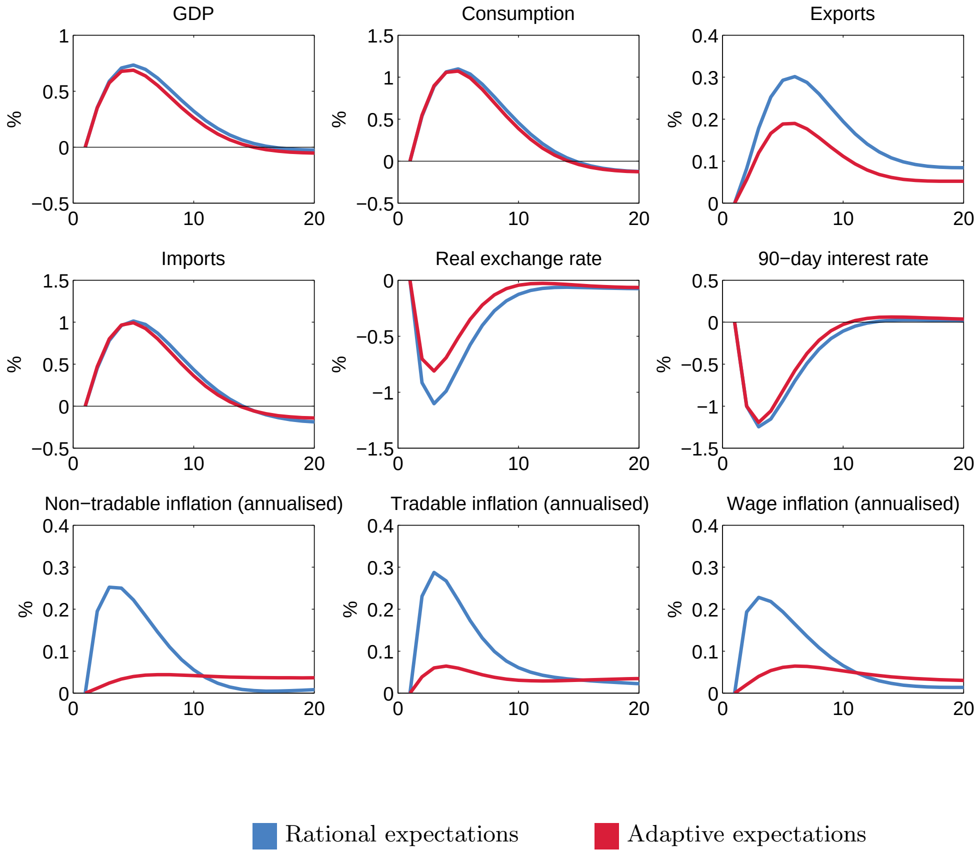
Note: This figure compares the model based forecast to an alternative scenario where interest rates are held constant. Refer to section 5 for details.

Figure 9: CPI inflation expectations (1 quarter ahead, annualised)



Note: This figure compares the model-based 1 quarter ahead inflation expectations for both the baseline and extended model (see section 6) to an official survey measure produced by the RBNZ.

Figure 10: Responses to a 1 percent monetary policy shock



Note: This figure shows the impulse responses to a 1% expansionary monetary policy shock for two models: the baseline model and the extended model detailed in section 6.

