Yield Curve and Monetary Policy Expectations in Small Open Economies[*]

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Abstract

This paper estimates a New Keynesian dynamic stochastic general equilibrium (DSGE) model in small open economies using the yield curve data as well as standard macro data. The DSGE model is estimated on the data of three inflation-targeting small open economies (Australia, Canada, and New Zealand) using Bayesian methods. We find that the long-end of the yield curve is highly correlated with the current and future short-term interest rates determined by domestic central banks. Yield curve data are particularly informative about the future stance of monetary policy in Australia and Canada in that the correlation between the model-implied monetary policy expectations and the ex-post realized policy interest rates increases when the yield curve data are used in estimation. Unlike the estimation results solely based on the macro data that imply the cental bank's relatively strong focus on inflation stabilization, our results using yield curve information suggest that even inflation-targeting central banks have a significant concern for output stabilization. We also document that persistent domestic shocks, not foreign disturbances, drive the average level of the yield curve in these three countries.

Keywords: a dynamic general equilibrium model, a small open economy model, yield curve, monetary policy expectations

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1 Introduction

The yield curve[1] contains information on the future evolution of the short-term interest rate perceived by financial market participants. Such information might be useful to better understand monetary policy transmission channels because long-term interest rates matter more in the decision over consumption and investment made by households and firms. It is particularly important for small open economy central banks to understand this connection between the short-end of the yield curve, primarily determined by monetary policy, and the long-end of the yield curve, determined by financial markets, since foreign variables that cannot be influenced by their actions may intervene in this transmission channel.

This paper aims to study information on monetary policy expectations embedded in the yield curve using a DSGE model with standard monetary policy transmission mechanism in small open economies. The core of our DSGE model is a standard small open economy model in the New Keynesian tradition. We extend this otherwise standard small open economy DSGE model to include the yield curve data by deriving solutions for arbitrage-free bond yields at different maturities based on equilibrium conditions of the DSGE model. Our DSGE model is taken to the yield curve data as well as the major macroeconomic data of Australia, Canada, and New Zealand using Bayesian methods. To rule out structural changes in the conduct of monetary policy, we use data after the adoption of the inflation targeting regime in these countries.

In this paper, we address two main questions regarding the conduct of monetary policy in inflation-targeting small open economies. First, we try to see if the standard monetary policy transmission channel from the short-rate to long-term interest rates is still effective in these economies. In other words, is the long-end of the yield curve connected to the expectations of the future monetary policy actions on the short-term interest rate? Second, do inflation-targeting central banks in three countries solely focus on inflation stabilization or do they have a significant concern for other objectives such as output and exchange rate stabilization? While the literal interpretation of strict inflation targeting implies that central banks only care for inflation stabilization, in practice they keep some room for maneuvering in order to achieve additional goals like output stabilization. In particular, the three central banks in our study express their inflation target in terms of a band rather than a single number. Such flexibility may allow central banks to take actions when there is a short-run tradeoff between inflation stabilization and output stabilization.

Using the yield curve data directly in the estimation of a DSGE model in which the central bank's response function is explicitly modeled can help us to answer these questions. Our main result is that the long end of the yield curve is significantly affected by expectations of monetary policy actions of central banks in all three countries. In this sense, we find evidence to support the view that a standard monetary policy transmission channel from the short-rate to long-term interest rates can be effective in small open economies. In particular, including the yield curve data in estimation better aligns the model-implied expectations of the future short-term interest rates with the ex-post realized ones in Australia and Canada. Such a pattern is not strongly observed in New Zealand but this is because

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[1] We use the yield curve and the term structure of interest rates interchangeably in this paper.

the level of the short-rate itself is very highly correlated with long-term interest rates. Therefore, the current level of the short-term interest rate provides sufficient information on the future stance of monetary policy in New Zealand. Regarding the preference of central banks, we find that the estimated policy rule with term structure data contains a significant concern for minimizing output variability in all the three countries even though central banks adopted inflation targeting. However, central banks in the three countries are much less concerned for exchange rate stabilization when the yield curve data are included although we still observe a small positive monetary policy response to exchange rate fluctuations in Australia.

Our paper is related to the literature on the small open economy model of monetary policy transmission mechanisms. Gali and Monacelli (2005) build on a closed-economy model with nominal price rigidities and extend it to model a small open economy while Monacelli (2005) introduces an incomplete exchange rate pass-through on import prices into a small open economy model. Lubik and Schorfheide (2007) estimate a model for small open economies including Australia, Canada and New Zealand and using Bayesian model comparison find that central banks of Canada did respond to the nominal exchange rate while the central bank of Australia and New Zealand did not. Justiniano and Preston (2010) study the problem of optimal monetary policy based on an estimated small open economy model for Australia, Canada and New Zealand. Kam et al. (2009) back out preferences of three small open economy central banks by estimating DSGE models in which central banks set policy optimally. They find little evidence for output and exchange rate stabilization but conclude that central banks care for minimizing inflation and nominal interest rate variability. Our paper shares many features documented in these papers but the use of term structure data in estimation distinguishes our paper from them.

Our paper is also related to the literature using the yield curve data in the estimation of a DSGE model. De Graeve et al. (2009) estimate a medium-scale DSGE model with the U.S. yield curve data as well as macro data and argue that the variation in long-term interest rates is well explained by monetary policy expectations derived from the model. Doh (2012) shows that long-run inflation expectations from a DSGE model are more highly correlated with the survey data when the term structure data are included in the estimation of the DSGE model. Our paper is different from these studies in that we use a small open economy model rather than a large closed economy model. Kulish and Rees (2011), who estimate a small open economy model with term structure data, is closest to our paper. However, their model is way more stylized than ours abstracting from more realistic features in terms of the specification of shocks and frictions. Unlike Kulish and Rees (2011), we introduce multiple real and nominal disturbances and incorporate realistic frictions such as local currency pricing and incomplete international risk sharing.

The rest of the paper is organized as follows. Section 2 describes the small open economy DSGE model used in estimation. It is followed by Section 3 that explains how we derive equilibrium bond yields from the solution of the DSGE model. We present and discuss the empirical results in Section 4 and conclude in Section 5.

2 Model

Our model extends the New Keynesian framework for the closed-economy by, for example, Woodford (2003) to a small open economy. The model consists of a small open economy and the rest of the world. The rest of the world is modeled like a single country and we often refer to it as a foreign country in the paper. The small open economy is negligibly small in size relative to the rest of the world. Below, we describe the model from the perspective of the small open economy. Therefore, "domestic" implies the small open economy.

The main features of the model are the following. First, the law of one price for imported goods does not hold in general in the small open economy while it holds at the dock. There are importers in the small open economy who import foreign intermediate goods and sell them to the imported good retailers within the same small open economy. The importers are monopolistically competitive and can set prices of imported goods, which leads to the breakdown of the law of one price. As a result, the model features incomplete pass-through of exchange rates. Second, risk sharing is complete for domestic risks of the small open economy but not for foreign risks. We assume that agents of the small open economy can trade state-contingent assets with which they can insure against domestic shocks while only non-state contingent nominal bonds are traded internationally. Also, the model includes a debt-elastic risk premium shock. Third, we do not consider endogenous capital accumulation for comparison with the literature and simplicity.

The model is similar to Justiniano and Preston (2010), which is closely related to Monacelli (2005) and Gali and Monacelli (2005). We add additions source of real rigidity and more real and nominal disturbances to the model in Justiniano and Preston (2010). In our model, the labor market is segmented and households supply firm-specific labor, a domestic cost-push shock produces exogenous variations in domestic inflation, and the monetary policy rule assumes a time-varying inflation target.

Finally, the model is augmented to include the term structure of domestic nominal bond yields. Using no-arbitrage conditions that involve the stochastic discount factor of the households of the small open economy, we derive equations that determine the term structure of domestic nominal bond yields. We abstract from default-risk by considering only government bond yields.

2.1 Households

The small open economy is populated by a continuum of identical households on a unit interval $[0, 1]$. Each household consumes a basket of domestic and imported goods and supplies a type of labor to domestic firms that is specific for production of a particular intermediate good.

Household $i \in [0, 1]$ maximizes the expected discounted sum of utilities

$$E_0 \sum_{t=0}^{\infty} \beta^t u_{b,t} \left[\log \left(C_t \left(i \right) - h C_{t-1} \right) - \frac{N_t \left(i \right)^{\varphi+1}}{\varphi + 1} \right], \tag{1}$$

where $C_t(i)$ is the consumption basket and $N_t(i)$ is the labor supply by household i.[2] The consump-

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[2] We assume the limiting cashless economy as in Woodford (2003) and do not include money in the model.

tion basket $C_t(i)$ is a constant-elasticity-of-substitution (CES) aggregate of the domestic final good $C_{H,t}(i)$ and the foreign final good $C_{F,t}(i)$

$$C_t(i) = \left[(1-\alpha)^{\frac{1}{\eta}} (C_{H,t}(i))^{1-\frac{1}{\eta}} + \alpha^{\frac{1}{\eta}} (C_{F,t}(i))^{1-\frac{1}{\eta}}\right]^{\frac{\eta}{\eta-1}},$$

where η is the elasticity of intratemporal substitution between the domestic goods and the foreign goods and α is the steady state share of foreign goods in the consumption basket. In particular, $\alpha < 1/2$ implies that there exists a home bias in consumption. Note that we assume that all goods are tradable. Since the household optimally allocates expenditures to purchase the consumption basket, the demand for each final good by household i is determined as

$$C_{H,t}(i) = (1-\alpha)\left(\frac{P_{H,t}}{P_t}\right)^{-\eta} C_t(i),$$

and

$$C_{F,t}(i) = \alpha\left(\frac{P_{F,t}}{P_t}\right)^{-\eta} C_t(i),$$

where $P_{H,t}$ and $P_{F,t}$ are the price index for the domestic and foreign final good, respectively, and P_t denotes the price index of a unit of the consumption basket or the consumer price index (CPI). The CPI is determined as

$$P_t = \left[(1-\alpha) P_{H,t}^{1-\eta} + \alpha P_{F,t}^{1-\eta}\right]^{\frac{1}{1-\eta}}. \tag{2}$$

The term C_{t-1} in (1) is aggregate consumption and hC_{t-1} represents external habit in consumption with the degree of habit formation parameter $0 < h < 1$. The variable $u_{b,t}$ represents a preference shock that disturbs intertemporal decision by the household and evolves as

$$u_{b,t} = u_{b,t-1}^{\rho_b} \exp(\varepsilon_{b,t}), \tag{3}$$

where $0 < \rho_b < 1$ and $\varepsilon_{b,t} \sim N(0, \sigma_b^2)$. The parameters β and φ are the subjective discount rate and the inverse of the Frisch labor supply elasticity, respectively.

The utility maximization by household i is subject to the following flow budget constraint

$$\begin{aligned} & P_t C_t(i) + D_t(i) + S_t B_t(i) + E_t[Q_{t,t+1} V_{t+1}(i)] + P_t T_t \\ = \; & D_{t-1}(i) R_{1,t-1} + S_t B_{t-1}(i) R_{1,t-1}^{*} \phi(a_{t-1}) + V_t(i) + W_t(i) N_t(i) + \Xi_{H,t} + \Xi_{F,t}, \end{aligned}$$

for all $t \geq 0$, where $W_t(i)$ is the nominal wage for type-i labor, $\Xi_{H,t}$ and $\Xi_{F,t}$ are profits distributed by domestic intermediate good producers and importers of foreign goods, and T_t is the lump-sum taxes net of transfers from the government.

The households trade domestic and foreign bonds: $D_t(i)$ and $B_t(i)$ are the holdings of domestic and foreign bonds by household i with gross one-period nominal interest rates $R_{1,t}$ and $R_{1,t}^{*}$, respectively. The foreign bonds are denominated in the foreign currency and converted to the domestic currency by the nominal exchange rate S_t. That is, S_t is the domestic currency price of a unit of the foreign currency. In addition to domestic and foreign bonds, each household trades state contingent nominal securities $V_{t+1}(i)$ at a price $Q_{t,t+1}$. The state contingent security however does not insure against foreign shocks and the risk premium shock described below. Therefore, all the households are insured against the domestic idiosyncratic risk but not against the risk due to foreign shocks and the risk premium shock.

In order to ensure the stationarity of the foreign debt level, we introduce, as in Schmitt-Grohe and Uribe (2003) and others, a debt-elastic interest rate premium by a function

$$\phi(a_{t-1}) = \exp\left(\tilde{\phi}_a a_{t-1} + u_{\phi,t-1}\right),$$

where $\tilde{\phi}_a > 0$,

$$a_{t-1} = -\frac{S_{t-1}B_{t-1}}{\bar{y}P_{t-1}Z_{t-1}},$$

is the real outstanding foreign debt as a fraction of steady state growth-adjusted or detrended output $\bar{y}$, and Z_t is the productivity shock that grows over time and thus induces exogenous growth of the small open economy. We describe the process of Z_t later. As the small open economy accumulates more foreign debt in terms of the domestic currency, it has to pay a higher risk premium. The risk premium is exogenously perturbed by a shock $u_{\phi,t}$ that follows

$$u_{\phi,t} = \rho_\phi u_{\phi,t-1} + \varepsilon_{\phi,t}, \tag{4}$$

where $0 < \rho_\phi < 1$ and $\varepsilon_{\phi,t} \sim N\left(0, \sigma_\phi^2\right)$.

2.2 Domestic good producers and exporters

2.2.1 Domestic final good producers

The domestic final good producers in the small open economy purchase a variety of domestic intermediate goods $Y_{H,t}(j)$ with $j \in [0,1]$ and pack them into the domestic final good with the technology

$$Y_{H,t} = \left[\int_0^1 Y_{H,t}(j)^{1-\frac{1}{\epsilon_t}} dj\right]^{\frac{\epsilon_t}{\epsilon_t - 1}}, \tag{5}$$

where $\epsilon_t > 1$ is a time-varying elasticity of intratemporal substitution among a variety of domestic intermediate goods. We define $u_{\epsilon,t} = \epsilon_t/(\epsilon_t - 1)$ and assume that

$$u_{\epsilon,t} = \bar{u}_\epsilon^{1-\rho_\epsilon} u_{\epsilon,t-1}^{\rho_\epsilon} \exp(\varepsilon_{\epsilon,t}),$$

where $\bar{u}_\epsilon = \bar{\epsilon}/(\bar{\epsilon} - 1)$, $0 < \rho_\epsilon < 1$ and $\varepsilon_{\epsilon,t} \sim N\left(0, \sigma_\epsilon^2\right)$. The parameter $\bar{\epsilon}$ is the steady state value of ϵ_t. There are a continuum of perfectly competitive, identical final good producers with measure one. With the final good producers optimally purchasing intermediate goods, the demand for domestic intermediate good j is determined as

$$Y_{H,t}(j) = \left(\frac{P_{H,t}(j)}{P_{H,t}}\right)^{-\epsilon_t} Y_{H,t}, \tag{6}$$

where $P_{H,t}(j)$ is the price of domestic intermediate good j. The price of the domestic final good is determined as

$$P_{H,t} = \left[\int_0^1 P_{H,t}(j)^{1-\epsilon_t}\, dj\right]^{\frac{1}{1-\epsilon_t}}. \tag{7}$$

Part of the domestic final goods is consumed by domestic households and the government and the rest is exported to the rest of the world.

2.2.2 Exporters

There are a continuum of perfectly competitive exporters who purchase the domestic final goods and export them to the rest of the world. They face the following demand function

$$C^*_{H,t} = \tilde{c}^*_H \left(\frac{P^*_{H,t}}{P^*_t}\right)^{-\eta} Y^*_t,$$

where $P^*_{H,t}$ is the foreign-currency price of the exports, P^*_t is the CPI in the rest of the world and $\tilde{c}^*_H$ is a constant to calibrate the steady state value of $C^*_{H,t}/Y_t$ to the data. The price elasticity of the demand is assumed identical to that for the small open economy. Since the small open economy is negligible in size relative to the rest of the world, the consumption of the small open economy's goods is negligible. We assume that the demand depends on output in the rest of the world. The exporters set the price in the domestic currency and thus

$$P^*_{H,t} = P_{H,t}/S_t.$$

It follows that

$$C^*_{H,t} = \tilde{c}^*_H \left(\frac{P_{H,t}}{S_t P^*_t}\right)^{-\eta} Y^*_t. \tag{8}$$

2.2.3 Domestic intermediate good producers

A continuum of firms on a unit interval $[0,1]$ produce differentiated intermediate goods. An intermediate-good producer $j \in [0,1]$ has a production technology

$$Y_{H,t}(j) = Z_t N_t(j), \tag{9}$$

where $N_t(j)$ is input of type-j labor. Let us define $u_{z,t} = Z_t/Z_{t-1}$, the growth rate of Z_t, with the steady state value $\bar{u}_z$. We assume that $u_{z,t}$ follows

$$u_{z,t} = (\bar{u}_z)^{1-\rho_z} u^{\rho_z}_{z,t-1} \exp(\varepsilon_{z,t}),$$

where $0 < \rho_z < 1$ and $\varepsilon_{z,t} \sim N\left(0, \sigma_z^2\right)$.

