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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. In New Zealand, estimation results based on only macro data produce a high correlation between the model-implied interest rate expectations and the ex-post realized interest rates because information from the yield curve has been explicitly incorporated in monetary policy decisions. We also document that a persistent shock to the inflation target driving the average level of the yield curve in these three countries is highly correlated with long-horizon inflation expectations in the U.S., indicating stronger financial linkages. **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 contains information on the future evolution of the short-term interest rate perceived by financial market participants.[1] Such information can be useful to better understand monetary policy transmission channels since not only current short-term interest rates, but also long-term interest rates and future short-term interest rates matter in consumption and investment decisions made by households and firms. It is particularly important for small open economy central banks to understand the 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 affect this transmission channel.

This paper aims to study information on monetary policy expectations embedded in the yield curve using a DSGE model with a 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.

We address two main questions regarding the conduct of monetary policy in inflation-targeting small open economies. First, we investigate whether 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 anchored to the expectations of the future monetary policy actions on the short-term interest rate? Second, are policy expectations driven by foreign disturbances or domestic disturbances? By incorporating multiple domestic and foreign shocks that can drive persistent movements in policy expectations, we provide the structural interpretation of forces driving policy expectations.

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 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 the central bank in New Zealand explicitly considered yield curve information in determining the short-term interest rate. Therefore, the current level of the short-term interest rate provides sufficient information on the future stance of monetary policy in New Zealand. While the estimated inflation target is highly correlated with survey data on long-horizon domestic consumer price inflation

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

expectations in Australia, the connection is much lower in Canada and even in the opposite direction in New Zealand. Interestingly, we find that the estimated inflation target is highly correlated with survey data evidence on long-horizon inflation expectations in the United States for all the three countries. Notably, our inflation target shock is not significantly correlated with contemporaneous inflation, output, and the short-term interest rate in domestic and foreign economies. In this sense, the time-varying inflation target may capture the impact of a distinctive foreign disturbance affecting the level of long-term interest rates in these three advanced small open economies.

Our paper is related to the literature on small open economy models 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 the central bank of Canada did respond to the nominal exchange rate while the central banks 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 more stylized than ours in that they abstract 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. They argue that foreign macro shocks are more persistent than domestic macro shocks, explaining higher international correlations in longer-term interest rates than short-term interest rates. While the inflation target shock shifting the level of long-term interest rates in our model is more highly correlated with long-term inflation expectations in the U.S., it is not so strongly correlated with the U.S. macro data. In this sense, our inflation target shock is distinguished from foreign macro shocks emphasized by Kulish and Rees (2011) and is more likely to be interpreted as a sort of international financial shock affecting the level of long-term interest rates in advanced small open economies at the same time.

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 the retail sector 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. We also assume that domestic exporters set their prices in the local currency so that the exchange rate pass-through to export prices is incomplete too. The local currency pricing of exporters is consistent with the predominant dollar-invoicing of exporters in non-US open economies as documented by Gopinath (2015). Second, we assume that domestic residents in small open economies entertain complete risk sharing for domestic idiosyncratic risks but not for domestic and foreign aggregate risks. We assume that agents of the small open economy can trade a complete set of state-contingent assets with which they can insure against domestic idiosyncratic shocks while they can trade only non-state contingent nominal bonds internationally. Also, the model includes a debt-elastic risk premium shock. Consequentially, international risk-sharing is incomplete and domestic agents cannot fully insure themselves against both domestic and foreign aggregate risks. Third, we do not consider endogenous capital accumulation in order to facilitate comparison with the literature and maintain simplicity.

The model is similar to Justiniano and Preston (2010), which is closely related to Monacelli (2005) and Gali and Monacelli (2005). However, we add more real and nominal disturbances to the model in Justiniano and Preston (2010) and adopt the local currency pricing of exporters as well as importers.[2] In our model, markup shocks produce exogenous variations in inflation for both domestically produced goods and imported goods, and the monetary policy rule includes a time-varying inflation target that can take various degrees of persistence. In addition, we include the term structure of domestic nominal bond yields in the estimation of the model unlike in Justinian and Preston (2010). Using

[2] Choudhri and Hakura (2015) consider a mix of producer and local currency pricing of exporters in a small open economy model to match the degree of exchange rate pass-through. Since our main objective is not to match the degree of the exchange rate pass-through, we consider only one type of currency pricing for exporters and importers for the beauty of simplicity but it would be an interesting extension to consider such a mix.

no-arbitrage conditions that involve the stochastic discount factor of the representative household 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.[3]

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.