9 Tables

Table 1: Linearized model equations

Consumption Equation	$\hat{c}_t = \frac{\chi_c}{(1+\chi_c)}\hat{c}_{t-1} + \frac{1}{(1+\chi_c)}\hat{c}_{t+1} - \frac{\omega_n n^{1+\sigma_n}(1-\chi_c)}{1+\chi_c}\Delta E_t\hat{n}_{t+1} - \frac{(1-\chi_c)\left(1-\frac{\omega_n n^{1+\sigma_n}}{1+\sigma_n}\right)}{\sigma(1+\chi_c)}\left(\hat{R}_t^h - \hat{\pi}_{t+1}\right) + \frac{(1-\rho_{\omega_c})(1-\chi_c)\left(1-\frac{\omega_n n^{1+\sigma_n}}{1+\sigma_n}\right)}{\sigma(1+\chi_c)}\hat{\omega}_t^c$
Marginal Rate of Substitution	$m\hat{r}s_t = \sigma_n\hat{n}_t$
Wage Philips curve	$\hat{\pi}_t^w = \frac{\gamma_W}{1+\beta\gamma_W}\hat{\pi}_{t-1}^w + \frac{\beta}{(1+\beta\gamma_W)}\hat{\pi}_{t+1}^w + \frac{1}{\psi_W(1+\beta\gamma_W)(\lambda_w-1)}\left(m\hat{r}s_t - \hat{w}_t^h + \hat{\lambda}_{w,t}\right)$
Imports Demand	$\hat{m}_t = -\upsilon\hat{p}_{T,t} + \hat{c}_t - \eta_T(1-\tau)\left(\hat{p}_{m,t} - \hat{p}_{N,t}\right))$
Domestic Production	$\hat{y}_t = \frac{y+F_N}{y}(\hat{w}_t^y + \alpha\hat{n}_t)$
Domestic Phillips Curve	$\hat{\pi}_t^N = \frac{\gamma_{P_N}}{1+\beta\gamma_{P_N}}\hat{\pi}_{t-1}^N + \frac{\beta}{1+\beta\gamma_{P_N}}\hat{\pi}_{t+1}^N + \frac{1}{(\lambda^N-1)\psi_{P_N}\left(1+\beta\gamma_{P_N}\right)}\left(\hat{mc}_{N,t} + \hat{\lambda}_t^N\right)$
Domestic Marginal Cost	$mc_{N,t} = \hat{w}_t^h + \frac{1-\alpha}{\alpha}\frac{y}{y+F_N}\hat{y}_t - \frac{1}{\alpha}\hat{\omega}_t^y - \hat{p}_{N,t}$
Imports Phillips Curve	$\hat{\pi}_{T,t} = \frac{\gamma_{P_T}}{1+\beta\gamma_{P_T}}\hat{\pi}_{T,t-1} + \frac{\beta}{1+\beta\gamma_{WT}}\hat{\pi}_{T,t+1} + \frac{1}{(1+\beta\gamma_T)\psi_{P_T}(\lambda_T-1)}\left(\hat{p}_{m,t}^* - \hat{q}_t - \hat{p}_{T,t} + \hat{\lambda}_{T,t}\right)$
Exports Phillips Curve	$\hat{\pi}_{X,t} = \frac{\gamma_{P_X}}{1+\beta}\hat{\pi}_{X,t-1} + \frac{\beta}{1+\beta\gamma_X}\hat{\pi}_{X,t+1} + \frac{1}{(1+\beta\gamma_X)\psi_{P_X}(\lambda_X-1)}\left(\hat{p}_{N,t} + \hat{q}_t - \hat{p}_{X,t} + \hat{\lambda}_{X,t}\right)$
Exports Demand	$\hat{c}_{X,t} = -\upsilon_f\hat{p}_{X,t} + \hat{y}_t^*$
Balance of Payments	$b_t^{y,f} = \frac{\pi R^*}{\pi^*}b_{t-1}^{y,f} + \frac{p_X^*}{Q}\frac{c_X}{y}\left(\hat{p}_{X,t}^* + \hat{c}_{X,t} - \hat{p}_{M,t}^* - \hat{m}_t\right)$
Resource Constraint	$\hat{y}_t = \frac{C}{Y}\hat{c}_t + \frac{I}{Y}\hat{i}_t + \frac{G}{Y}\hat{g}_t + \frac{X}{Y}\hat{x}_t - \frac{M}{Y}\hat{m}_t$
UIP	$\hat{r}_t - E_t\hat{\pi}_{t+1} - (\hat{r}_t^* - E_t\pi_{t+1}^*) = \hat{q}_t - \hat{q}_{t+1} - \psi_{uip}\left[\hat{r}_{t-1} - \hat{\pi}_t - (\hat{r}_{t-1}^* - \hat{\pi}_t^*) + \hat{q}_t - \hat{q}_{t-1}\right] + \omega_t^s$
Retail Interest Rates	$\hat{r}_t^h = \hat{r}_t - \phi_B\hat{b}_t + \omega_t^R$
Central Bank Policy Rule	$\hat{r}_t = \rho_r\hat{r}_{t-1} + (1-\rho_r)\left[\phi_\pi\hat{\pi}_t + \phi_y\hat{y}_t - \phi_Q\left(\hat{q}_t + \hat{q}_{t-1} - \hat{\pi}_t + \hat{\pi}_t^*\right) + \omega_t^r\right]$