Since these differentiated goods are imperfect substitutes in the final good production as shown in (5), intermediate good producers are monopolistically competitive and have some market power over goods they produce. We introduce nominal price rigidities by following Calvo (1983) and Yun (1996) and assuming that a fraction $0 < \theta_H < 1$ of the intermediate-good producers cannot adjust their prices optimally in a given period. Instead, such a producer ι simply resets the price according to the indexation rule

$$P_{H,t}(\iota) = P_{H,t-1}(\iota)\,\Pi_{H,t-1}^{\gamma_H}\bar{\Pi}_H^{1-\gamma_H},$$

where $\Pi_{H,t} = P_{H,t}/P_{H,t-1}$ is the gross inflation rate of the price index of the domestic final good, $\bar{\Pi}_H$ is its steady state level, and $0 < \gamma_H < 1$ governs the extent of indexation to the past inflation rate. A producer j who can reset its price chooses a price $\tilde{P}_{H,t}(j)$ to maximize the present value of current and future profits

$$E_t \sum_{k=0}^{\infty} \theta_H^k Q_{t,t+k} \left[\tilde{P}_{H,t}(j)\,\Upsilon_{H,t,k} - \frac{W_{t+k}(j)}{u_{z,t+k}}\right] Y_{H,t+k}(j),$$

where $Q_{t,t+k} = \prod_{s=0}^{k-1} Q_{t+s,t+1+s}$ and

$$\Upsilon_{H,t,k} = \begin{cases} \left(\Pi_{H,t}\Pi_{H,t+1}\cdots\Pi_{H,t+k-1}\right)^{\gamma_H}\bar{\Pi}_H^{(1-\gamma_H)k}, & k > 0, \\ 1, & k = 0, \end{cases}$$

subject to the demand for intermediate good j

$$Y_{H,t+k}(j) = \left(\frac{\tilde{P}_{H,t}(j)\,\Upsilon_{H,t,k}}{P_{H,t+k}}\right)^{-\epsilon_{t+k}} Y_{H,t+k},$$

for $k \geq 0$.

We consider symmetric equilibirum where all the producers who reset prices choose a common price $\tilde{P}_{H,t} = \tilde{P}_{H,t}(j)$. Then, (7) leads to

$$P_{H,t} = \left[\theta_H \left(P_{H,t-1}\Pi_{H,t-1}^{\gamma_H}\bar{\Pi}_H^{1-\gamma_H}\right)^{1-\epsilon_t} + (1-\theta_H)\left(\tilde{P}_{H,t}\right)^{1-\epsilon_t}\right]^{\frac{1}{1-\epsilon_t}}. \tag{10}$$

2.3 Imported good retailers and importers

2.3.1 Imported good retailers

Foreign intermediate goods are imported by importers and sold to domestic retail firms that supply those to the domestic market. The retail firms purchase a variety of imported intermediate goods from importers and pack them into the foreign final good with the technology

$$Y_{F,t} = \left[\int_0^1 Y_{F,t}(j)^{1-\frac{1}{\epsilon_t^*}}\,dj\right]^{\frac{\epsilon_t^*}{\epsilon_t^*-1}}, \tag{11}$$

where $\epsilon_t^* > 1$ is a time-varying elasticity of intratemporal substitution among differentiated imported goods. We define $u_{\epsilon^*,t} = \epsilon_t^* / (\epsilon_t^* - 1)$ and assume that

$$u_{\epsilon^*,t} = \bar{u}_{\epsilon^*}^{1-\rho_{\epsilon^*}} u_{\epsilon^*,t-1}^{\rho_{\epsilon^*}} \exp(\varepsilon_{\epsilon^*,t}),$$

where $\bar{u}_{\epsilon^*} = \bar{\epsilon}^* / (\bar{\epsilon}^* - 1)$, $0 < \rho_{\epsilon^*} < 1$ and $\varepsilon_{\epsilon^*,t} \sim N(0, \sigma_{\epsilon^*}^2)$. The parameter $\bar{\epsilon}^*$ is the steady state value of ϵ_t^*, which is assumed to be equal to $\bar{\epsilon}$. There are a continuum of identical, perfectly-competitive retail firms with measure one. The demand for imported intermediate good j is determined as

$$Y_{F,t}(j) = \left(\frac{P_{F,t}(j)}{P_{F,t}} \right)^{-\epsilon_t^*} Y_{F,t}, \tag{12}$$

where $P_{F,t}(j)$ is the price of imported intermediate good j and $P_{F,t}$ is the price of the foreign final good which is determined as

$$P_{F,t} = \left[\int_0^1 P_{F,t}(j)^{1-\epsilon_t^*} dj \right]^{\frac{1}{1-\epsilon_t^*}}. \tag{13}$$

2.3.2 Importers

A continuum of firms on a unit interval $[0,1]$ import differentiated intermediate goods from the rest of the world. Since these differentiated imported goods are imperfect substitutes for the production of the foreign final good as shown in (11), the importers are monopolistically competitive and have some market power over goods they supply to the imported good retailers. It follows that the importers can set the domestic currency price of the intermediate goods they import. This is simply a modeling device to introduce incomplete pass-through of exchange rates. As a result, exchange rate fluctuations do not pass through immediately and the law of one price does not hold in general. Note that the law of one price (LOOP) holds at the dock in terms of the foreign (producer) currency.

The unit cost of imported intermediate goods in the domestic (local) currency is $S_t P_{F,t}^*(j)$ where $P_{F,t}^*(j)$ is the price of imported intermediate good j in the foreign currency. For simplicity, we follow Monacelli (2005) and assume that the price of the imported intermediate good is the same as $P_{F,t}^*$ across different j's. In addition, as the exports of the small open economy to the rest of the world accounts for a negligible fraction of its consumption basket, we have that $P_{F,t}^* = P_t^*$. In sum, the real marginal cost of imported intermediate good j can be written as

$$\frac{S_t P_{F,t}^*(j)}{P_t} = \frac{S_t P_t^*}{P_t} \equiv e_t, \tag{14}$$

where e_t is the real exchange rate.

Furthermore, we introduce nominal price rigidities in a similar way for the domestic intermediate good producers. A fraction $0 < \theta_F < 1$ of the importers cannot adjust its good's price optimally in a given period. Such an importer ι simply resets the price according to the indexation rule

$$P_{F,t}(\iota) = P_{F,t-1}(\iota) \Pi_{F,t-1}^{\gamma_F} \bar{\Pi}_F^{1-\gamma_F},$$

where $\Pi_{F,t} = P_{F,t}/P_{F,t-1}$ is the gross inflation rate of the price index of the foreign final good, $\bar{\Pi}_F$ is its steady state level, and $0 < \gamma_F < 1$ governs the extent of indexation to the past inflation rate. An importer j who can reset its price chooses a price $\tilde{P}_{F,t}(j)$ to maximize the present value of current and future profits

$$E_t \sum_{k=0}^{\infty} \theta_F^k Q_{t,t+k} \left[\tilde{P}_{F,t} \Upsilon_{F,t,k} - e_{t+k} P_{t+k} \right] Y_{F,t+k}(j),$$

where $Q_{t,t+k} = \prod_{s=0}^{k-1} Q_{t+s,t+1+s}$,

$$\Upsilon_{F,t,k} = \begin{cases} (\Pi_{F,t}\Pi_{F,t+1} \cdots \Pi_{F,t+k-1})^{\gamma_F} \bar{\Pi}_F^{(1-\gamma_F)k}, & k > 0, \\ 1, & k = 0. \end{cases}$$

The profit maximization problem is subject to the demand for imported intermediate good j given in (12).

We again consider symmetric equilibrium where all firms who can reset their prices choose a common price $\tilde{P}_{F,t} = \tilde{P}_{F,t}(j)$, which leads to

$$P_{F,t} = \left[\theta_F \left(P_{F,t-1} \Pi_{F,t-1}^{\gamma_F} \bar{\Pi}_F^{1-\gamma_F} \right)^{1-\epsilon_t^*} + (1-\theta_F) \left(\tilde{P}_{F,t} \right)^{1-\epsilon_t^*} \right]^{\frac{1}{1-\epsilon_t^*}}. \tag{15}$$

2.4 Government

We assume a simple fiscal policy: the government expenditure along the balanced growth path of the small open economy is an exogenous stochastic process,

$$u_{g,t} = \bar{u}_g^{1-\rho_g} u_{g,t-1}^{\rho_g} \exp(\varepsilon_{g,t}), \tag{16}$$

with $0 < \rho_g < 1$ and $\varepsilon_{g,t} \sim N(0, \sigma_g^2)$. The steady state value of $u_{g,t}$ is $\bar{u}_g$. Note that the actual government expenditure is given by $G_t = u_{g,t} \times Z_t$. Also, the fiscal authority collects lump-sum taxes so that the primary surplus is zero every period: $T_t = G_t$. The government consumes only the domestically-produced final good and its consumption is assumed to be completely wasteful. The flow budget constraint for the government is simply[3]

$$D_t + T_t = D_{t-1} R_{1,t-1} + G_t.$$

The monetary authority, or the central bank, adjusts one-period nominal interest rates $R_{1,t}$ according to a Taylor-type rule

$$\frac{R_{1,t}}{\bar{R}_1} = \left(\frac{R_{1,t-1}}{\bar{R}_1} \right)^{\rho_R} \left[\left(\frac{\Pi_t}{\bar{\Pi}_t} \right)^{\psi_\pi} \left(\frac{Y_t/Z_t}{\bar{y}} \right)^{\psi_Y} \left(\frac{S_t/S_{t-1}}{\bar{\Delta S}} \right)^{\psi_S} \right]^{1-\rho_R} \exp(\varepsilon_{R,t}), \tag{17}$$

where $\Pi_t = P_t/P_{t-1}$, $\bar{\Pi}$ is its steady state level, Y_t/Z_t is detrended aggregate output, and $\bar{\Delta S}$ is the

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[3] We extend this budget constraint to include longer-term bonds later.

steady state value of the nominal exchange rate depreciation. The shock $\varepsilon_{R,t}$ captures unexpected deviations of nominal interest rates from the prescribed policy rule, which is assumed to follow $N\left(0,\sigma_R^2\right)$. We augment the standard Taylor-type rule so that the central bank adjusts nominal interest rates in response to the fluctuations of the nominal exchange rate following the findings by Lubik and Schorfheide (2007). However, we allow ψ_S to have zero and negative values as well and use the normal distribution as its prior in order to test their finding in our model.

We incorporate a time-varying inflation target $\tilde{\Pi}_t$ to explain potential low-frequency movements of inflation in our baseline specification. The inflation target evolves as

$$\tilde{\Pi}_t = \bar{\Pi}^{1-\rho_{\tilde{\pi}}}\tilde{\Pi}_{t-1}^{\rho_{\tilde{\pi}}}\exp\left(\varepsilon_{\tilde{\pi},t}\right),$$

with $0 < \rho_\pi < 1$ and $\varepsilon_{\tilde{\pi},t} \sim N\left(0,\sigma_{\tilde{\pi}}^2\right)$. The persistence parameter of the inflation target ρ_π is assumed to be high in the prior distribution as explained in detail later on, which implies that the central bank adjusts its inflation target very persistently. This time-varying inflation target intends to allow for some leeway to achieve the announced target. In all the countries that we analyze, the central banks did not aim to achieve a point of the inflation rate immediately. Rather, they target a band for inflation rates (in Australia and New Zealand) or aimed to achieve an inflation target point gradually in a few years after inflation targeting was announced (in Canada). We also consider two alternative specifications as well with respect to the inflation target where the persistence parameter ρ_π is fixed at 0.995, which means that the inflation target process is close to a unit root process though technically still stationary, and the inflation target is constant all the time.

The parameters ψ_π, ψ_Y and ψ_S represent the strength of the monetary policy reaction to the inflation gap, the output gap, and the nominal exchange rate depreciation, respectively. The central bank adjusts nominal interest rates with inertia by partly pegging to its lagged value with the smoothing parameter $0 < \rho_R < 1$.

2.5 Rest of the World

While Monacelli (2005) specifies the rest of the world as a closed-economy version of the New Keynesian model, Justiniano and Preston (2010) leave the rest of the world exogenous by modelling it as evolving as a vector autoregression (VAR). We follow the latter and specify a VAR with 2 lags for detrended aggregate output $y_t^* = Y_t^*/Z_t$, inflation $\Pi_t^* = P_t^*/P_{t-1}^*$, and gross nominal interest rates $R_{1,t}^*$ for the rest of the world.[4] Let $\xi_t^* = \left(y_t^*, \Pi_t^*, R_{1,t}^*\right)'$. Then

$$\xi_t^* = \left(1-\Phi_1-\Phi_2\right)\bar{\xi} + \Phi_1\xi_{t-1}^* + \Phi_2\xi_{t-2}^* + \begin{pmatrix} 1 & 0 & 0 \\ L_{21} & 1 & 0 \\ L_{31} & L_{32} & 1 \end{pmatrix} u_{\xi,t},$$

---

[4] To improve the empirical fit of our model, we allow foreign aggregate output to grow at a different rate from $\bar{u}_z$, the steady state growth rate of the small open economy, which is incorporated in the measurement equation of our model.

where Φ_1 and Φ_2 satisfy the stationarity condition and the 3×1 vector $u_{\xi,t} \sim N\left(0, \Sigma_{\xi}\right)$ with

$$\Sigma_{\xi} = \begin{pmatrix} \sigma^2_{\xi,y^*} & 0 & 0 \\ 0 & \sigma^2_{\xi,\pi^*} & 0 \\ 0 & 0 & \sigma^2_{\xi,R_1^*} \end{pmatrix}.$$

2.6 International Relative Prices

The terms of trade or the relative price of exports in terms of imports is defined as

$$\tau_t = \frac{P_{H,t}}{P_{F,t}},$$

and the gap of the law of one price is defined as

$$\chi_{F,t} = \frac{S_t P^*_{F,t}}{P_{F,t}}.$$

The real exchange rate is defined as

$$e_t = \frac{S_t P^*_t}{P_t}. \tag{18}$$

2.7 Market clearing conditions

The representative households have identical initial wealth and thus choose identical consumption plans. It follows that

$$\begin{aligned} C_t &= \int_0^1 C_t\left(j\right) dj = C_t\left(i\right), \\ C_{H,t} &= \int_0^1 C_{H,t}\left(j\right) dj = C_{H,t}\left(i\right), \\ C_{F,t} &= \int_0^1 C_{F,t}\left(j\right) dj = C_{F,t}\left(i\right), \end{aligned}$$

for all $i \in [0, 1]$.

For market clearing of domestic intermediate goods, we implicitly assumed that the demand for and supply of a domestic intermediate good match. The supply of the domestic final good is equal to the sum of domestic private and public consumption and exports to the rest of the world

$$Y_{H,t} = C_{H,t} + u_{g,t} Z_t + C^*_{H,t}.$$

Market clearing of the foreign final good requires

$$Y_{F,t} = C_{F,t}.$$

We also implicitly imposed market clearing of imported intermediate goods. Gross domestic product is defined as

$$Y_t = \left(\frac{P_{H,t}}{P_t}\right) Y_{H,t} + \left(\frac{P_{F,t} - P_t e_t}{P_t}\right) Y_{F,t}.$$

For the domestic bond, we assume zero net supply as

$$D_t = \int_0^1 D_t(i)\, di = 0,$$

where we assume that the foreign holdings of the domestic bonds is zero. The domestic holdings of the foreign bond

$$B_t = \int_0^1 B_t(i)\, di,$$

can be non-zero while the net supply of the foreign bonds is zero.

Lastly, we implicitly assumed market clearing of the firm-specific labor market by matching the supply of type-i labor in (1) and the demand for the same type of labor in (9) for all $i \in [0,1]$.

2.8 Model Solution

We consider a symmetric equilibrium where all the domestic intermediate good producers and foreign intermediate good importers set a common price with their relevant peers that update prices. The model equilibrium is a set of the prices and quantities that satisfy optimality conditions of households and firms, the household budget constraint, the government budget constraint and the market clearing conditions given the monetary and fiscal policy rule. In order to study the dynamic properties of the model, we first detrend real variables by normalizing them with the productivity level Z_t, then get the first order accurate approximation to the equilibrium conditions around a deterministic steady state and lastly apply the linear rational expectations model solution method by Sims (2002) to find a unique stable solution given parameter values.[5]

3 Term Structure of Bond Yields

In this section we describe how to extend the baseline model to include the term structure of interest rates. For simplicity, we assume here that the government issues nominal bonds of various maturities. Then, the flow budget constraint for household i is modified as

$$\begin{aligned} & P_t C_t(i) + \sum_{n=1}^{\infty} (R_{n,t})^{-n} \left[D_{n,t}(i) - D_{n+1,t-1}(i)\right] + S_t B_t(i) + E_t\left[Q_{t,t+1} V_{t+1}(i)\right] + P_t T_t \\ = \; & D_{1,t-1}(i) + S_t B_{t-1}(i) R^*_{1,t-1} \phi(A_{t-1}) + V_t(i) + W_t(i) N_t(i) + \Xi_{H,t} + \Xi_{F,t}, \end{aligned}$$

---

[5] The details of equilibrium conditions, deterministic steady state, and log-linearized solutions are provided in the Appendix which is available from authors upon request.

where $R_{n,t}$ is the gross bond yield of maturity n periods and $D_{n,t}(i)$ is the holdings of a domestic discount bond of maturity n periods. The government budget constraint becomes

$$\sum_{n=1}^{\infty} (R_{n,t})^{-n} \left[D_{n,t} - D_{n+1,t-1}\right] + T_t = D_{1,t-1} + G_t,$$

where

$$D_{n,t} = \int_0^1 D_{n,t}(i)\, di,$$

for $n = 1, 2, \cdots$ and all t's. Despite the extension of the model, its dynamics do not change up to the first order since the certainty equivalence holds. We simply combine the term structure of government bond yields to the first order approximate solution of the model.