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

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

where $C_t(i)$ is the consumption basket and $N_t(i)$ is the labor supply by household i.[4] The consumption 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 $C_{F,t}(i)$

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

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

[3] Since we consider nominal government bonds denominated in domestic currency, the risk of "default" in the contractual sense is nearly zero although the higher than expected inflation can erode the real values of these bonds.

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

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 $\varepsilon_{b,t} \sim N\left(0, \sigma_b^2\right)$. 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

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

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 goods 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 aggregate shocks. Therefore, households are insured against the domestic idiosyncratic risk, but not against the risk due to domestic and foreign aggregate shocks.

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 domestic final goods with the technology

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

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

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

where $\bar{u}_\epsilon = \bar{\epsilon}/(\bar{\epsilon}-1)$, $0 < \rho_{\epsilon_H} < 1$ and $\varepsilon_{\epsilon_H,t} \sim N\left(0, \sigma_{\epsilon_H}^2\right)$. The parameter $\bar{\epsilon}$ is the steady state value of $\epsilon_{H,t}$. 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 for domestic consumption is determined as

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

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

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

2.2.2 Domestic intermediate good producers

A continuum of firms on a unit interval $[0,1]$ produce differentiated intermediate goods. They produce goods for both domestic consumption, denoted by $Y_{H,t}(j)$, and exports, denoted by $Y_{H,t}^*(j)$. An intermediate-good producer $j \in [0,1]$ has a production technology

$$Y_{H,t}(j) + Y_{H,t}^*(j) = Z_t N_t(j), \tag{8}$$

where $N_t(j)$ is labor input. 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

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

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.[5] Firms price to market and set domestic currency prices and foreign currency prices separately. We first consider the optimal pricing problem of firms in terms of domestic currency. Here, 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 in domestic currency 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 domestic currency 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

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

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

$$P_{H,t} = \left[\theta_H \left(P_{H,t-1}\Pi_{H,t-1}^{\gamma_H}\bar{\Pi}_H^{1-\gamma_H} \right)^{1-\epsilon_{H,t}} + (1-\theta_H)\left(\tilde{P}_{H,t}\right)^{1-\epsilon_{H,t}} \right]^{\frac{1}{1-\epsilon_{H,t}}}. \tag{9}$$

We define $u_{\epsilon_H,t} = \epsilon_{H,t}/(\epsilon_{H,t}-1)$ and assume that

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

where $\bar{u}_\epsilon = \bar{\epsilon}/(\bar{\epsilon}-1)$, $0 < \rho_{\epsilon_H} < 1$ and $\varepsilon_{\epsilon_H,t} \sim N\left(0, \sigma_{\epsilon_H}^2\right)$. The parameter $\bar{\epsilon}$ is the steady state value of $\epsilon_{H,t}$.

Now we consider the optimal pricing problem of firms in terms of foreign currency. We assume

[5] We assume that foreign importers of domestically produced intermediate goods have a similar aggregation technology such as $Y_{H,t}^* = \left[\int_0^1 Y_{H,t}^*(j)^{1-\frac{1}{\epsilon_{H,t}^*}} dj\right]^{\frac{\epsilon_{H,t}^*}{\epsilon_{H,t}^*-1}}$.

that firms convert all the profits from exports to the domestic economy and set foreign currency prices to maximize the expected present value of profit streams from exports in terms of domestic currency.[6] Firms are exposed to a different degree of nominal rigidity in the foreign market. Each period, a fraction $0 < \theta_H^* < 1$ of the intermediate-good producers cannot adjust their prices in domestic currency 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 foreign currency 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 in terms of domestic currency

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

where

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

subject to the demand for intermediate good j

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

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,

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

We define $u_{\epsilon_H^*,t} = \epsilon_{H,t}^* / \left(\epsilon_{H,t}^* - 1 \right)$ and assume that

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

where $\bar{u}_\epsilon = \bar{\epsilon}/(\bar{\epsilon}-1)$, $0 < \rho_{\epsilon_H^*} < 1$ and $\varepsilon_{\epsilon_H^*,t} \sim N\left(0, \sigma_{\epsilon_H^*}^2\right)$. The parameter $\bar{\epsilon}$ is the steady state value of $\epsilon_{H,t}^*$.

[6] Choudhri and Hakura (2015) adopt the same assumption in solving the optimal pricing problem for exporters under the local currency pricing.