All variables are per capita log-deviations from steady state.
r = nominal interest rate, i = investment, π^N = non-tradable inflation,
π^w = nominal wage inflation, π^T = Tradable Inflation, w = real wage,
q = Real Exchange Rate, p_N = Relative Non-tradable prices, p_T = Relative Tradable Prices, $b^{y,f}$ = foreign debt,
c = consumption, y = GDP, m = imports, g = government, mrs = Marginal Rate of Substitution, c_X = exports.
n = Labour, $\widetilde{tfp}$ = Total Factor Productivity, P_X = Export Prices,
P_M = Wholesale Import Prices, $p_{X,t}$ = Export Prices, y^* = Foreign GDP,
ω^y = temporary productivity changes,
λ^i = Markup Shocks, ω^i = Other shocks,
E_t preceding variables represent expectations taken at time t

Table 2: Measurement equations

Observable	**Model variables**
Output growth	$y_t - y_{t-1} + \Delta tfp_t$
Consumption growth	$c_t - c_{t-1} + \Delta tfp_t$
Export growth	$x_t - x_{t-1} + \Delta tfp_t$
Interest Rate	$4 * (r_t + r + \pi + \Delta tfp_t(\sigma - 1) + 100(1/\beta - 1))$
Wage inflation	$\pi_t^w + \pi^w + \pi + \Delta tfp_t + e_{w,t}^m$
CPI Inflation	$\pi_t + \pi + e_{P,t}^m$
Domestic inflation	$\pi_{D,t} + \pi_D + e_{D,t}^m$
Change in the exchange rate	$q_t - q_{t-1} - \pi_{D,t} + p_t^*$
Growth in the Terms of trade	$\pi_t^x - \pi_{m,t}^* + \bar{tot}$