Suppose that the first order approximate solution of our model leads to the following transition equation of a state vector $\hat{\boldsymbol{x}}_t$

$$\hat{\boldsymbol{x}}_t = \Gamma \hat{\boldsymbol{x}}_{t-1} + \Psi \boldsymbol{\varepsilon}_t,$$

where $\boldsymbol{\varepsilon}_t \sim N(0, I)$ is a vector of innovations to all shocks.[6] Then the log deviation of the one-period ahead domestic discount factor from its steady state, $\hat{q}_{t,t+1}$, is given by

$$\begin{aligned}\hat{q}_{t,t+1} &= \hat{u}_{b,t+1} - \hat{u}_{b,t} - \frac{1}{\bar{u}_z - h}\left[(\bar{u}_z \hat{c}_{t+1} - h\hat{c}_t) - (\bar{u}_z \hat{c}_t - h\hat{c}_{t-1}) + (\bar{u}_z \hat{u}_{z,t+1} - h\hat{u}_{z,t})\right] - \hat{\pi}_{t+1} \\ &= Q_x \hat{\boldsymbol{x}}_t + Q_\epsilon \boldsymbol{\varepsilon}_{t+1}\end{aligned}$$

where Q_x and Q_ε denote a selection vector from $\hat{\boldsymbol{x}}_t$ and $\boldsymbol{\varepsilon}_{t+1}$. Given the multivariate normality of $\boldsymbol{\varepsilon}_t$, $\hat{q}_{t,t+1}$ follows a normal distribution.

Denote the log deviation of the n-quarter nominal bond yield from the steady state nominal interest rate by $\hat{r}_{n,t}$. No-arbitrage conditions imply that the one-period return of holding a bond of any maturity should be equal to one when it is discounted by $Q_{t,t+1}$.[7] In the first-order accurate approximation, this implies that

$$E_t\left[\exp\left(\hat{q}_{t,t+1} - (n-1)\hat{r}_{n-1,t+1} + n\hat{r}_{n,t}\right)\right] = 1.$$

Because of the normality of $\hat{q}_{t,t+1}$ and the linearity of the transition equation for $\hat{\boldsymbol{x}}_t$, $\hat{r}_{n,t}$ is derived as an affine function of $\hat{\boldsymbol{x}}_t$: $\hat{r}_{n,t} = h_{1,n} + h_{2,n}\hat{\boldsymbol{x}}_t$, where $h_{1,n}$ and $h_{2,n}$ are a function of the struc-

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[6] We denote the log deviation of x_t from its steady state by $\hat{x}_t$. All the shocks are included in the state vector $\hat{\boldsymbol{x}}_t$ and therefore, $\boldsymbol{\varepsilon}_t$ contains innovations to these shocks.

[7] It is worthwhile to note that we do not explicitly introduce the foreign term structure of interest rates here. Under the assumption of complete markets, the domestic term structure of interest rates would be tightly linked with the foreign term structure of interest rates through the term structure of exchange rates. Hence, it is easy in this case to derive the foreign term structure of interest rates just like the domestic term structure of interest rates. However, asset markets are incomplete and international risk sharing is not perfect in our model. To derive the foreign term structure of interest rates explicitly, we need to take a stand on the term structure of debt elastic interest risk premium too. Although this extension might be interesting, it is beyond the current scope of our paper in which we try to explain the domestic term structure of interest rates in a small open economy given exogenous dynamics of the foreign economy.

tural parameters. Recursively applying no-arbitrage conditions, one obtains a recursion formula for coefficients $h_{1,n}$ and $h_{2,n}$ for any $n \geq 0$ as

$$\exp\left[-n\left(h_{1,n}+h_{2,n}\hat{\boldsymbol{x}}_t\right)\right] = E_t\left\{\exp\left[\begin{array}{l} \left(Q_x-(n-1)\,h_{2,n-1}\Gamma\right)\hat{\boldsymbol{x}}_t-(n-1)\,h_{1,n-1} \\ +\frac{1}{2}\left(Q_\epsilon-(n-1)\,h_{2,n-1}\Psi\right)\left(Q_\epsilon-(n-1)\,h_{2,n-1}\Psi\right)' \end{array}\right]\right\},$$

which leads to

$$\begin{aligned} h_{1,n} &= \left(\frac{n-1}{n}\right)h_{1,n-1}-\frac{1}{2n}\left[Q_\epsilon-(n-1)\,h_{2,n-1}\Psi\right]\left[Q_\epsilon-(n-1)\,h_{2,n-1}\Psi\right]', \\ h_{2,n} &= \left(\frac{n-1}{n}\right)h_{2,n-1}\Gamma-\frac{Q_x}{n}. \end{aligned}$$

We start the recursion from $n = 1$ using the fact that $h_{1,0} = 0$ and $h_{2,0} = 0$. Then it follows that

$$\hat{r}_{1,t} = -0.5\left(Q_\epsilon Q_\epsilon'\right)+Q_{r1}\hat{\boldsymbol{x}}_t,$$

and therefore $h_{1,1} = -0.5\left(Q_\epsilon Q_\epsilon'\right)$ and $h_{2,1} = Q_{r1}$, where Q_{r1} is the vector that selects $\hat{r}_{1,t}$ in $\hat{\boldsymbol{x}}_t$.

4 Estimation

4.1 Estimation Method

We use standard Bayesian methods to fit the model on the data for Australia, Canada and New Zealand.[8] These countries were chosen because there are many previous studies that investigate some intereseting issues of a small open economy using their data and thus we can compare our results with existing research; and it is interesting to analyze the role of inflation targeting policy that these three countries adopted one after another in inflation and policy rate expectations.

The dataset includes the growth rate of GDP per capita $\Delta\log\left(GDP_t\right)$, annualized CPI inflation rates $4\times\log\left(\Pi_t\right)$, annualized one-period nominal interest rates $4\times\log\left(R_{1,t}\right)$, and the growth rate of the terms of trade $\Delta\log\left(\tau_t\right)$. We also use the depreciation rate of bilateral nominal exchange rates of each country against the US dollar, $\Delta\log S_t$. The term structure data includes 2-year, 3-year, 5-year and 10-year government bond yields for Australia and Canada and 1-year, 2-year, 5-year and 10-year government bond yields for New Zealand. All term structure yields are annualized. The choice of maturities of the term structure data were made in consideration of sample availability for each country. The frequency of the data is a quarter and the sample covers the period from 1993Q1 through 2006Q4 for Australia, the period from 1992Q2 through 2006Q4 for Canada, and the period from 1988Q2 through 2006Q4 for New Zealand. We use the first four observations to initialize the Kalman filter during our estimation. The detailed description of our dataset is provided in the appendix.

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[8] For a general introduction of Bayesian methods for macroeconomics, see Del Negro and Schorfheide (2011).

The measurement equation for macro data of the small open economy is

$$\begin{aligned}
\Delta \log (GDP_t) &= \hat{y}_t - \hat{y}_{t-1} + \log \bar{u}_z + \hat{u}_{z,t}, \\
\log (\Pi_t) &= 4\left(\hat{\pi}_t + \log \bar{\Pi}\right), \\
\log (R_{1,t}) &= 4\left(\hat{r}_{1,t} + \log \bar{R}_1\right), \\
\Delta \log S_t &= \Delta \hat{s}_t + \log \widetilde{\Delta s}, \\
\Delta \log (\tau_t) &= \Delta \hat{\tau}_t + \log \widetilde{\Delta \tau},
\end{aligned}$$

where $\hat{y}_t$, $\hat{\pi}_t$, $\hat{r}_{1,t}$, $\Delta \hat{s}_t$, and $\hat{\tau}_t$ are the log deviation of $y_t = Y_t/Z_t$, Π_t, $R_{1,t}$, S_t/S_{t-1}, and τ_t from their steady state values, respectively.[9] For the term structure data, the measurement equation is

$$R_{n,t} = 4\left(\hat{r}_{n,t} + \log \bar{R}_n\right) + u_{r_n,t},$$

with the measurement error, $u_{r_n,t} \sim N\left(0, \sigma^2_{r_n}\right)$, where $\hat{r}_{n,t}$ is the log deviation of $R_{n,t}$ from its steady state value.

For the rest of the world, we use the data of the United States: the growth rate of GDP per capita $\Delta \log (GDP^*_t)$, annualized CPI inflation rates $4 \times \log (\Pi^*_t)$, and annualized federal funds rates $4 \times \log \left(R^*_{1,t}\right)$. The measurement equation of the rest of the world is

$$\begin{gathered}
\Delta \log (GDP^*_t) = \hat{y}^*_t - \hat{y}^*_{t-1} + \log \bar{u}_{z^*}, \\
\log (\Pi^*_t) = 4\left(\hat{\pi}^*_t + \log \bar{\Pi}^*\right), \\
\log \left(R^*_{1,t}\right) = 4\left(\hat{r}^*_{1,t} + \log \bar{R}^*_1\right),
\end{gathered}$$

where $\hat{y}^*_t$, $\hat{\pi}^*_t$, and $\hat{r}^*_{1,t}$ are the log deviation of $y^*_t = Y^*_t/Z_t$, Π^*_t, and $R^*_{1,t}$ from their steady state values, respectively. Because of different sample periods for different countries, the mean of $\log \bar{u}_{z^*}$, $\log \bar{\Pi}^*$, and $\log \bar{R}^*_1$ is set to their respective sample counterparts during the sample period for each country. Figures 1 $\sim$ 3 describe the historical data used in estimation alongside the fitted values from the model.[10]

We take into account the following specifics for each country.

4.1.1 Australia

Over the sample period, the average ratio of private consumption to output in Australia is 52.0%, to which we fix $\bar{c}/\bar{y}$. The ratio of exports to output is determined by the value of $\bar{c}/\bar{y}$ and the assumption that $\bar{a} = 0$.

For the openness parameter α, we use the sample average of the share of imports to final private consumption, 0.205. We set the prior mean of $\log \bar{u}_z$, $\log \bar{\Pi}$, $\log \widetilde{\Delta s}$ and $\log \tilde{\tau}$ to 0.0059, 0.0264/4,

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[9] Though our model implies that the nominal exchange rate depreciation is zero in the steady state and the terms of trade does not grow over time, we include a potentially non-zero depreciation rate of nominal exchange rates, $\log \widetilde{\Delta s}$, and potentially non-zero growth rate of the terms of trade, $\log \widetilde{\Delta \tau}$, in the measurement equation to account for trend-like behavior of these variables during the sample period.

[10] For each country, we use the best-fitting model specification for inflation target

-0.0018 and 0.0075, respectively, that match their sample counterparts. Note that $\bar{R}_1$ is endogenously determined. The prior mean of $\log \bar{u}_{z^*}$, $\log \bar{\Pi}^*$, and $\log \bar{R}_1^*$ is set to 0.0049, 0.0256/4, and 0.0404/4, respectively.

4.1.2 Canada

Over the sample period, the average ratio of private consumption to output is 52.2% in Canada. We fix $\bar{c}/\bar{y}$ to this number. The ratio of exports to output is determined by the value of $\bar{c}/\bar{y}$ and the assumption that $\bar{a} = 0$.

For the openness parameter α, we use the sample average of the share of imports to final private consumption, 0.513. We set the prior mean of $\log \bar{u}_z$, $\log \bar{\Pi}$, $\log \widetilde{\Delta s}$ and $\log \widetilde{\Delta \tau}$ to 0.0077, 0.0185/4, -0.0006 and 0.0021, respectively, that match their sample counterparts. Note that $\bar{R}_1$ is endogenously determined. The prior mean of $\log \bar{u}_{z^*}$, $\log \bar{\Pi}^*$, and $\log \bar{R}_1^*$ is set to 0.0051, 0.0257/4, and 0.0401/4, respectively.

4.1.3 New Zealand

Over the sample period, the average ratio of private consumption to output is 58.9% in New Zealand, to which we fix $\bar{c}/\bar{y}$. The ratio of exports to output is determined by the value of $\bar{c}/\bar{y}$ and the assumption that $\bar{a} = 0$.

For the openness parameter α, we use the sample average of the share of imports to final private consumption, 0.479. We set the prior mean of $\log \bar{u}_z$, $\log \bar{\Pi}$, $\log \widetilde{\Delta s}$ and $\log \widetilde{\Delta \tau}$ to 0.0072, 0.0248/4, -0.0003 and 0.0019, respectively, that match their sample counterparts. Note that $\bar{R}_1$ is endogenously determined. The prior mean of $\log \bar{u}_{z^*}$, $\log \bar{\Pi}^*$, and $\log \bar{R}_1^*$ is set to 0.0046, 0.0296/4, and 0.0475/4, respectively.

4.2 Inflation Target Specifications

Our model features a time-varying inflation target which follows a first-order autoregressive process with the persistence parameter ρ_π when log-linearized. In our baseline specification, we estimate ρ_π with a high prior mean,[11] while in "Model 2," we fix it to 0.995. The idea behind the specification of Model 2 is that the central bank may want to change its inflation target very gradually when it sees necessary and thus the inflation target process can be modelled as a unit root process. Since a unit root inflation target process introduces unnecessary complications into solving our model, we instead use a value which is slightly smaller than unit root so that the inflation target process replicates the unit root process though technically stationary. Cogley, Primicery and Sargent (2010) use a similar process. In another specification "Model 3," we consider a constant inflation target.

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[11] The prior distribution for ρ_π is the Beta distribution with mean 0.9 and standard deviation 0.05 for Australia and Canada and the Beta distribution with mean 0.85 and standard deviation 0.05 for New Zealand. We use a lower prior mean for New Zealand for fast and stable convergence. We do not set prior means closer to a unit root because inflation series of these countries are not too much persistent. The sample first-order autocorrelation is 0.0645, 0.1020, and 0.3776 for Australia, Canada, and New Zealand, respectively. However, a highly persistent inflation target process is not necessarily incompatible as the low autocorrelation of inflation if volatility of an inflation target shock is small. We let the data pick up the best specification for the inflation target process among three alternative specifications.

4.3 Prior Distribution of the Parameters

We present the details of the prior distribution in Table 1. A common prior distribution is used for all three countries except for those parameters that are related to the sample mean of variables whose prior mean is described in Section 4.1. Another parameter whose prior mean is different across countries is $\tilde{\phi}_a$. We use 0.001 as its prior mean for Australia and New Zealand and 0.01 at its prior mean for Canada to ensure fast convergence of posterior estimation. The prior distributions of other parameters are fairly standard and comparable to the existing literature. One parameter to note is the intratemporal elasticity of substitution between domestically produced goods and imported goods, η, whose prior distribution is the Gamma distribution with mean 1.5 and standard deviation 0.3. We observe that low values of η make the model explosive and hence effectively its prior distribution is truncated below.

Since the inverse of the Frisch elasticity of labor supply φ and the elasticity of substitution of domestic differentiated goods $\bar{\epsilon}$ are not well identified, we fix $\varphi = 1$ and $\bar{\epsilon} = 8$. For the parameters of the foreign-country VAR model, we set their prior distribution as

$$(\Phi_1)_{ii} \sim N(0.6, 0.2) \text{ and } (\Phi_1)_{ij} \sim N(0, 0.2),$$

for $i \neq j$,

$$(\Phi_2)_{ij} \sim N(0, 0.2),$$

for all i's and j's,

$$L_{21}, L_{31}, L_{32} \sim N(0, 0.3),$$

and $\sigma_{\xi,i}$'s for $i = y^*, \pi^*, R^*$ follows the inverted-Gamma with mean 0.01 and standard deviation 0.02. Note that the stationarity condition is automatically imposed by the stability condition of a linear rational expectations model.

Lastly, the prior distribution of the standard deviation of the measurement errors for the term structure data is the Inverse Gamma distribution with mean 0.002 and standard deviation 0.005. The size of the measurement errors is restricted to be small in order to prevent the measurement errors from explaining too much variation of the term structure data.

4.4 Estimation Results

4.4.1 Parameter Estimates

We compare the data fit of different specifications based on estimated marginal likelihoods presented in Table 2. Tables 3 and 8 present the posterior mean and 90% highest posterior density (HPD) interval of the structural parameters for Australia, Canada, and New Zealand, respectively, in the specification of inflation target process most favored by the data.