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

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

where $\epsilon_{F,t} > 1$ is a time-varying elasticity of intratemporal substitution among differentiated imported goods. We define $u_{\epsilon_F,t} = \epsilon_{F,t}/\left(\epsilon_{F,t}-1\right)$ and assume that

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

where $\bar{u}_{\epsilon_F} = \bar{\epsilon_F}/\left(\bar{\epsilon_F}-1\right)$, $0 < \rho_{\epsilon_F} < 1$ and $\varepsilon_{\epsilon_F,t} \sim N\left(0, \sigma_{\epsilon_F}^2\right)$. The parameter $\bar{\epsilon}_F$ is the steady state value of $\epsilon_{F,t}$, 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

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

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

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

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 $S_t P_{F,t}^*\left(j\right)$ where $P_{F,t}^*\left(j\right)$ 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 export 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

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

where $\Pi_{F,t} = P_{F,t}/P_{F,t-1}$ is the gross inflation rate of the domestic currency 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

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

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,

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

with $0 < \rho_g < 1$ and $\varepsilon_{g,t} \sim N\left(0, \sigma_g^2\right)$. 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[7]

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

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

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

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 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 findings in our model.

We incorporate a time-varying inflation target $\tilde{\Pi}_t$ to explain potential low-frequency movements of inflation or the nominal interest rate in our baseline specification.[8]

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 inflation target moves very slowly. 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 $0 < \rho_R < 1$.

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

[8] Since we assume the stationary process for $\tilde{\Pi}_t$, it shows up in the monetary policy rule but does not have any impact in Phillips curves for various measures of inflation. For this reason, it can be best interpreted as a persistent shock to the intercept of a Taylor rule.

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.[9] Let $\xi_t^* = \left(y_t^*, \Pi_t^*, R_{1,t}^*\right)'$. Then

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

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

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

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

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

[9] 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.

$$C_{F,t} \quad = \quad \int_0^1 C_{F,t}\left(j\right)dj = C_{F,t}\left(i\right),$$

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

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

where $C_{H,t}^* = Y_{H,t}^*$ is the exports to the rest of the world. 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

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

For the domestic bond, we assume zero net supply as

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

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

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

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

Lastly, the market clearing condition for labor is given by

$$N_t = \int_0^1 N_t(i)di.$$

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.[10]

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

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

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.[11] 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.

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

[11] 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.

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 $Q_{t,t+1}$.[12] 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 structural 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.[13] 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; it is interesting to analyze the role of inflation targeting policy that these three countries adopted one after another in determining inflation and policy rate expectations.

[12] 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.

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

The dataset includes the growth rate of GDP per capita $\Delta \log (GDP_t)$, annualized CPI inflation rates $4 \times \log (\Pi_t)$, annualized one-period nominal interest rates $4 \times \log (R_{1,t})$, and the growth rate of the terms of trade $\Delta \log (\tau_t)$. 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 was made in consideration of sample availability for each country. The frequency of the data is quarterly 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.

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

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

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.[14] 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, $u_{r_n,t} \sim N\left(0, \sigma_{r_n}^2\right)$, 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

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

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 $\log \bar{u}_{z^*}$,

[14] 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, $\log \tilde{\Delta s}$, and potentially non-zero growth rate of the terms of trade, $\log \tilde{\Delta \tau}$, in the measurement equation to account for trend-like behavior of these variables during the sample period.

$\log \bar{\Pi}^*$, and $\log \bar{R}_1^*$ is set to their respective sample counterparts during the sample period for each country. 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 $\log \bar{u}_z$, $\log \bar{\Pi}$, $\log \tilde{\Delta s}$ and $\log \tilde{\tau}$ to 0.0059, 0.0264/4, -0.0018 and 0.0075, respectively, that match their sample counterparts. Note that $\bar{R}_1$ is endogenously determined by estimated parameters. 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 $\log \bar{u}_z$, $\log \bar{\Pi}$, $\log \tilde{\Delta s}$ and $\log \tilde{\Delta \tau}$ to 0.0077, 0.0185/4, -0.0006 and 0.0021, respectively, that match their sample counterparts. 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 $\log \bar{u}_z$, $\log \bar{\Pi}$, $\log \tilde{\Delta s}$ and $\log \tilde{\Delta \tau}$ to 0.0072, 0.0248/4, -0.0003 and 0.0019, respectively, that match their sample counterparts. 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,[15] while in "Model 2," we fix it to 0.995. The idea behind the specification of

[15] 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 since otherwise the posterior simulator tends to get stuck at the unit root. 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

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.

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 as its prior mean for Canada.[16] 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.

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.

[16] When the prior mean of $\tilde{\phi}_a$ is low for Canada, the posterior simulator did not converge well. We suspect that there is an identification problem associated with $\tilde{\phi}_a$.