Table 3: Prior and Posterior distributions

Parameter	**Symbol**	**Prior distribution**	**Posterior mean**	**Prob. interval**
Productivity Growth	$\widetilde{\Delta tfp}$	$\Gamma(0.40, 0.10)$	0.32	[0.24, 0.39]
Consumption Habit Parameter	χ_c	$\beta(0.40, 0.05)$	0.47	[0.41, 0.54]
Domestic Sector Indexation Parameter	γ_N	$\beta(0.50, 0.10)$	0.35	[0.21, 0.48]
Tradable Sector Indexation Parameter	γ_T	$\beta(0.50, 0.10)$	0.39	[0.24, 0.54]
Wage Indexation Parameter	γ_W	$\beta(0.50, 0.10)$	0.33	[0.18, 0.47]
Export Sector Indexation Parameter	γ_X	$\beta(0.50, 0.10)$	0.49	[0.33, 0.64]
Tradable Price Elasticity of Demand	η	$\Gamma(1.50, 1.00)$	1.65	[0.79, 2.45]
Import Price Elasticity of Demand	η_T	$\Gamma(1.50, 1.00)$	0.52	[0.10, 0.91]
Export Price Elasticity of Demand	η_X	$\Gamma(1.00, 0.10)$	0.81	[0.68, 0.94]
Central Bank Output Growth Parameter	$\phi_{\Delta y}$	$N(0.15, 0.10)$	0.08	[-0.07, 0.24]
Central Bank Inflation Parameter	ϕ_π	$\Gamma(2.00, 0.10)$	1.99	[1.82, 2.15]
Central Bank Exchange Rate Parameter	ϕ_s	$N(0.15, 0.10)$	-0.01	[-0.06, 0.03]
Central Bank Output Parameter	ϕ_y	$N(0.15, 0.10)$	0.25	[0.15, 0.36]
Persistence of Preference Shock	ϱ_c	$\beta(0.50, 0.10)$	0.46	[0.31, 0.61]
Persistence of Government Spending	ϱ_g	$\beta(0.50, 0.10)$	0.83	[0.77, 0.90]
Persistence of Import Price Shock	$\varrho_{p_m^*}$	$\beta(0.50, 0.10)$	0.54	[0.37, 0.72]
Persistence of Domestic cost-push shock	ϱ_N	$\beta(0.50, 0.10)$	0.33	[0.21, 0.46]
Persistence of Tradable Cost-Push Shock	ϱ_T	$\beta(0.50, 0.10)$	0.46	[0.31, 0.61]
Persistence of Export Price Shock	ϱ_X	$\beta(0.50, 0.10)$	0.55	[0.40, 0.69]
Persistence of Monetary Policy Shock	ϱ_r	$\beta(0.50, 0.10)$	0.52	[0.39, 0.65]
Interest Rate Smoothing	ρ_r	$\beta(0.75, 0.05)$	0.81	[0.76, 0.86]
Persistence of Exchange Rate Shock	ϱ_q	$\beta(0.50, 0.10)$	0.66	[0.55, 0.77]
Persistence of Total Factor Productivity Shock	$\varrho_{\widetilde{tfp}}$	$\beta(0.50, 0.10)$	0.52	[0.35, 0.69]
Persistence of Wage Cost-Push Shock	ϱ_w	$\beta(0.50, 0.10)$	0.32	[0.19, 0.44]
Persistence of Foreign Demand Shock	ϱ_{y^*}	$\beta(0.50, 0.10)$	0.94	[0.92, 0.97]
Inverse Frisch Elasticity	σ_n	$\Gamma(2.00, 1.00)$	1.39	[0.73, 2.04]
Standard Deviation of Preference Shock	ϵ_c	$\Gamma^{-1}(0.10, 2.00)$	2.54	[1.40, 3.63]
Standard Deviation of Government Spending	ϵ_g	$\Gamma^{-1}(0.10, 2.00)$	3.24	[2.24, 4.23]
Standard Deviation of CPI Measurement Error	ϵ_P	$\Gamma^{-1}(0.00, 2.00)$	0.16	[0.10, 0.21]
Standard Deviation of Import Price Shock	$\epsilon_{p_m^*}$	$\Gamma^{-1}(0.10, 2.00)$	0.88	[0.55, 1.20]
Standard Deviation of Domestic Cost-push shock	ϵ_N	$\Gamma^{-1}(0.10, 2.00)$	0.12	[0.08, 0.15]
Standard Deviation of Domestic Price Measurement Error	ϵ_N	$\Gamma^{-1}(0.00, 2.00)$	0.03	[0.01, 0.06]
Standard Deviation of Tradable Cost-push shock	ϵ_T	$\Gamma^{-1}(0.10, 2.00)$	0.12	[0.08, 0.17]
Standard Deviation of Export Price Shock	ϵ_X	$\Gamma^{-1}(0.10, 2.00)$	0.37	[0.18, 0.55]
Standard Deviation of Monetary Policy shock	ϵ_r	$\Gamma^{-1}(0.10, 2.00)$	0.11	[0.08, 0.14]
Standard Deviation of Exchange Rate Shock	ϵ_q	$\Gamma^{-1}(0.10, 2.00)$	0.87	[0.48, 1.24]
Standard Deviation of Total Factor Productivity Shock	$\epsilon_{\widetilde{\Delta tfp}}$	$\Gamma^{-1}(0.03, 2.00)$	0.14	[0.06, 0.22]
Standard Deviation of Wage cost-push Shock	ϵ_W	$\Gamma^{-1}(0.10, 2.00)$	0.12	[0.07, 0.19]
Standard Deviation of Wage Measurement Error	ϵ_W	$\Gamma^{-1}(0.00, 2.00)$	0.24	[0.10, 0.39]
Standard Deviation of Foreign Demand Shock	ϵ_{y^*}	$\Gamma^{-1}(0.10, 2.00)$	1.67	[1.15, 2.17]
UIP Smoother	ψ_{uip}	$\beta(0.50, 0.10)$	0.53	[0.40, 0.67]
Domestic Price Adjustment Cost	$\frac{1}{\psi_N}$	$\Gamma(200^{-1}, 800^{-1})$	205^{-1}	$[144^{-1}, 350^{-1}]$
Tradable Sector Price Adjustment Cost	$\frac{1}{\psi_T}$	$\Gamma(200^{-1}, 600^{-1})$	769^{-1}	$[503^{-1}, 1643^{-1}]$
Wage Adjustment Cost	$\frac{1}{\psi_W}$	$\Gamma(200^{-1}, 800^{-1})$	249^{-1}	$[178^{-1}, 427^{-1}]$
Import Price Adjustment Cost	$\frac{1}{\psi_X}$	$\Gamma(200^{-1}, 800^{-1})$	229^{-1}	$[167^{-1}, 366^{-1}]$