Tables 3 - 4 show parameter estimates using Australian data. In this case, the baseline specification in which the persistence of inflation target shock is estimated is favored by both macro and joint estimation. While posterior distributions of certain parameters change little, there are some parameters whose posterior distributions shift a lot. In the case of Australia, parameters governing dynamic indexation, steady states and foreign block dynamics are similar. Among parameters whose posterior distributions change a lot by adding the term structure data, most noticeable are monetary policy response parameters to inflation and output (ψ_π ,ψ_y), habit persistence paramter (h), Calvo parameter governing import price inflation (θ_F), and AR(1) coefficient parameters for the risk premium shock and the import markup shock (ρ_ϕ, $\rho_{\varepsilon^\star}$). Monetary policy response to inflation in the joint estimation is around 1.5 which is somewhat less aggressive than the macro estimation result of around 2.2. In contrast, the response to output is about 0.47 in the joint estimation which is more aggressive than the macro estimation result of 0.13. While the literal interpretation of strict inflation targeting may imply a negligible response to output, the Reserve Bank of Australia actually allowed a small band around the target mainly to keep flexibility in dealing with the short-run tradeoff between inflation stabilization and output stabilization (Debelle 1999). To the extent that the central bank has a concern for output implicitly, the plausibility of different estimates of policy response parameters draws on how much they can explain the future policy rates, which we discuss in the following subsection.

The posterior mean of habit parameter declines from 0.51 in the macro estimation to 0.19 in the joint estimation, implying that consumption is less backward-looking when the term structure data are added. In the macro estimation, the nominal rigidity in import retailers is estimated to be 0.37 that is much lower than the corresponding estimate of 0.82 in the domestically produced goods sector. However, both Calvo parameters are as high as about 0.88 in the joint estimation. On the other hand, an import markup shock is very persistent with the AR(1) coefficient hovering around 0.998 in the macro estimation but nearly i.i.d. with the AR(1) coefficient less than 0.2 in the joint estimation. The macro estimation results for the Calvo parameter and the persistence of markup shock in the imported goods sector are comparable to Justiniano and Preston (2010) who also use only the macro data for a longer sample period. The joint estimation result implies that fluctuations in the exchange rate would be passed to import price inflation in a more sluggish way, generating a significant endogenous variations in the markup. In contrast, an exogenous variation in the desired markup seems to play a quantitatively small role becuase it is not very persistent. The opposite pattern holds in the macro estimation.[12]

Finally, the AR(1) coefficient of the risk premium shock increases from 0.42 in the macro estimation to 0.86 in the joint estimation. The finding is somewhat different from Justiano and Preston (2010) who find that both import markup and risk premium shocks are highly persistent. Our addition of a persistent inflation target shock to an otherwise similar model may explain some of the difference because the inflation target shock is somewhat more persistent in the macro estimation and may offset the lower persistence of risk premium shock.

Tables 5 and 6 show parameter estimates using Canadian data. In this case, Model 2 in which the persistence of inflation target shock is fixed at 0.995 is favored in the joint estimation but the

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[12] While the distinction of sources of variations in import markup is relevant for the design of the optimal monetary policy, it is difficult to read too much from this finding because we do not use the separate import price deflator in the estimation.

baseline specification in which the AR(1) coefficient of inflation target shock is estimated is favored in the macro estimation. For parameters whose posterior distributions shift with the inclusion of the term structure data, the pattern is very similar to Australia with the except for the Calvo parameter in the imported goods sector that is pretty much the same across macro and joint estimation.

Tables 7 and 8 show parameter estimates for New Zealand. In this case, Model 2 in which the persistence of inflation target shock is fixed at 0.995 is also favored in the joint estimation but Model 3 with the constant target is most favored in the macro estimation. Like Australia, posterior distributions of monetary policy response parameters to inflation and output, the Calvo parameter in the imported goods sector, and persistence of import markup shock and risk premiums shock shift a lot. Interestingly, the pattern of these shifts is remarkably similar to Australia and Canada. Monetary policy response coefficient on inflation decreases but the corresponding coefficient on output increases in the joint estimation. The Calvo parameter in the imported goods sector and AR(1) coefficients of import markup shock and risk premium shock increase in the joint estimation. In some ways, the quantitative magnitude of these shifts is more pronounced in New Zealand.

4.4.2 Impulse Response and Variance Decomposition

Using Euro-area data, Adolfson et al. (2007) point out that "domestic" shocks account for most of the variation in domestic variables while "open economy" shocks account for most of the variation in the real exchange rate. A similar pattern is observed in our estimation results. Tables 9 - 14 show variance decomposition from parameter estimates. Such a disconnect is broadly observed with the exception for the macro estimation in Canada where a domestic monetary policy shock explains a significant portion of nominal exchange rate fluctuations.[13] In all the countries, risk premium shock explain a bulk of variation in the exchange rate when term structure data are included in estimation. As the persistence of the risk premium shock increases in the joint estimation, it plays a much bigger role in explaining fluctuations in the nominal exchange rate in the joint estimation. Figure 4 shows the response of macro and term structure variables to risk premiuim shock in the joint estimation using Australian data. A positive risk premium shock increases the domestic interest rate and leads to exchange rate depreciation through the international risk sharing. The depreciation increases imported goods inflation and overall inflation. Since the short term interest rate moves back to the steady state level 10 quarters after a positive risk premium shock, its impact on the long end of the yield curve is rather limited.[14]

Since bond yields are highly persistent, the most persistent shock in the model always explains most of their variations. In Australia, it is government spending shock while it is inflation target shock in New Zealand and Canada. Figure 5 shows the response of macro and term structure variables to a positive government spending shock in the joint estimation using Australian data. Since government spending uses only domestically produced goods, the increased overall demand for home goods results

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[13] A similar finding was noted in Justiniano and Preston (2010).

[14] In the macro estimation, import markup shock explains a significant portion of nominal exchange rate fluctuations in Australia and New Zealand while domestic markup shock and monetary policy shock explain a bulk of variation in the nominal exchange rate for Canada.

in the term of trade improvement and exchange rate appreciation in the short run, lowering inflation for both home goods and foreign goods.[15] Given the strong nominal rigidity in the joint estimation, inflation moves up very slowly after initial decline while output moves back to the steady state relatively quickly. The systematic response of monetary policy to inflation and output implies that the short term interest rate also decrease and moves back to the steady state only gradually. Since the term structure reflect the future path of the short term interest rate, long-term bond yields also declines in response to a positive government spending shock and slowly move back to the steady state level. Therefore, a sequence of positive government spending shock can explain the persistent decline in the average level of the yield curve during the sample period.

Figure 6 shows the responses of macro and term structure variables to a positive inflation target shock in Canada. An increase in inflation target boosts current inflation through increased inflation expectations. Given nominal rigidity, inflation shows a peak response a few quarters later and output and consumption temporarily increases as the real interest rate drops. Since a part of consumption is imported, the exchange rate depreciates. Over time, inflation and the nominal interest rate moves one-to-one with an inflation target shock which moves back to the steady state value very gradually. As a result, a positive innovation to inflation target generates an upward shift in the average level of nominal interest rates. Since our model is linear, the same mechanism can explain a persistent decline in the average level of the yield curve during the sample period by a sequence of negative inflation target shock.

4.4.3 Policy Expectations Implied by the Term Structure Data

Using the term structure data may provide additional information about expected interest rates in the future. Since monetary policy response parameter estimates vary a lot depending on the inclusion of the term structure data, it is useful to compare the model implied expected interest rate with the realized data to see which estimates are more plausible. Figures 7-9 show the average policy rate expectation during a year from now implied by the model estimates ($\sum_{j=1}^{4} E_t r_{t+j}/4$) together with the corresponding average interest rate ex-post realized ($\sum_{j=1}^{4} r_{t+j}/4$). The model implied interest rate expectation is generally in line with the ex-post realized one, reflecting the fact that the degree of interest rate smoothing is as high as around 0.8 in all the estimation results. However, correlation coefficients between the model implied expected interet rate and the ex-post realized one are higher in the joint estimation when we look at Ausutralian and Canadian data. In New Zealand, the macro estimation does as well as the joint estimation. The finding suggests that the term structure data provide additional information for the future interest rate in Australia and Canada but not so much in New Zealand. As noted by Fischer (1995), this may be because the Reserve Bank of New Zealand considered the average level of interest rates as a variable in the monetary policy decision, creating a high correlation between the yield curve level and the short-term interest rate.[16] Therefore, the

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[15] Domestic inflation decreases in spite of the increased demand if the terms of trade improvement is strong.

[16] In fact, the correlation between the short rate and the yield curve level computed by the average bond yields of three different maturities is 0.9512 in New Zealand while the magnitude is 0.6979 and 0.8002 in Australia and Canada, respectively.

current level of the short-term interest rate contains sufficient information about the future value. Basically the same pattern holds when we extend the horizon from one-year to five-year which we do not report here for the interest of space.[17]

The fact that the model implied policy expectations are better aligned with the data indicates that the Reserve Bank of Australia and the Bank of Canada actually have a significant concern for minimizing output fluctuations in addition to inflation fluctuations. Given the presence of open economy shocks that can create the short-run tradeoff between inflation fluctuations and output fluctuations, the active response to output fluctuations is not inconsistent with the welfare maximizing monetary policy. Our estimation results that such a behavior can be consistent with expectations held by bond market investors.

Kulish and Rees (2011) argue that long-term interest rates in a number of inflation-targeting small open economies including three countries in our sample have tended to be strongly correlated with those of the United States. They interpret this finding as a result that foreign shocks are more persistent although long-term interest rates are still determined by future expectations of the domestic short-term interest rate. While our finding is consistent with the notion that long-term interest rates reflect expectations of the short-term interest rates in small open economies, we do not find evidence that foreign shocks are more persistent than domestic disturbances. Our results imply that domestic shocks such as government spending shock and inflation target shock can be fundamental drivers of long-term interest rates. A direct comparison of our results with their results may not be relevant. First, they use HP-filtered data while we use raw data.[18] Second, their model has only two shocks while our model contains a richer set of shocks and realistic frictions.

5 Conclusion

This paper tries to use information on the expected interest rate in the term structure of interest rates using a DSGE model of monetary policy transmission mechanisms for a small open economy. For this purpose, we extend an otherwise standard small open economy DSGE model to include the yield curve data. The extended DSGE model is estimated on major macroeconomic data and yield curve data of three inflation-targeting small open economies such as Australia, Canada, and New Zealand using Bayesian methods. We find that including the yield curve data in the estimation enables us to make use of information contained in the yield curve about monetary policy expectations. The model-implied expectations of the short-term policy rate is better aligned with ex-post realized ones in Australia and Canada when we include term structure data in estimation, suggesting that the estimated monetary policy parameters describe the actual behavior of central banks better. The finding can be regarded as evidence that a standard monetary policy transmission channel from the short rate to long-term interest rates is still effective in a small open economy setup even in the presence of persistent foreign disturbances. While the estimation results solely based on the macro

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[17] We are a bit agnostic about the source of this improvement because a similar improvement is not observed in the case of inflation and output growth. We leave a more structural investigation of this issue as future research agenda.

[18] Since interest rates are highly persistent, eliminating low-frequency movements can change correlations between different interest rates.

data indicate that central banks in these countries predominantly care for inflation stabilization with little concern for output and exchange rate stabilization, the estimation results including term structure data imply that they have a significant concern for output stabilization too. In addition, our results attribute most of variations in the long-end of the yield curve to persistent domestic shocks such as government spending shock or inflation target shock while some of the existing literature imply bigger roles for foreign disturbances. We suspect that these differences may arise from the fact that we use raw data rather than HP-filtered data and estimate a DSGE model with a richer set of domestic shocks and realistic frictions.

Nonetheless, the current exercise uses a quite stylized model for small open economies for simplicity in estimation. We plan to include rich features such as endogenous capital accumulation and model the rest of the world in a more sophisticated way. Also, the influence of China on the economy of these small open economies has grown dramatically over the last decade or so albeit for different reasons. And the use of a separate import price deflator data may help us to better identify parameters related to import markup shock and nominal rigidity in the import sector. We leave these as a promising future research agenda.

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Appendix

A Data

A.1 Australia

GDP per capita is GDP divided by population aged between 15 and 64. Annual population data was converted to quarterly figures using the cubic-spline method wiht Eviews by matching the last option. The growth rate of per capita GDP is the log difference of this series. Inflation is 4 times seasonally adjusted CPI inflation rates for all groups. This series excludes interest and tax changes of 1999 and 2000. Nominal interest rates are the interbank cash rate per annum. The depreciation rate of nominal exchange rates is the first difference of log nominal exchange rates of Australian Dollar against US Dollar. The growth rate of the terms of trade data is the first difference of the log of the terms of trade.

Data on GDP, population, and nominal exchange rates were taken from the OECD database. CPI and nominal interest rates are provided by the Reserve Bank of Australia. The terms of trade data are taken from the database of the Australian Bureau of Statistics. GDP, CPI, and the terms of trade are seasonally adjusted.

All national accounts data are seasonally adjusted and taken from the OECD database. The term structure data were obtained from Bloomberg.

A.2 Canada

GDP per capita is GDP divided by population aged between 15 and 64. Annual population data was converted to quarterly figures using the cubic-spline method by Eviews with matching the last option. The growth rate of per capita GDP is the log difference of this series. Inflation is 4 times seasonally adjusted CPI inflation rates for all items. Nominal interest rates are the effective overnight money market financing rate. The depreciation rate of nominal exchange rates is the first difference of log nominal exchange rates of Canadian Dollar against US Dollar. The growth rate of the terms of trade data is the first difference of the log of the terms of trade, which is the ratio of the deflator of exports to the deflator of imports.

Data on GDP, population, nominal exchange rates and exports and imports deflators were taken from the OECD database. Inflation rates and nominal interest rates are published by Stats Canada and Bank of Canada, respectively, and both of them were obtained through Haver Analytics. GDP, CPI and exports and imports deflators are seasonally adjusted.

All national accounts data are seasonally adjusted and taken from the OECD database. The term structure data were obtained from Bloomberg.

A.3 New Zealand

GDP per capita is GDP divided by population aged between 15 and 64. Annual population data was converted to quarterly figures using the cubic-spline method by Eviews with matching the last option. The growth rate of per capita GDP is the log difference of this series. Inflation is 4 times seasonally adjusted CPI inflation rates for all items. Nominal interest rates are the call money market rate. The depreciation rate of nominal exchange rates is the first difference of log nominal exchange rates of New Zealand Dollar against US Dollar. The growth rate of the terms of trade data is the first difference of the log of the terms of trade, which is the ratio of the deflator of exports to the deflator of imports.

Data on GDP, population, CPI, and nominal exchange rates were taken from the OECD database. Nominal interest rates are provided by the Reserve Bank of New Zealand. GDP, CPI, and exports and imports deflators are seasonally adjusted.

All national accounts data are seasonally adjusted and taken from the OECD database. The term structure data were obtained from Bloomberg.

A.4 The United States

GDP per capita is GDP divided by civilian noninstitutional population. The growth rate of per capita GDP is the log difference of this series. Inflation is 4 times seasonally adjusted CPI inflation rates for all items. Nominal interest rates are the effective federal funds rate.

B Equations for Estimation

For estimation, we use the following equations. Detailes of the derivation are provided in the technical appendix which is available upon request.