Table 5: Standard Deviations

Variables	Data [5 95]	Model [5 95]
Interest Rates	2.04	1.52
	[1.37,2.84]	[1.01,2.37]
CPI Inflation	0.35	0.26
	[0.3,0.41]	[0.2,0.35]
Domestic Inflation	0.32	0.24
	[0.28,0.37]	[0.19,0.34]
Wage Inflation	0.53	0.3
	[0.46,0.6]	[0.24,0.49]
Exchange Rate Growth	3.91	2.36
	[3.37,4.44]	[1.54,3.62]
GDP Growth	0.75	0.97
	[0.65,0.86]	[0.78,1.31]
Consumption Growth	0.85	0.92
	[0.74,0.98]	[0.7,1.39]
Export Growth	2.33	1.64
	[2,2.62]	[1.27,2.26]

Table 6: Comparing the importance of the model's features

	Base	$\chi_c = 0$	$uip = 0$	$\gamma_W = 0$ $\psi_W = 0.01$	$\gamma_T = 0$ $\psi_T = 0.01$	$\gamma_N = 0$ $\psi_N = 0.01$	χ_n	υ	Adaptive Expectations
	Marginal likelihood								
	-772	-804	-787	-832	-923	-781	-788	-771	-761
	Mode of the estimated parameters								
$\Delta\widetilde{tfp}$	0.28	0.27	0.28	0.36	0.29	0.32	0.28	0.27	0.36
υ	0	0	0	0	0	0	0	0.32	0
χ_n	0	0	0	0	0	0	0.19	0	0
χ_c	0.46	0	0.47	0.32	0.48	0.46	0.49	0.49	0.48
σ_n	1.16	0.38	1.13	0.25	1.02	1.5	1.04	0.73	1.91
η	1.56	1.89	1.27	0.66	0.39	2.93	1.71	1.96	1.67
η_T	0.41	0.32	0.7	0.89	0.52	0.29	0.38	0.38	0.49
η_X	0.82	0.8	0.82	1.03	0.83	0.81	0.82	0.82	0.8
γ_W	0.23	0.24	0.23	0	0.22	0.34	0.23	0.24	0.31
γ_X	0.49	0.49	0.47	0.43	0.44	0.51	0.5	0.51	0.49
γ_N	0.36	0.35	0.36	0.35	0.38	0	0.38	0.38	0.41
γ_T	0.4	0.39	0.4	0.38	0	0.4	0.4	0.41	0.49
ψ_W	261.01	209.61	271.12	0.01	273.37	308.01	273.89	275.77	198.41
ψ_N	250.91	265.05	245.62	321.11	263.83	0.01	251.01	250.68	255.44
ψ_T	868.82	848	857.68	5585.31	0.01	1059.36	856.61	896.44	452.96
ψ_X	246.61	249.31	224.06	374.46	209.13	247.71	243.49	244.97	252.68
ϕ_π	1.99	1.98	2	2	1.94	1.98	1.99	2	1.97
ϕ_y	0.21	0.22	0.23	0.12	0.3	0.3	0.21	0.1	0.23
ϕ_s	-0.01	0	0.02	0	-0.16	-0.02	-0.01	0	0.02
$\phi_{\Delta y}$	0.1	0.08	0.12	0.06	0.2	0.1	0.1	0.2	0.1
ρ_r	0.81	0.77	0.81	0.83	0.83	0.79	0.82	0.8	0.78
ψ_{uip}	0.52	0.53	0	0.56	0.48	0.54	0.52	0.54	0.52
ϱ_r	0.55	0.43	0.56	0.51	0.57	0.53	0.55	0.52	0.5
ϱ_q	0.69	0.65	0.83	0.73	0.7	0.7	0.68	0.65	0.74
ϱ_c	0.45	0.85	0.43	0.64	0.46	0.47	0.48	0.73	0.38
ϱ_N	0.34	0.35	0.33	0.37	0.33	0.5	0.36	0.37	0.33
ϱ_T	0.44	0.45	0.45	0.47	0.5	0.46	0.45	0.46	0.46
ϱ_w	0.24	0.23	0.24	0.5	0.25	0.31	0.25	0.25	0.22
ϱ_{y^*}	0.95	0.96	0.95	0.56	0.95	0.94	0.95	0.96	0.95
ϱ_X	0.58	0.57	0.6	0.72	0.57	0.6	0.59	0.59	0.58
$\varrho_{p_m^*}$	0.55	0.54	0.57	0.94	0.7	0.56	0.56	0.55	0.55
$\varrho_{\widetilde{tfp}}$	0.52	0.48	0.53	0.49	0.48	0.48	0.5	0.48	0.5
ϱ_g	0.83	0.81	0.86	0.86	0.87	0.79	0.81	0.79	0.84