- [1] Consumption Euler equation

$$\left(\bar{u}_z\hat{c}_t - h\hat{c}_{t-1}\right) = \left(\bar{u}_z E_t\hat{c}_{t+1} - h\hat{c}_t\right) - \left(\bar{u}_z - h\right)\left(\hat{r}_{1,t} - E_t\hat{\pi}_{t+1}\right) + \hat{\hat{u}}_{b,t} + \left(\bar{u}_z\rho_z - h\right)\hat{u}_{z,t}$$

where $\hat{u}_{b,t}$ is reparameterized as

$$\hat{\hat{u}}_{b,t} = \left(\bar{u}_z - h\right)\left(1 - \rho_b\right)\hat{u}_{b,t}.$$

- [2] Aggregate consumption

$$\hat{c}_t = \left(1 - \alpha\right)\hat{c}_{H,t} + \alpha\hat{c}_{F,t}$$

- [3] Domestic final good consumption

$$\hat{c}_{H,t} = -\eta\hat{p}_{H,t} + \hat{c}_t$$

- [4] Foreign final good consumption

$$\hat{c}_{F,t} = -\eta\hat{p}_{F,t} + \hat{c}_t$$

- [5] Domestic final good price

$$\hat{p}_{H,t} = \hat{p}_{H,t-1} + \left(\hat{\pi}_{H,t} - \hat{\pi}_t\right)$$

- [6] Foreign final good price

$$\hat{p}_{F,t} = \hat{p}_{F,t-1} + \left(\hat{\pi}_{F,t} - \hat{\pi}_t\right)$$

- [7] International risk sharing condition

$$\hat{r}_{1,t} = \hat{r}^*_{1,t} + E_t\Delta\hat{s}_{t+1} + \tilde{\phi}_a\hat{a}_t + \hat{u}_{\phi,t}$$

- [8] Output-foreign debt ratio (flow budget constraint)

$$\frac{\bar{c}}{\bar{y}}\hat{c}_t - \hat{a}_t = -\beta^{-1}\hat{a}_{t-1} + \hat{y}_t - \frac{\bar{u}_g}{\bar{y}}\hat{u}_{g,t}$$

- [9] NK Phillips curve for domestic final good inflation

$$\left(\hat{\pi}_{H,t} - \gamma_H\hat{\pi}_{H,t-1}\right) \quad = \quad \beta\left(E_t\hat{\pi}_{H,t+1} - \gamma_H\hat{\pi}_{H,t}\right)$$

$$+\frac{(1-\theta_H\beta)(1-\theta_H)}{\theta_H(1+\varphi\bar{\epsilon})}\left[\varphi\hat{y}_{H,t}+\frac{1}{\bar{u}_z-h}\left(\bar{u}_z\hat{c}_t-h\hat{c}_{t-1}+h\hat{u}_{z,t}\right)-\alpha\hat{\tau}_t\right]+\hat{\hat{u}}_{\epsilon,t},$$

where $\hat{u}_{\epsilon,t}$ is reparameterized as

$$\hat{\hat{u}}_{\epsilon,t}=\frac{(1-\theta_H\beta)(1-\theta_H)}{\theta_H(1+\varphi\bar{\epsilon})}\hat{u}_{\epsilon,t}.$$

- [10] NK Phillips curve for foreign final good inflation

$$\left(\hat{\pi}_{F,t}-\gamma_F\hat{\pi}_{F,t-1}\right)=\beta\left(E_t\hat{\pi}_{F,t+1}-\gamma_F\hat{\pi}_{F,t}\right)+\frac{(1-\theta_F\beta)(1-\theta_F)}{\theta_F}\hat{\chi}_{F,t}+\hat{\hat{u}}_{\epsilon^*,t},$$

where $\hat{u}_{\epsilon^*,t}$ is reparameterized as

$$\hat{\hat{u}}_{\epsilon^*,t}=\frac{(1-\theta_F\beta)(1-\theta_F)}{\theta_F}\hat{u}_{\epsilon^*,t}$$

- [11] Terms of trade

$$\hat{\tau}_t=\hat{p}_{H,t}-\hat{p}_{F,t}$$

- [12] Real exchange rate

$$\widehat{e}_t=\widehat{e}_{t-1}+\Delta\hat{s}_t+\hat{\pi}^*_t-\hat{\pi}_t$$

- [13] Law of one price gap

$$\hat{\chi}_{F,t}=\hat{e}_t-\hat{p}_{F,t}$$

- [14] Monetary policy rule

$$\hat{r}_{1,t}=\rho_R\hat{r}_{1,t-1}+(1-\rho_R)\left[\psi_\pi\left(\hat{\pi}_t-\hat{\hat{\pi}}_t\right)+\psi_Y\hat{y}_t+\psi_S\Delta\hat{s}_t\right]+\varepsilon_{R,t}$$

- [15-17] Rest of the world

$$\hat{\xi}^*_t=\Phi_1\hat{\xi}^*_{t-1}+\Phi_2\hat{\xi}^*_{t-2}+\begin{pmatrix}1&0&0\\L_{21}&1&0\\L_{31}&L_{32}&1\end{pmatrix}\hat{u}_{\xi,t},$$

where $\hat{\xi}^*_t=\left(\hat{y}^*_t,\hat{\pi}^*_t,\hat{r}^*_{1,t}\right)'$.

- [18] Exports

$$\hat{c}^*_{H,t}=-\eta\left(\hat{p}_{H,t}-\hat{e}_t\right)+\hat{y}^*_t$$

- [19] Domestic final good

$$\hat{y}_{H,t}=(1-\alpha)\frac{\bar{c}}{\bar{y}}\hat{c}_{H,t}+\frac{\bar{u}_g}{\bar{y}}\hat{u}_{g,t}+\frac{\bar{c}^*_H}{\bar{y}}\hat{c}^*_{H,t}$$

- [20] Gross domestic product

$$\hat{y}_t=\hat{p}_{H,t}+\hat{y}_{H,t}-\alpha\frac{\bar{c}}{\bar{y}}\hat{\chi}_{F,t}$$

- [21-27] Exogenous shock processes

$$\hat{\hat{u}}_{b,t}=\rho_b\hat{\hat{u}}_{b,t-1}+\varepsilon_{b,t},$$

$$
\begin{aligned}
\hat{u}_{\phi,t} &= \rho_{\phi}\hat{u}_{\phi,t-1} + \varepsilon_{\phi,t}, \\
\hat{\tilde{u}}_{\epsilon,t} &= \rho_{\epsilon}\hat{\tilde{u}}_{\epsilon,t-1} + \varepsilon_{\epsilon,t}, \\
\hat{\tilde{u}}_{\epsilon^*,t} &= \rho_{\epsilon^*}\hat{\tilde{u}}_{\epsilon^*,t-1} + \varepsilon_{\epsilon^*,t}, \\
\hat{u}_{z,t} &= \rho_{z}\hat{u}_{z,t-1} + \varepsilon_{z,t}, \\
\hat{u}_{g,t} &= \rho_{g}\hat{u}_{g,t-1} + \varepsilon_{g,t}, \\
\hat{\tilde{\pi}}_{t} &= \rho_{\pi}\hat{\tilde{\pi}}_{t-1} + \varepsilon_{\tilde{\pi},t},
\end{aligned}
$$

where we reparameterize the standard deviation of $\varepsilon_{b,t}$, $\varepsilon_{\epsilon,t}$, and $\varepsilon_{\epsilon^*,t}$ according to the reparameterization of $\hat{\tilde{u}}_{b,t}$, $\hat{\tilde{u}}_{\epsilon,t}$, and $\hat{\tilde{u}}_{\epsilon^*,t}$, respectively.

C Tables and figures

Table 1: Prior distribution of the structural parameters

Parameters	Dist.	Mean	Std. Dev.	Parameters	Dist.	Mean	Std. Dev.
$-\log(\beta)$	Gamma	0.0025	0.001	ρ_R	Beta	0.6	0.2
h	Beta	0.5	0.2	ρ_b	Beta	0.6	0.2
η	Gamma	0.9	0.1	ρ_ϕ	Beta	0.6	0.2
γ_H	Beta	0.6	0.2	ρ_ϵ	Beta	0.6	0.2
γ_F	Beta	0.6	0.2	ρ_{ϵ^*}	Beta	0.6	0.2
θ_H	Beta	0.6	0.2	ρ_g	Beta	0.6	0.2
θ_F	Beta	0.6	0.2	ρ_z	Beta	0.6	0.2
ψ_π	Gamma	1.75	0.3	ρ_π	Beta	note 3	0.05
ψ_Y	Gamma	0.3	0.1	σ_R	Inv-Gamma	0.01	0.02
ψ_S	Normal	0.0	0.1	σ_b	Inv-Gamma	0.01	0.02
$\log \bar{u}_z$	Gamma	note 1	0.002	σ_ϕ	Inv-Gamma	0.01	0.02
$\log \bar{\Pi}$	Gamma	note 1	0.002	σ_ϵ	Inv-Gamma	0.01	0.02
$\log \tilde{\Delta} s$	Normal	note 1	0.002	σ_{ϵ^*}	Inv-Gamma	0.01	0.02
$\log \tilde{\tau}$	Normal	note 1	0.002	σ_g	Inv-Gamma	0.01	0.02
$\log \bar{u}_{z^*}$	Gamma	note 1	0.002	σ_z	Inv-Gamma	0.01	0.02
$\log \bar{\Pi}^*$	Gamma	note 1	0.002	σ_π	Inv-Gamma	0.001	0.001
$\log \bar{R}_1^*$	Gamma	note 1	0.002	σ_{r_n}	Inv-Gamma	0.002	0.005
$\tilde{\phi}_a$	Gamma	note 2	0.0005				

Notes: 1) the mean of these parameters is country-specific and described in Section 4.1. 2) Parameter $\tilde{\phi}_a$ has prior mean 0.001 for Australia and New Zealand while it is fixed at 0.01 for Canada. 3) The prior mean of ρ_π is 0.9 for Australia and Canada and 0.85 for New Zealand.

Notes: Parameter σ_{r_n} is the standard deviation of measurement errors for the term structure data, which has an identical prior distribution for all maturities. The prior distribution of the foreign block (VAR) is explained in Section 4.3.

Table 2: Estimated marginal likelihoods of different specifications

	Baseline	**Model 2**	**Model 3**
	ρ_π is estimated	$\rho_\pi = 0.995$	constant target
Australia			
Joint estimation	**2392.7**	2229.2	2213.4
	(0.3)	(0.1)	(0.2)
Macro data-only estimation	**1324.6**	1218.8	1225.5
	(0.04)	(0.05)	(0.05)
Canada			
Joint estimation	2381.1	**2385.5**	2372.0
	(0.06)	(0.06)	(0.2)
Macro data-only estimation	**1321.8**	1321.1	1317.8
	(0.03)	(0.05)	(0.04)
New Zealand			
Joint estimation	2844.2	**2847.3**	2827.2
	(0.05)	(0.3)	(0.06)
Macro data-only estimation	1573.5	1573.2	**1574.0**
	(0.1)	(0.09)	(0.2)

Notes: Model 2 is a specification where ρ_π is fixed at 0.995 and Model 3 is a specification where the inflation target is assumed constant (zero). Marginal likelihoods are estimated using the draws from the posterior distribution by the modified harmonic mean estimator of Geweke (1999). The numbers in parentheses are standard errors of the marginal likelihood estimates.

Table 3: Posterior distribution of the structural parameters for Australia: Baseline (joint estimation)

Parameters	mean	90% HPD interval	Parameters	mean	90% HPD interval
$-\log(\beta)$	0.0022	[0.0009, 0.0034]	ρ_R	0.8503	[0.8059, 0.8962]
h	0.1859	[0.0576, 0.3039]	ρ_b	0.3400	[0.1278, 0.5332]
η	1.1204	[1.0290, 1.2095]	ρ_ϕ	0.8611	[0.8185, 0.9028]
γ_H	0.1950	[0.0547, 0.3296]	ρ_ϵ	0.1948	[0.0548, 0.3246]
γ_F	0.1708	[0.0441, 0.2901]	ρ_{ϵ^*}	0.1858	[0.0461, 0.3146]
θ_H	0.8911	[0.8545, 0.9284]	ρ_g	0.9963	[0.9919, 0.9999]
θ_F	0.8764	[0.8442, 0.9099]	ρ_z	0.8311	[0.7682, 0.8960]
ψ_π	1.5240	[1.1981, 1.8446]	ρ_π	0.8201	[0.7488, 0.8920]
ψ_Y	0.4731	[0.2857, 0.6551]	σ_R	0.0037	[0.0022, 0.0051]
ψ_S	0.0774	[0.0173, 0.1377]	σ_b	0.0059	[0.0037, 0.008]
$\log \bar{u}_z$	0.0076	[0.0054, 0.0097]	σ_ϕ	0.0047	[0.0036, 0.0057]
$\log \bar{\Pi}$	0.0061	[0.0035, 0.0086]	σ_ϵ	0.0109	[0.0087, 0.0130]
$\log \tilde{\Delta} s$	-0.0007	[-0.0034, 0.002]	σ_{ϵ^*}	0.0036	[0.0026, 0.0045]
$\log \tilde{\tau}$	0.0079	[0.0057, 0.0101]	σ_g	0.0016	[0.0013, 0.0019]
$\log \bar{u}_{z^*}$	0.0042	[0.0034, 0.0049]	σ_z	0.0050	[0.0033, 0.0068]
$\log \bar{\Pi}^*$	0.0062	[0.0045, 0.0077]	σ_π	0.0035	[0.0021, 0.0049]
$\log \bar{R}_1^*$	0.0109	[0.0082, 0.0135]	σ_{r_8}	0.0007	[0.0005, 0.0009]
$\tilde{\phi}_a$	0.0005	[0.0000, 0.0010]	$\sigma_{r_{12}}$	0.0007	[0.0005, 0.0008]
			$\sigma_{r_{20}}$	0.0005	[0.0004, 0.0006]
			$\sigma_{r_{40}}$	0.0006	[0.0004, 0.0008]

Notes: The table presents the posterior mean and 90% highest probability density (HPD) interval of the structural parameters for the baseline specification estimated on macro and term structure data jointly.

Table 4: Posterior distribution of the structural parameters for Australia: Baseline (macro data only)

Parameters	mean	90% HPD interval	Parameters	mean	90% HPD interval
$-\log(\beta)$	0.0022	[0.0010, 0.0034]	ρ_R	0.8996	[0.8689, 0.9299]
h	0.5052	[0.1944, 0.8229]	ρ_b	0.3955	[0.1342, 0.6538]
η	0.9320	[0.9242, 0.9393]	ρ_ϕ	0.4160	[0.1539, 0.6759]
γ_H	0.2370	[0.0663, 0.3996]	ρ_ϵ	0.2182	[0.0552, 0.3728]
γ_F	0.2110	[0.0311, 0.3916]	ρ_{ϵ^*}	0.9983	[0.9963, 1.0000]
θ_H	0.8751	[0.8213, 0.9303]	ρ_g	0.5166	[0.1977, 0.8336]
θ_F	0.4997	[0.3744, 0.6271]	ρ_z	0.3453	[0.0921, 0.5799]
ψ_π	2.2050	[1.7221, 2.6828]	ρ_π	0.9018	[0.8463, 0.9595]
ψ_Y	0.1325	[0.0516, 0.2095]	σ_R	0.0054	[0.0028, 0.0081]
ψ_S	0.2012	[0.0964, 0.3032]	σ_b	0.0042	[0.0024, 0.0060]
$\log \bar{u}_z$	0.0058	[0.0047, 0.007]	σ_ϕ	0.0044	[0.0034, 0.0054]
$\log \bar{\Pi}$	0.0063	[0.0035, 0.0092]	σ_ϵ	0.0224	[0.0081, 0.0360]
$\log \tilde{\Delta s}$	-0.0016	[-0.0047, 0.0015]	σ_{ϵ^*}	0.0038	[0.0023, 0.0052]
$\log \tilde{\tau}$	0.0071	[0.0043, 0.0100]	σ_g	0.0017	[0.0014, 0.0020]
$\log \bar{u}_{z^*}$	0.0049	[0.0044, 0.0053]	σ_z	0.0066	[0.0035, 0.0094]
$\log \bar{\Pi}^*$	0.0062	[0.0052, 0.0072]	σ_π	0.0006	[0.0003, 0.0009]
$\log \bar{R}_1^*$	0.0097	[0.0075, 0.0119]			
$\tilde{\phi}_a$	0.0012	[0.0003, 0.0021]			

Notes: The table presents the posterior mean and 90% highest probability density (HPD) interval of the structural parameters for the baseline specification estimated on *macro data only*.

Table 5: Posterior distribution of the structural parameters for Canada: Model 2 (joint estimation)

Parameters	mean	90% HPD interval	Parameters	mean	90% HPD interval
$-\log(\beta)$	0.0018	[0.0008, 0.0028]	ρ_R	0.7889	[0.7294, 0.8533]
h	0.2554	[0.0787, 0.4188]	ρ_b	0.3249	[0.1556, 0.4929]
η	1.2228	[1.1437, 1.3018]	ρ_ϕ	0.9053	[0.8694, 0.9422]
γ_H	0.184	[0.0493, 0.3136]	ρ_ϵ	0.2085	[0.0640, 0.3470]
γ_F	0.1953	[0.0589, 0.3251]	ρ_{ϵ^*}	0.1985	[0.0619, 0.3285]
θ_H	0.8597	[0.7981, 0.9213]	ρ_g	0.8948	[0.8699, 0.9207]
θ_F	0.9733	[0.9673, 0.9796]	ρ_z	0.4996	[0.2585, 0.7504]
ψ_π	1.0465	[0.7721, 1.3139]	ρ_π	0.995	n/a
ψ_Y	0.729	[0.5077, 0.9408]	σ_R	0.0049	[0.003, 0.0068]
ψ_S	0.0861	[-0.0011, 0.1704]	σ_b	0.0034	[0.0023, 0.0044]
$\log \bar{u}_z$	0.0079	[0.0067, 0.0092]	σ_ϕ	0.0085	[0.0065, 0.0104]
$\log \bar{\Pi}$	0.0067	[0.0035, 0.0098]	σ_ϵ	0.0062	[0.0048, 0.0075]
$\log \tilde{\Delta} s$	-0.0005	[-0.0034, 0.0023]	σ_{ϵ^*}	0.003	[0.0022, 0.0038]
$\log \tilde{\tau}$	0.0042	[0.0026, 0.0058]	σ_g	0.002	[0.0017, 0.0024]
$\log \bar{u}_{z^*}$	0.0051	[0.0045, 0.0057]	σ_z	0.0127	[0.0096, 0.0157]
$\log \bar{\Pi}^*$	0.0061	[0.0048, 0.0074]	σ_π	0.0008	[0.0005, 0.0012]
$\log \bar{R}_1^*$	0.0104	[0.0075, 0.0132]	σ_{r_8}	0.0006	[0.0004, 0.0008]
$\tilde{\phi}_a$	0.01	n/a	$\sigma_{r_{12}}$	0.0008	[0.0006, 0.001]
			$\sigma_{r_{20}}$	0.0005	[0.0004, 0.0006]
			$\sigma_{r_{40}}$	0.0005	[0.0004, 0.0007]

Notes: The table presents the posterior mean and 90% highest probability density (HPD) interval of the structural parameters for Model 2 estimated on macro and term structure data jointly. Note that Model 2 is a specification where ρ_π is fixed at 0.995.

Table 6: Posterior distribution of the structural parameters for Canada: Baseline (macro data only)

Parameters	mean	90% HPD interval	Parameters	mean	90% HPD interval
$-\log(\beta)$	0.0019	[0.0007, 0.003]	ρ_R	0.8628	[0.8234, 0.9039]
h	0.7915	[0.6298, 0.9639]	ρ_b	0.5868	[0.3661, 0.8083]
η	1.0845	[1.0058, 1.1628]	ρ_ϕ	0.4850	[0.2015, 0.7735]
γ_H	0.1857	[0.0455, 0.3198]	ρ_ϵ	0.2028	[0.0537, 0.3477]
γ_F	0.1552	[0.0314, 0.2717]	ρ_{ϵ^*}	0.1666	[0.0353, 0.2866]
θ_H	0.8747	[0.8054, 0.9457]	ρ_g	0.6620	[0.3792, 0.9627]
θ_F	0.9860	[0.9755, 0.9976]	ρ_z	0.4535	[0.1865, 0.7124]
ψ_π	1.5088	[1.1168, 1.8904]	ρ_π	0.9394	[0.899, 0.9807]
ψ_Y	0.2422	[0.1132, 0.3660]	σ_R	0.0047	[0.0026, 0.0067]
ψ_S	0.2769	[0.1504, 0.4050]	σ_b	0.0048	[0.0026, 0.0070]
$\log\bar{u}_z$	0.0073	[0.006, 0.0086]	σ_ϕ	0.0084	[0.0064, 0.0103]
$\log\bar{\Pi}$	0.0038	[0.0017, 0.0057]	σ_ϵ	0.0058	[0.0046, 0.0070]
$\log\tilde{\Delta s}$	-0.0013	[-0.0041, 0.0015]	σ_{ϵ^*}	0.0032	[0.0023, 0.0041]
$\log\tilde{\tau}$	0.0011	[-0.0008, 0.0031]	σ_g	0.0021	[0.0018, 0.0025]
$\log\bar{u}_{z^*}$	0.0051	[0.0046, 0.0056]	σ_z	0.0041	[0.0026, 0.0055]
$\log\bar{\Pi}^*$	0.0061	[0.0050, 0.0072]	σ_π	0.0011	[0.0005, 0.0017]
$\log\bar{R}_1^*$	0.0098	[0.0072, 0.0124]			
$\tilde{\phi}_a$	0.0100	[0.0092, 0.0108]			

Notes: The table presents the posterior mean and 90% highest probability density (HPD) interval of the structural parameters for the baseline specification estimated on *macro data only*.

Table 7: Posterior distribution of the structural parameters for New Zealand: Model 2 (joint estimation)

Parameters	mean	90% HPD interval	Parameters	mean	90% HPD interval
$-\log(\beta)$	0.0030	[0.0014, 0.0046]	ρ_R	0.8063	[0.7516, 0.8612]
h	0.0699	[0.0083, 0.1304]	ρ_b	0.7081	[0.5836, 0.8358]
η	1.1903	[1.1040, 1.2844]	ρ_ϕ	0.9402	[0.9094, 0.9701]
γ_H	0.1461	[0.0359, 0.2489]	ρ_ϵ	0.1490	[0.0389, 0.2538]
γ_F	0.1183	[0.0271, 0.2038]	ρ_{ϵ^*}	0.1318	[0.0355, 0.2246]
θ_H	0.8893	[0.8490, 0.9300]	ρ_g	0.9100	[0.8873, 0.9335]
θ_F	0.9702	[0.9600, 0.9808]	ρ_z	0.2286	[0.0618, 0.3887]
ψ_π	1.1588	[0.8615, 1.4470]	ρ_π	0.995	fixed
ψ_Y	0.551	[0.3588, 0.7408]	σ_R	0.0024	[0.0018, 0.0030]
ψ_S	0.0202	[-0.0345, 0.0740]	σ_b	0.0030	[0.0019, 0.0041]
$\log \bar{u}_z$	0.0094	[0.0073, 0.0115]	σ_ϕ	0.0087	[0.0071, 0.0103]
$\log \bar{\Pi}$	0.0084	[0.0050, 0.0118]	σ_ϵ	0.0106	[0.0088, 0.0123]
$\log \tilde{\Delta s}$	-0.0009	[-0.0039, 0.0021]	σ_{ϵ^*}	0.0124	[0.0103, 0.0145]
$\log \tilde{\tau}$	0.0034	[0.0013, 0.0056]	σ_g	0.0022	[0.0019, 0.0026]
$\log \bar{u}_{z^*}$	0.0046	[0.0039, 0.0054]	σ_z	0.0267	[0.0197, 0.0336]
$\log \bar{\Pi}^*$	0.0068	[0.0056, 0.0080]	σ_π	0.0008	[0.0005, 0.0012]
$\log \bar{R}_1^*$	0.0108	[0.0086, 0.0129]	σ_{r_4}	0.0009	[0.0005, 0.0013]
$\tilde{\phi}_a$	0.0013	[0.0000, 0.0023]	σ_{r_8}	0.0012	[0.0009, 0.0015]
			$\sigma_{r_{20}}$	0.0007	[0.0005, 0.0009]
			$\sigma_{r_{40}}$	0.0006	[0.0004, 0.0008]

Notes: The table presents the posterior mean and 90% highest probability density (HPD) interval of the structural parameters for Model 2 estimated on macro and term structure data jointly. Note that Model 2 is a specification where ρ_π is fixed at 0.995.

Table 8: Posterior distribution of the structural parameters for New Zealand: Model 3 (macro data only)

Parameters	mean	90% HPD interval	Parameters	mean	90% HPD interval
$-\log(\beta)$	0.0031	[0.0015, 0.0046]	ρ_R	0.7846	[0.7339, 0.836]
h	0.3779	[0.0521, 0.7235]	ρ_b	0.4524	[0.1705, 0.7374]
η	0.8111	[0.7727, 0.8480]	ρ_ϕ	0.5540	[0.3937, 0.7132]
γ_H	0.2289	[0.0362, 0.4201]	ρ_ϵ	0.4179	[0.1271, 0.6801]
γ_F	0.3624	[0.0682, 0.6608]	ρ_{ϵ^*}	0.9977	[0.9957, 0.9999]
θ_H	0.7274	[0.5817, 0.8722]	ρ_g	0.4178	[0.1038, 0.7319]
θ_F	0.2197	[0.1193, 0.3158]	ρ_z	0.5313	[0.2233, 0.8410]
ψ_π	2.0714	[1.6801, 2.4582]	ρ_π	n/a	n/a
ψ_Y	0.2095	[0.1054, 0.3097]	σ_R	0.0111	[0.0026, 0.0231]
ψ_S	0.0335	[-0.0258, 0.0922]	σ_b	0.0047	[0.0028, 0.0066]
$\log\bar{u}_z$	0.0078	[0.0061, 0.0095]	σ_ϕ	0.0079	[0.0056, 0.0101]
$\log\bar{\Pi}$	0.0059	[0.0031, 0.0086]	σ_ϵ	0.1299	[0.0462, 0.2173]
$\log\tilde{\Delta s}$	-0.0001	[-0.0030, 0.0028]	σ_{ϵ^*}	0.006	[0.0027, 0.0094]
$\log\tilde{\tau}$	0.0017	[-0.0002, 0.0035]	σ_g	0.0027	[0.0022, 0.0031]
$\log\bar{u}_{z^*}$	0.005	[0.0045, 0.0055]	σ_z	0.0167	[0.0037, 0.0258]
$\log\bar{\Pi}^*$	0.0069	[0.0057, 0.0080]	σ_π	n/a	n/a
$\log\bar{R}_1^*$	0.0105	[0.0086, 0.0125]			
$\tilde{\phi}_a$	0.0009	[0.0002, 0.0016]			

Notes: The table presents the posterior mean and 90% highest probability density (HPD) interval of the structural parameters for the baseline specification estimated on *macro data only*. Note that Model 3 is a specification where the inflation target is assumed constant (zero).

Table 9: One-step ahead forecast error variance decomposition for Australia: Baseline (joint estimation)

	pref	risk	dom markup	imp markup	tech	money policy	gov't spend	inf target	me2	me3	me5	me10	foreign
							1 quarter ahead						
output growth	0.06	0.00	0.02	0.01	0.66	0.06	0.01	0.18	0.00	0.00	0.00	0.00	0.00
inflation	0.00	0.01	0.73	0.20	0.00	0.00	0.05	0.01	0.00	0.00	0.00	0.00	0.00
short term interest rates	0.00	0.10	0.24	0.07	0.01	0.50	0.04	0.03	0.00	0.00	0.00	0.00	0.02
exchange rate depreciation	0.00	0.73	0.00	0.00	0.02	0.02	0.06	0.07	0.00	0.00	0.00	0.00	0.09
terms of trade growth	0.00	0.04	0.17	0.77	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.01
2-year yields	0.04	0.07	0.19	0.02	0.08	0.15	0.31	0.11	0.01	0.00	0.00	0.00	0.02
3-year yields	0.02	0.04	0.13	0.01	0.10	0.09	0.47	0.10	0.00	0.01	0.00	0.00	0.02
5-year yields	0.01	0.02	0.07	0.00	0.08	0.04	0.69	0.06	0.00	0.00	0.01	0.00	0.02
10-year yields	0.00	0.00	0.02	0.00	0.04	0.01	0.86	0.02	0.00	0.00	0.00	0.02	0.03
							40 quarters ahead						
output growth	0.06	0.00	0.02	0.01	0.69	0.05	0.01	0.15	0.00	0.00	0.00	0.00	0.00
inflation	0.00	0.01	0.27	0.07	0.00	0.00	0.60	0.02	0.00	0.00	0.00	0.00	0.03
short term interest rates	0.00	0.02	0.07	0.01	0.05	0.06	0.70	0.04	0.00	0.00	0.00	0.00	0.04
exchange rate depreciation	0.00	0.72	0.00	0.00	0.02	0.02	0.08	0.07	0.00	0.00	0.00	0.00	0.10
terms of trade growth	0.00	0.09	0.15	0.69	0.01	0.00	0.02	0.01	0.00	0.00	0.00	0.00	0.03
2-year yields	0.00	0.01	0.02	0.00	0.04	0.01	0.83	0.03	0.00	0.00	0.00	0.00	0.04
3-year yields	0.00	0.01	0.01	0.00	0.03	0.01	0.87	0.02	0.00	0.00	0.00	0.00	0.05
5-year yields	0.00	0.00	0.01	0.00	0.02	0.00	0.90	0.01	0.00	0.00	0.00	0.00	0.05
10-year yields	0.00	0.00	0.00	0.00	0.01	0.00	0.91	0.00	0.00	0.00	0.00	0.00	0.07

Notes: pref- preference shock, risk- risk premium shock, dom markup- domestic goods mark-up shock, imp markup- imported goods mark-up shock, tech- technology shock, money policy- monetary policy shock, gov't spend- government spending shock, inf target- inflation target shock, me2- measurement errors for 2-year yields, me3- measurement errors for 3-year yields, me5- measurement errors for 5-year yields, me10- measurement error for 10-year yields, foreign- aggregate of three shocks to the foreign block.

Table 10: One-step ahead forecast error variance decomposition for Australia: Baseline (macro estimation)

	pref	risk	dom markup	imp markup	tech	money policy	gov't spend	inf target	foreign
1 quarter ahead									
output growth	0.29	0.00	0.01	0.00	0.33	0.01	0.29	0.01	0.06
inflation	0.00	0.02	0.38	0.12	0.00	0.23	0.00	0.14	0.11
short term interest rates	0.01	0.05	0.05	0.03	0.00	0.50	0.00	0.15	0.20
exchange rate depreciation	0.00	0.04	0.15	0.36	0.00	0.23	0.00	0.11	0.10
terms of trade growth	0.00	0.02	0.42	0.14	0.00	0.20	0.00	0.11	0.11
40 quarters ahead									
output growth	0.30	0.00	0.01	0.01	0.30	0.02	0.29	0.01	0.06
inflation	0.01	0.01	0.30	0.11	0.00	0.24	0.00	0.21	0.12
short term interest rates	0.06	0.02	0.17	0.06	0.00	0.18	0.00	0.27	0.24
exchange rate depreciation	0.00	0.05	0.15	0.36	0.00	0.23	0.00	0.11	0.10
terms of trade growth	0.00	0.02	0.39	0.15	0.00	0.20	0.00	0.12	0.12

Notes: pref- preference shock, risk- risk premium shock, dom markup- domestic goods mark-up shock, imp markup- imported goods mark-up shock, tech- technology shock, money policy- monetary policy shock, gov't spend- government spending shock, inf target- inflation target shock, foreign- aggregate of three shocks to the foreign block.

Table 11: One-step ahead forecast error variance decomposition for Canada: Model 2 (joint estimation)

	pref	risk	dom markup	imp markup	tech	money policy	gov't spend	inf target	me2	me3	me5	me10	foreign
							1 quarter ahead						
output growth	0.08	0.02	0.02	0.01	0.37	0.07	0.32	0.06	0.00	0.00	0.00	0.00	0.05
inflation	0.00	0.00	0.54	0.43	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00
short term interest rates	0.01	0.06	0.13	0.17	0.00	0.54	0.01	0.03	0.00	0.00	0.00	0.00	0.05
exchange rate depreciation	0.00	0.42	0.02	0.03	0.00	0.03	0.22	0.08	0.00	0.00	0.00	0.00	0.20
terms of trade growth	0.00	0.00	0.65	0.35	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2-year yields	0.08	0.04	0.04	0.19	0.00	0.17	0.06	0.26	0.01	0.00	0.00	0.00	0.14
3-year yields	0.04	0.03	0.01	0.16	0.00	0.11	0.07	0.41	0.00	0.02	0.00	0.00	0.15
5-year yields	0.02	0.01	0.00	0.12	0.00	0.05	0.05	0.61	0.00	0.00	0.01	0.00	0.13
10-year yields	0.01	0.00	0.01	0.06	0.00	0.01	0.01	0.81	0.00	0.00	0.00	0.02	0.07
							40 quarters ahead						
output growth	0.09	0.02	0.02	0.01	0.38	0.07	0.30	0.05	0.00	0.00	0.00	0.00	0.05
inflation	0.00	0.00	0.29	0.24	0.00	0.00	0.02	0.39	0.00	0.00	0.00	0.00	0.06
short term interest rates	0.01	0.02	0.06	0.09	0.00	0.10	0.03	0.60	0.00	0.00	0.00	0.00	0.09
exchange rate depreciation	0.00	0.41	0.02	0.03	0.00	0.04	0.21	0.09	0.00	0.00	0.00	0.00	0.20
terms of trade growth	0.00	0.00	0.65	0.35	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2-year yields	0.01	0.01	0.04	0.05	0.00	0.02	0.03	0.77	0.00	0.00	0.00	0.00	0.08
3-year yields	0.00	0.01	0.03	0.04	0.00	0.01	0.02	0.81	0.00	0.00	0.00	0.00	0.07
5-year yields	0.00	0.01	0.03	0.03	0.00	0.00	0.01	0.86	0.00	0.00	0.00	0.00	0.06
10-year yields	0.00	0.01	0.03	0.02	0.00	0.00	0.00	0.90	0.00	0.00	0.00	0.00	0.05

Notes: pref- preference shock, risk- risk premium shock, dom markup- domestic goods mark-up shock, imp markup- imported goods mark-up shock, tech- technology shock, money policy- monetary policy shock, gov't spend- government spending shock, inf target- inflation target shock, me2- measurement errors for 2-year yields, me3- measurement errors for 3-year yields, me5- measurement errors for 5-year yields, me10- measurement error for 10-year yields, foreign- aggregate of three shocks to the foreign block.

Table 12: One-step ahead forecast error variance decomposition for Canada: Baseline (macro estimation)

	pref	risk	dom markup	imp markup	tech	money policy	gov't spend	inf target	foreign
					1 quarter ahead				
output growth	0.31	0.00	0.01	0.04	0.33	0.04	0.15	0.03	0.10
inflation	0.00	0.00	0.60	0.39	0.00	0.00	0.00	0.00	0.00
short term interest rates	0.02	0.04	0.06	0.16	0.00	0.59	0.00	0.07	0.06
exchange rate depreciation	0.02	0.11	0.19	0.01	0.00	0.23	0.01	0.30	0.14
terms of trade growth	0.00	0.00	0.68	0.32	0.00	0.00	0.00	0.00	0.00
					40 quarters ahead				
output growth	0.31	0.00	0.01	0.04	0.35	0.03	0.14	0.03	0.08
inflation	0.02	0.00	0.56	0.35	0.00	0.00	0.00	0.04	0.03
short term interest rates	0.23	0.01	0.13	0.21	0.01	0.31	0.00	0.05	0.06
exchange rate depreciation	0.02	0.13	0.18	0.01	0.00	0.22	0.01	0.29	0.15
terms of trade growth	0.00	0.00	0.68	0.31	0.00	0.00	0.00	0.01	0.00

Notes: pref- preference shock, risk- risk premium shock, dom markup- domestic goods mark-up shock, imp markup- imported goods mark-up shock, tech- technology shock, money policy- monetary policy shock, gov't spend- government spending shock, inf target- inflation target shock, foreign- aggregate of three shocks to the foreign block.

Table 13: One-step ahead forecast error variance decomposition for New Zealand: Model 2 (joint estimation)

	pref	risk	dom markup	imp markup	tech	money policy	gov't spend	inf target	me1	me2	me5	me10	foreign
1 quarter ahead													
output growth	0.02	0.00	0.01	0.01	0.80	0.03	0.10	0.03	0.00	0.00	0.00	0.00	0.01
inflation	0.00	0.00	0.42	0.55	0.00	0.00	0.01	0.02	0.00	0.00	0.00	0.00	0.00
short term interest rates	0.01	0.02	0.16	0.21	0.00	0.57	0.01	0.02	0.00	0.00	0.00	0.00	0.01
exchange rate depreciation	0.00	0.60	0.00	0.00	0.00	0.02	0.24	0.07	0.00	0.00	0.00	0.00	0.05
terms of trade growth	0.00	0.00	0.41	0.59	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2-year yields	0.13	0.02	0.14	0.20	0.00	0.32	0.05	0.12	0.01	0.00	0.00	0.00	0.02
3-year yields	0.08	0.02	0.09	0.15	0.00	0.20	0.08	0.30	0.00	0.03	0.00	0.00	0.03
5-year yields	0.02	0.01	0.02	0.06	0.00	0.06	0.06	0.72	0.00	0.00	0.02	0.00	0.03
10-year yields	0.00	0.00	0.00	0.02	0.00	0.01	0.01	0.90	0.00	0.00	0.00	0.02	0.03
40 quarters ahead													
output growth	0.02	0.00	0.01	0.01	0.79	0.03	0.11	0.03	0.00	0.00	0.00	0.00	0.00
inflation	0.00	0.01	0.21	0.27	0.00	0.00	0.05	0.44	0.00	0.00	0.00	0.00	0.01
short term interest rates	0.01	0.02	0.04	0.06	0.00	0.10	0.04	0.69	0.00	0.00	0.00	0.00	0.02
exchange rate depreciation	0.00	0.59	0.00	0.00	0.00	0.03	0.23	0.09	0.00	0.00	0.00	0.00	0.11
terms of trade growth	0.00	0.00	0.42	0.58	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
2-year yields	0.01	0.02	0.02	0.04	0.00	0.04	0.04	0.79	0.00	0.00	0.00	0.00	0.06
3-year yields	0.01	0.02	0.01	0.02	0.00	0.02	0.04	0.86	0.00	0.00	0.00	0.00	0.07
5-year yields	0.00	0.02	0.00	0.01	0.00	0.00	0.02	0.91	0.00	0.00	0.00	0.00	0.07
10-year yields	0.00	0.03	0.00	0.00	0.00	0.00	0.02	0.92	0.00	0.00	0.00	0.00	0.09

Notes: pref- preference shock, risk- risk premium shock, dom markup- domestic goods mark-up shock, imp markup- imported goods mark-up shock, tech- technology shock, money policy- monetary policy shock, gov't spend- government spending shock, inf target- inflation target shock, me1- measurement errors for 1-year yields, me2- measurement errors for 2-year yields, me5- measurement errors for 5-year yields, me10- measurement error for 10-year yields, foreign- aggregate of three shocks to the foreign block.

Table 14: One-step ahead forecast error variance decomposition for New Zealand: Model 3 (macro estimation)

	pref	risk	dom markup	imp markup	tech	money policy	gov't spend	inf target	foreign
					1 quarter ahead				
output growth	0.24	0.02	0.02	0.04	0.28	0.00	0.36	n/a	0.03
inflation	0.01	0.33	0.03	0.01	0.00	0.36	0.02		0.25
short term interest rates	0.01	0.41	0.03	0.01	0.00	0.24	0.00		0.30
exchange rate depreciation	0.00	0.05	0.09	0.79	0.00	0.04	0.00		0.03
terms of trade growth	0.01	0.08	0.76	0.01	0.00	0.07	0.00		0.06
					40 quarters ahead				
output growth	0.25	0.02	0.02	0.03	0.27	0.00	0.38	n/a	0.04
inflation	0.01	0.18	0.18	0.20	0.00	0.21	0.01		0.10
short term interest rates	0.05	0.10	0.32	0.25	0.00	0.05	0.00		0.15
exchange rate depreciation	0.00	0.06	0.09	0.77	0.00	0.04	0.00		0.11
terms of trade growth	0.01	0.08	0.78	0.01	0.00	0.06	0.00		0.09

Notes: pref- preference shock, risk- risk premium shock, dom markup- domestic goods mark-up shock, imp markup- imported goods mark-up shock, tech- technology shock, money policy- monetary policy shock, gov't spend- government spending shock, inf target- inflation target shock, foreign- aggregate of three shocks to the foreign block.

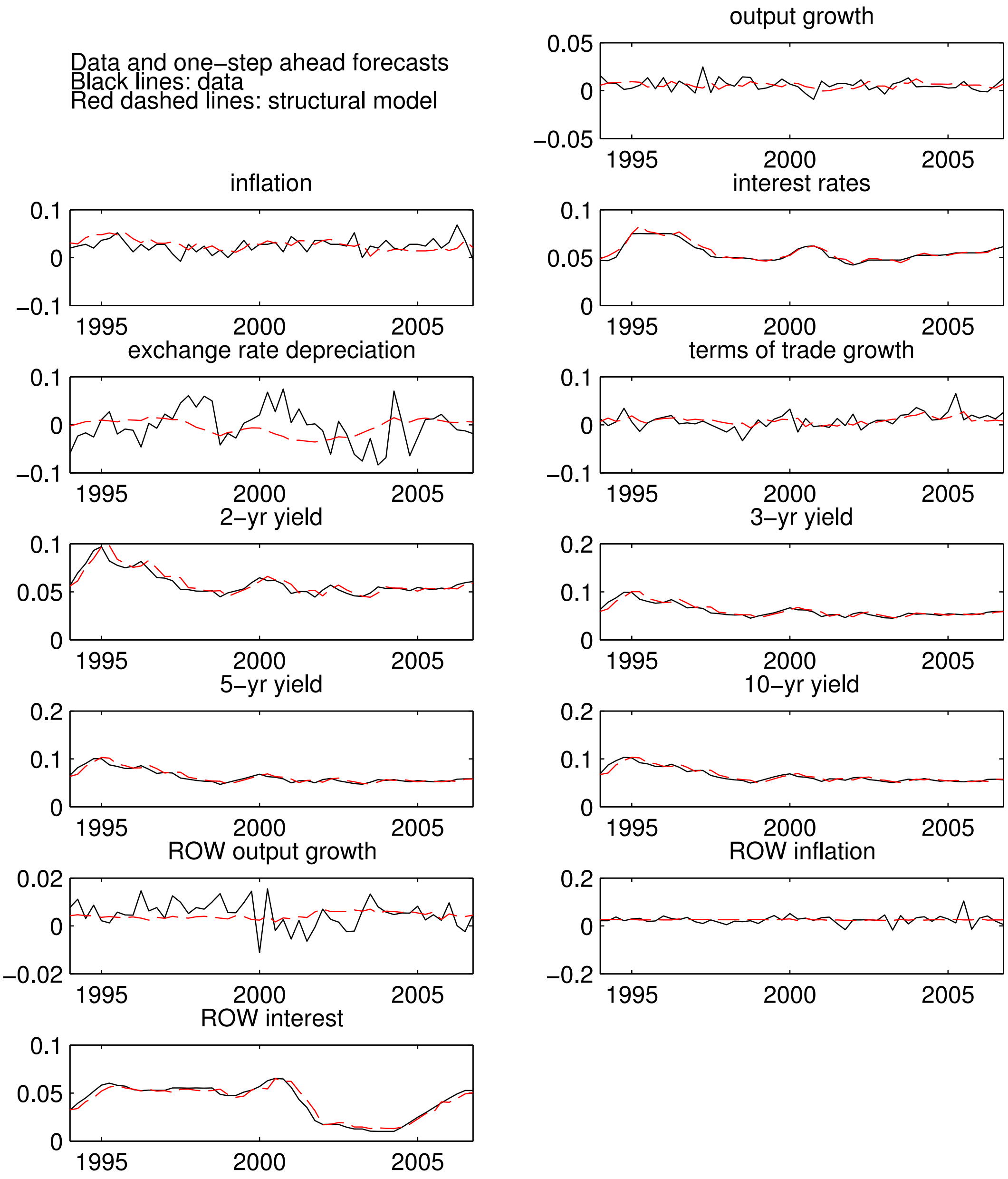

Figure 1: Data and Model Fit

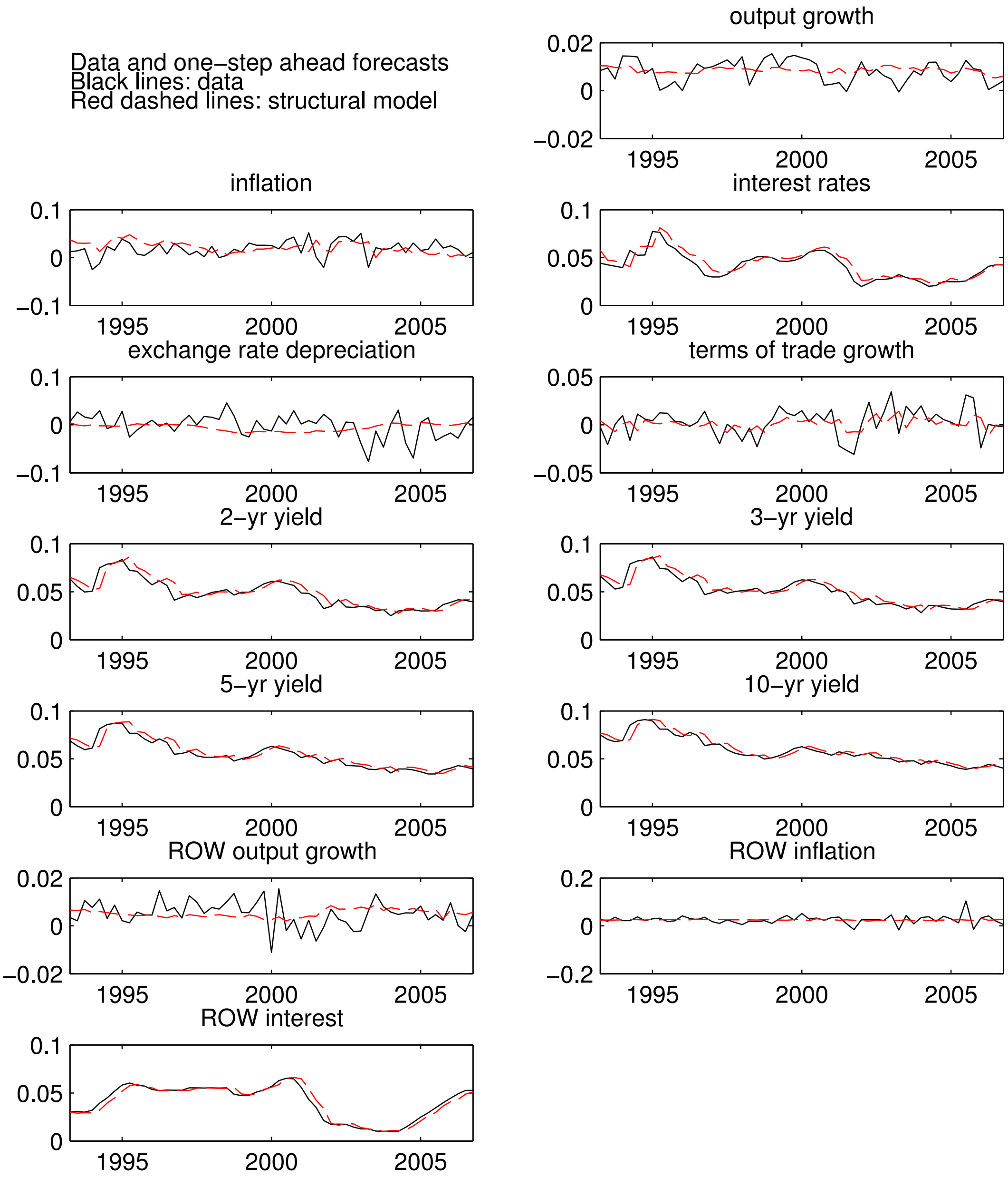

Figure 2: Data and Model Fit

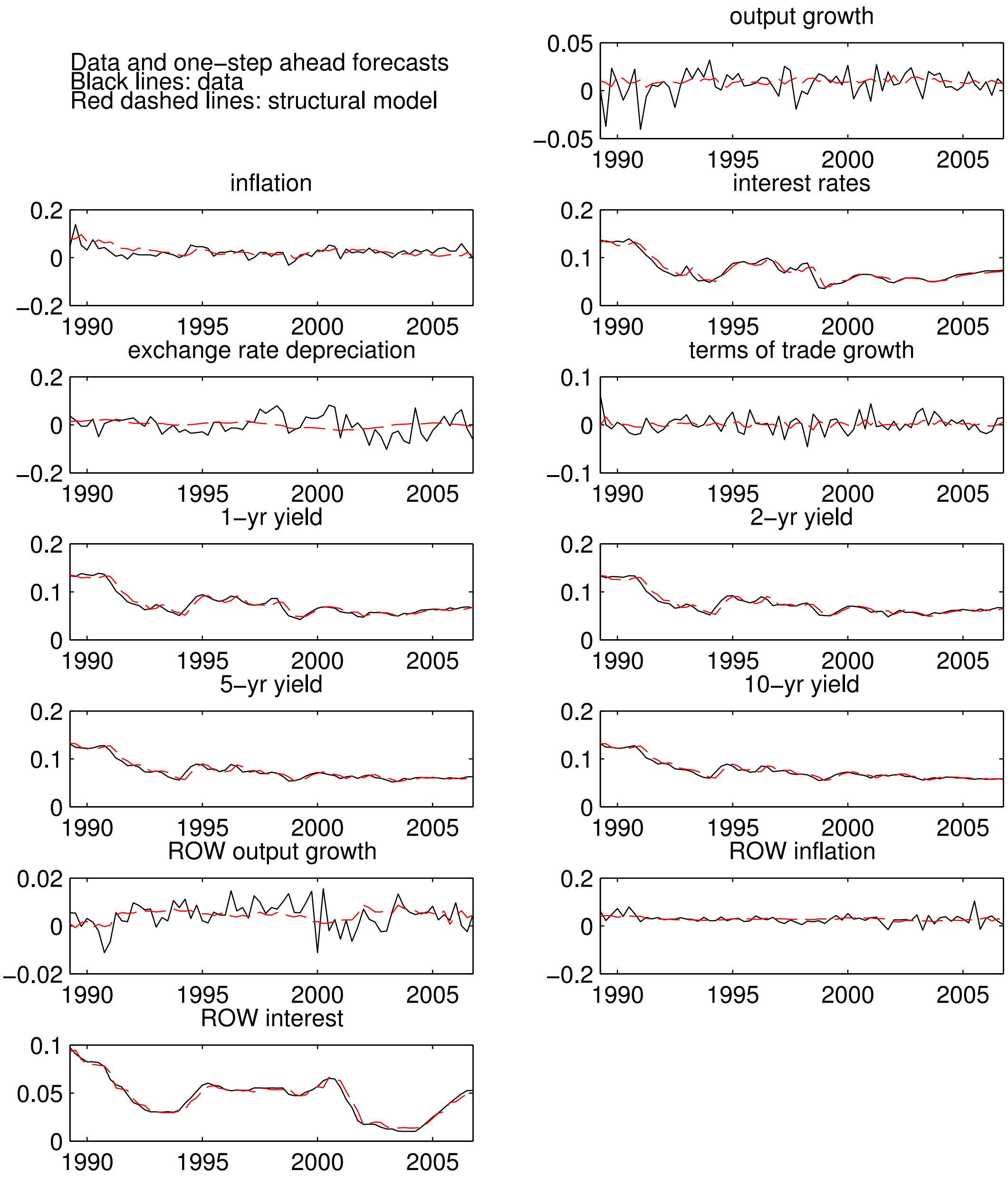

Figure 3: Data and Model Fit

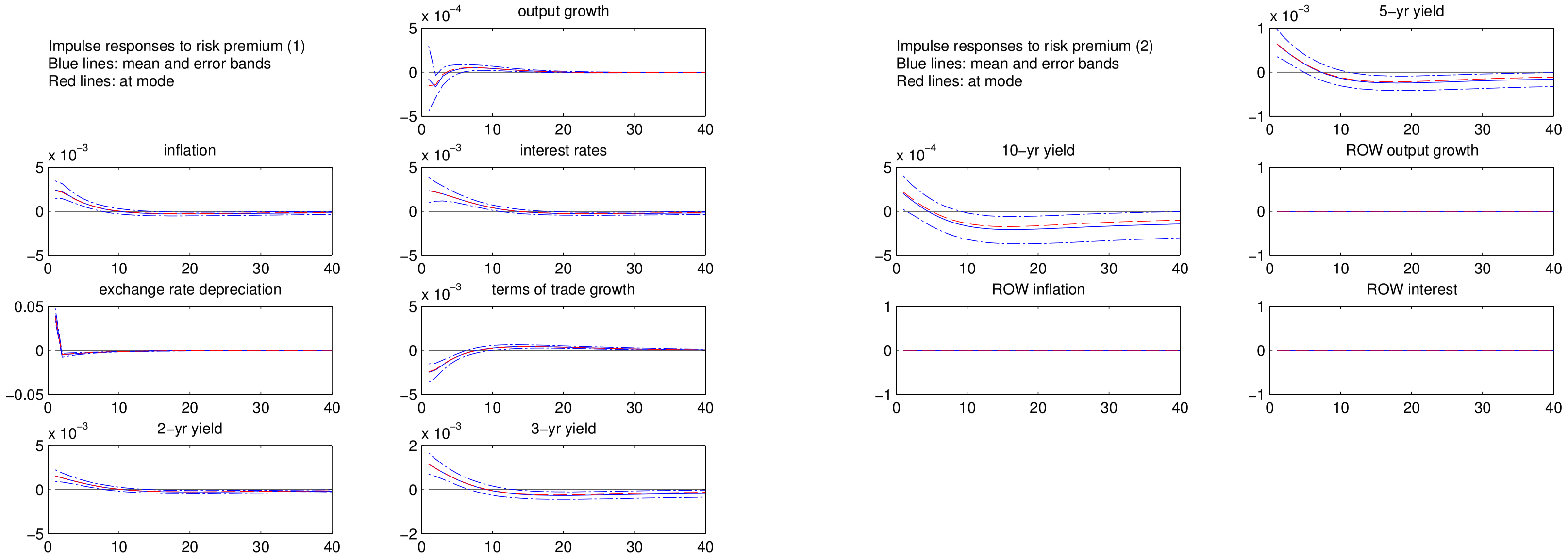

Figure 4: Impulse responses to the risk premium shock in Australia: Baseline (joint estimation)

Notes: The plots present the posterior mean and 5% and 95% quantiles of impulse responses at each point in time. The size of the shock is one standard deviation.

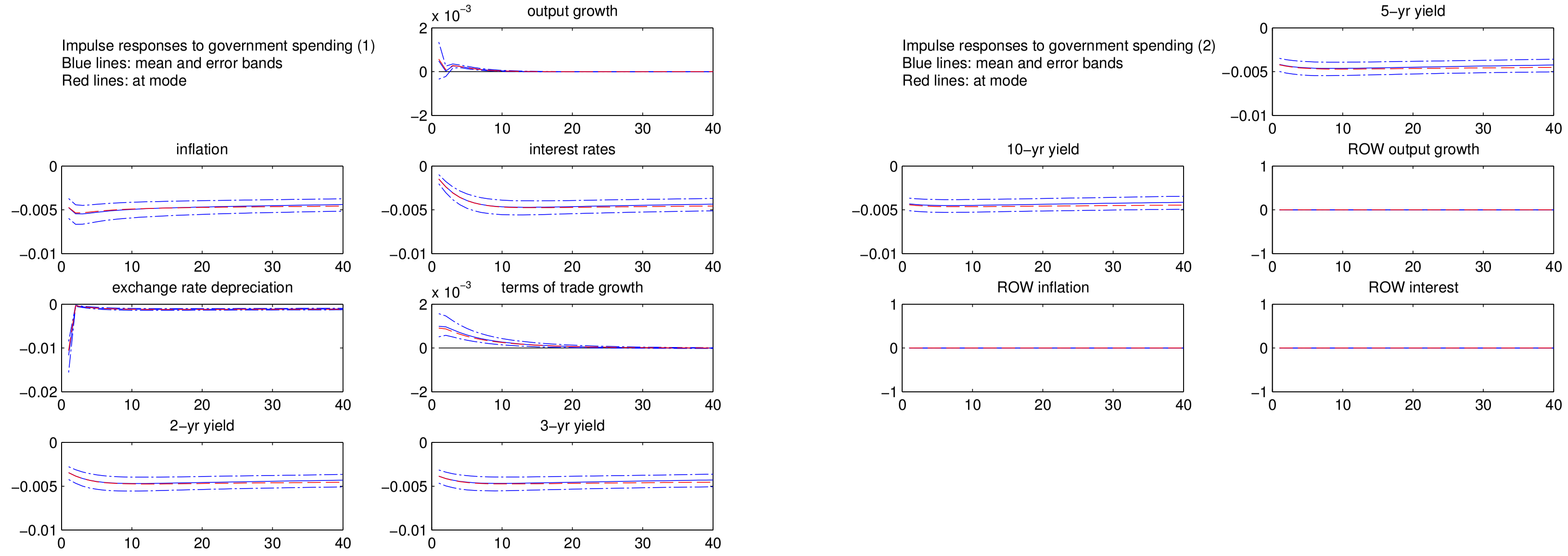

Figure 5: Impulse responses to the government spending shock in Australia: Baseline (joint estimation)

Notes: The plots present the posterior mean and 5% and 95% quantiles of impulse responses at each point in time. The size of the shock is one standard deviation.

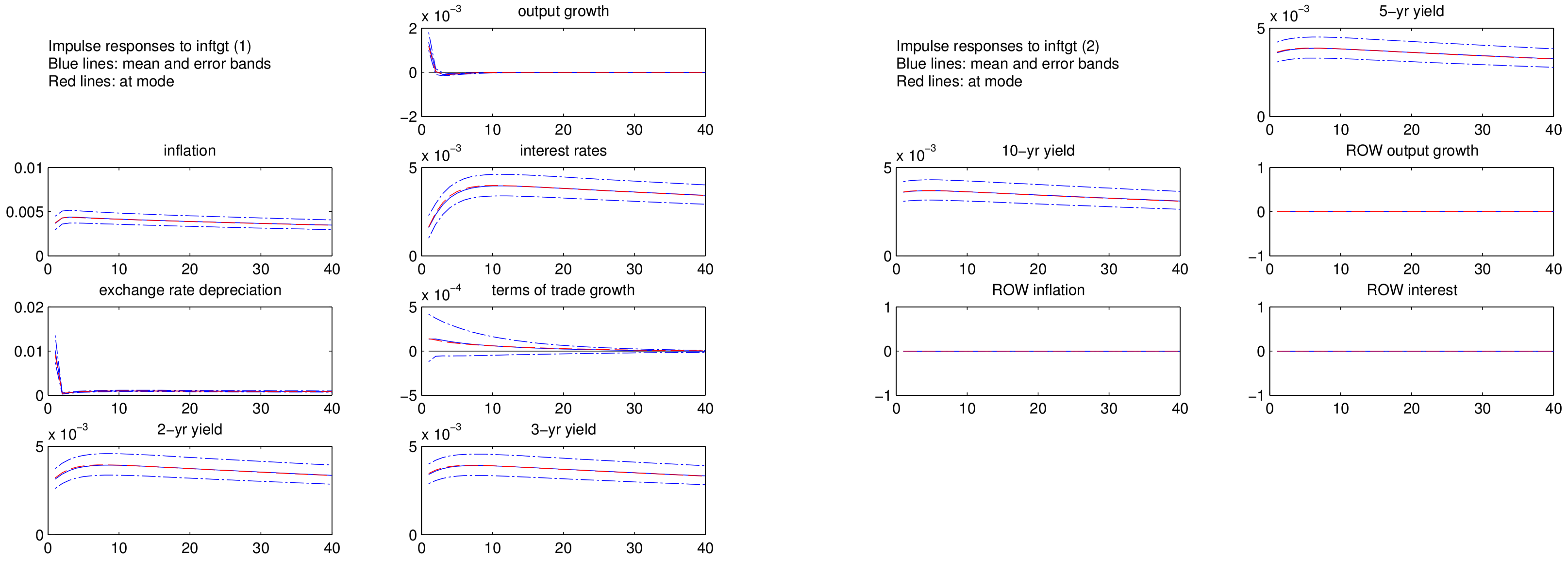

Figure 6: Impulse responses to the inflation target shock in Australia: Model 2(joint estimation)

Notes: The plots present the posterior mean and 5% and 95% quantiles of impulse responses at each point in time. The size of the shock is one standard deviation.

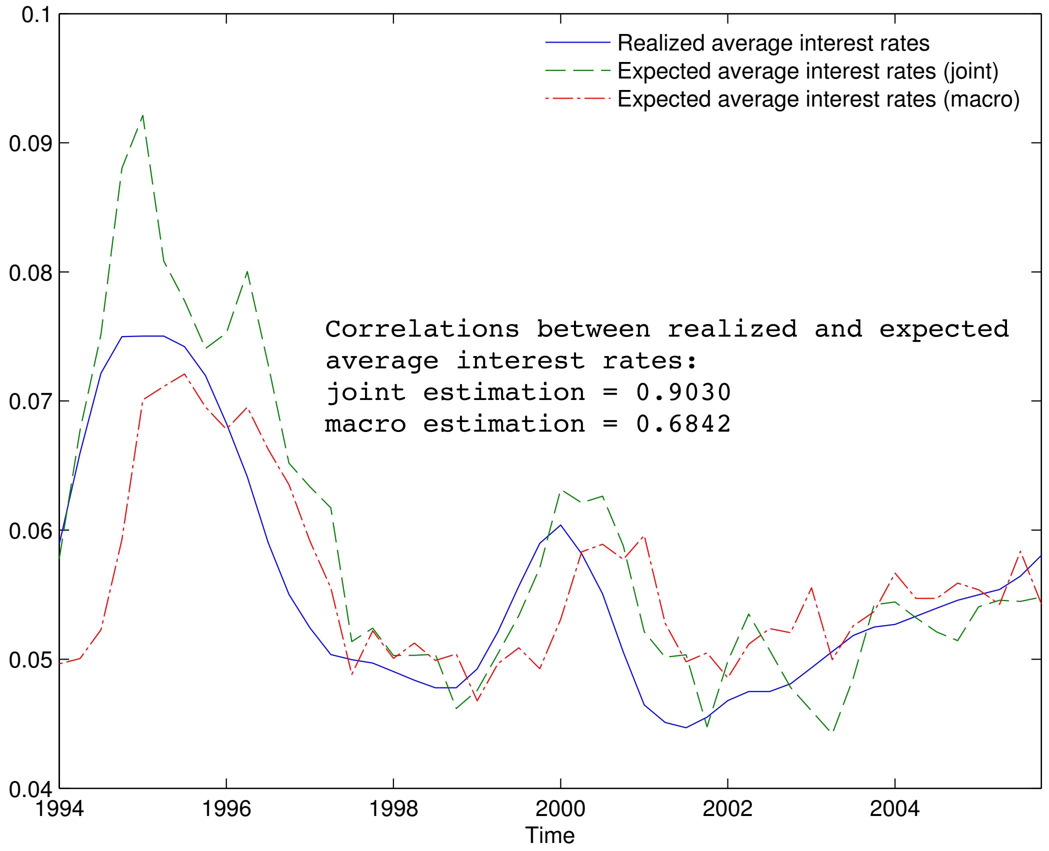

Figure 7: Expected vs. realized average policy interest rates over 1 year in Australia: best-fitting specification

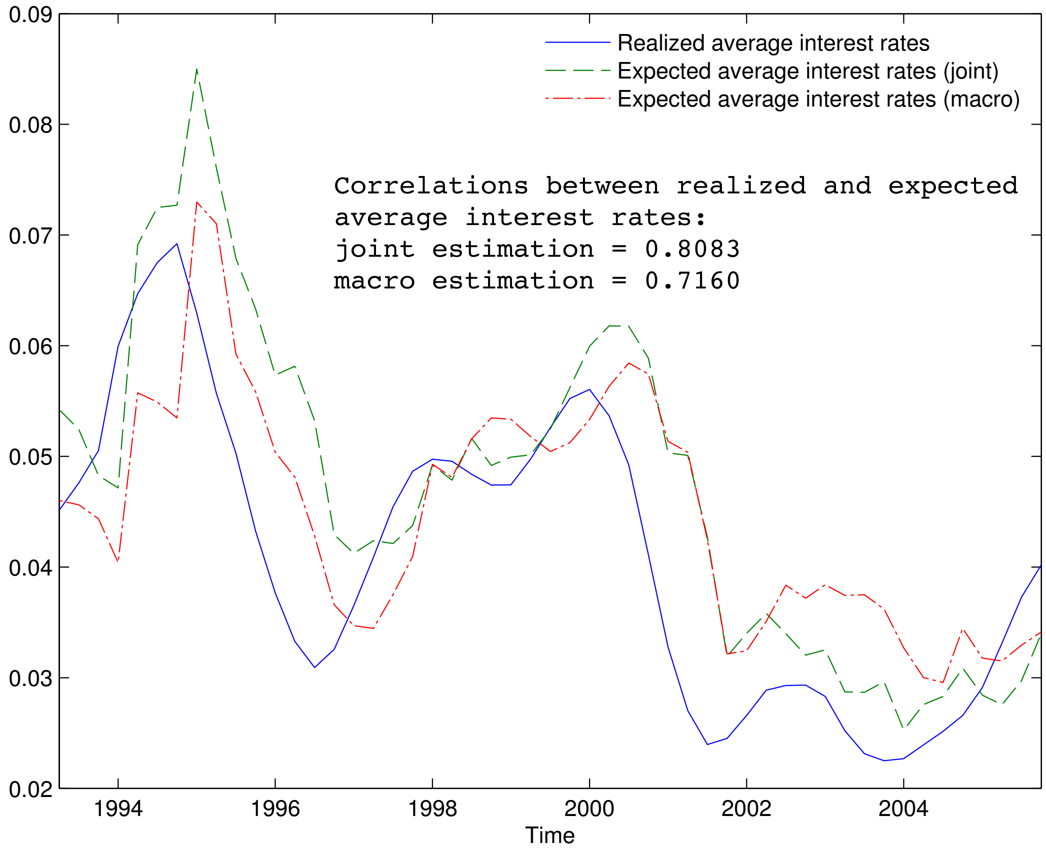

Figure 8: Expected vs. realized average policy interest rates over 1 year in Canada: best-fitting specification

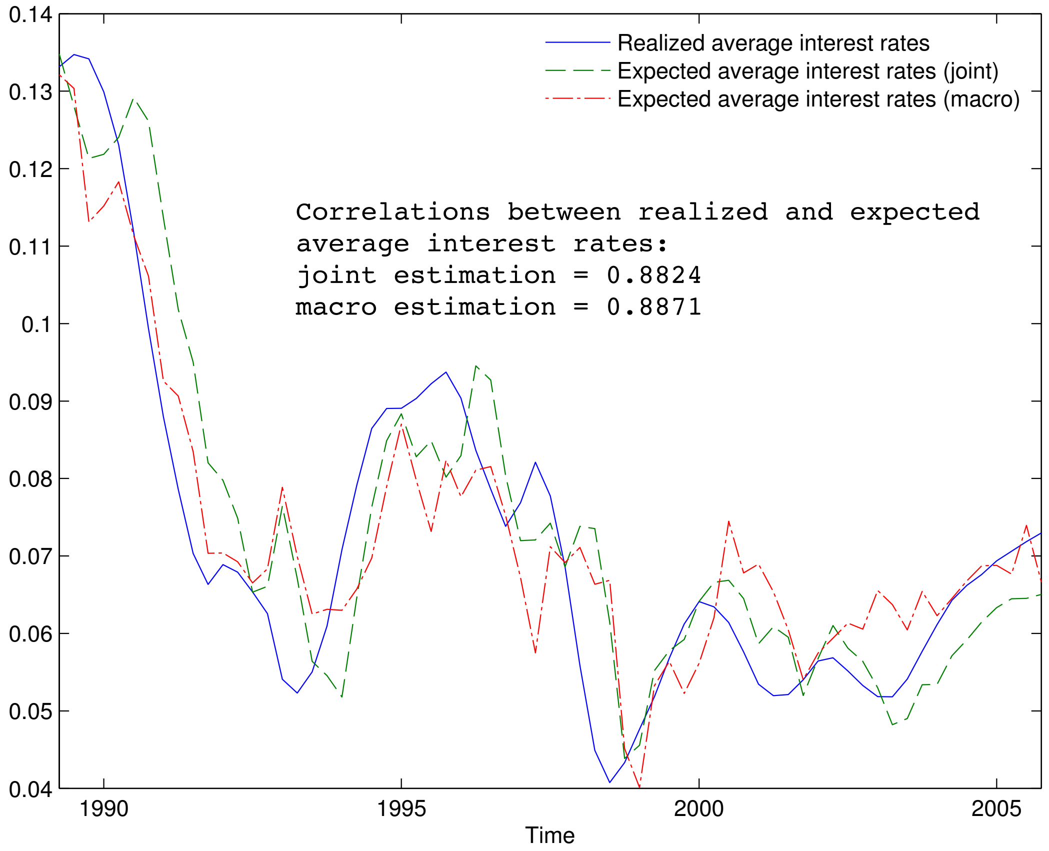

Figure 9: Expected vs. realized average policy interest rates over 1 year in New Zealand: best-fitting specification