4.4 Estimation Results

4.4.1 Model Selection

We compare the data fit of different specifications based on estimated marginal likelihoods presented in Table 2. Except for Australia, there are small differences in marginal likelihood among models with different degrees of inflation target persistence when only macro data are used in estimation. However, there appears to be significant differences in terms of fit among models when term structure data are included in estimation. Notably, for all the three countries, the model with a highly persistent inflation target comes out as the best-fitting model when term structure data are used. The finding suggests that long-term interest rates might be more sensitive to changes in the persistence of shocks affecting the intercept in the monetary policy rule than the short-term interest rate. Therefore, using yield curve data might be informative in discriminating different macro models with similar time-series fit.[17]

4.4.2 Parameter Estimates

Tables 3 - 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. Posterior intervals of most of the parameters show considerable overlapping between two estimation results, but there are some parameters whose posterior distributions shift a lot. Tables 3 and 4 show parameter estimates using Australian data. In this case, estimation results using only macro data favor the model with the constant inflation target, but using the term structure data in estimation shifts the result in favor of the model with a highly persistent inflation target. Regarding parameter estimates that change a lot across the two estimation results, most noticeable are the frequency of price adjustment in domestic markets for home goods (θ_H) and the persistence of markup shocks in domestic and import markets (ρ_{ε_H}, ρ_{ε_F}). In the joint estimation with the term structure data, domestic firms and importers adjust their prices frequently at home markets in face of highly persistent markup shocks with the posterior mean estimates of ρ_{ε_H} and ρ_{ε_F} both higher than 0.99. In contrast, in the macro estimation, the persistence of markup shocks are low to moderate, but firms can adjust price only very infrequently with θ_H hovering around 0.9936. In principle, both a high degree of nominal rigidity and a highly persistent markup shock may equally explain the observed persistence of inflation, but the Australian term structure data favor the model with highly persistent markup shocks. Indeed, when we use the posterior mode estimates from the macro estimation to fit term structure data as well as macro data, the fit for macro data deteriorates substantially.[18] However, when we use the posterior mode estimates from the joint estimation just to fit macro data, the fit is virtually the same. This finding is similar to what we

[17] Our result is comparable to the long-run risks literature pioneered by Bansal and Yaron (2004), in which asset pricing moments sharply distinguishes the model with serially uncorrelated consumption growth from the model with a small but highly persistent component in consumption growth while consumption growth data itself does not provide enough information to differentiate the two models.

[18] Mean absolute prediction errors for domestic variables increase more than three times while there are no changes in the fit for foreign variables.

discussed regarding model selection. Including term structure data provides additional information to distinguish alternative sources of persistence, which we may not be able to discriminate solely based on macro data.

Monetary policy reaction coefficients are largely similar across the two estimation results. Reaction coefficients on inflation and exchange rate depreciation are somewhat muted in the joint estimation than the macro estimation result, but the reaction coefficient on output is very similar to the posterior mean estimate between 0.26 and 0.28. The posterior interval estimates suggest that the reaction coefficient on output is significantly above zero in both estimation results while evidence is mixed for the response to exchange rate depreciation.[19] Although 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). Our estimates are consistent with this description of actual policy-making.

Tables 5 and 6 show parameter estimates using Canadian data. For both estimation results, the model with a highly persistent inflation target is favored. Among a few parameters whose posterior distributions shift significantly between specifications that include the term structure data or not, the persistence of risk premium shock (ρ_ϕ) stands out. A risk premium shock is much more persistent in the joint estimation with the posterior mean estimate of persistence equal to 0.8382 than the macro estimation in which the corresponding value is 0.4138. Since the risk premium shock mainly affects the domestic economy through the international risk sharing condition which links the domestic interest rate with the foreign interest rate and expected exchange rate depreciation, this difference is likely to play a big role in explaining the exchange rate and the short-term nominal interest rate as we see later in the discussion of variance decomposition.

Like Australia, monetary policy reaction coefficients are largely similar across the two estimation results. Interestingly, the policy reaction coefficient on the exchange rate (ψ_S) is significantly positive unlike in our estimation results for Australia and New Zealand. The finding is in line with Lubik and Schorfheide (2007) who estimate small open economy DSGE models for four countries and find that the Bank of Canada and the Bank of England include the nominal exchange rate in its policy rule, whereas the central banks of Australia and New Zealand do not.

Tables 7 and 8 show parameter estimates for New Zealand. In this case, the macro estimation favors the model in which inflation target is estimated while the joint estimation favors the model with the persistence of inflation target fixed at 0.995. The estimated persistence of the inflation target is lower than 0.995, but still quite persistent, with the posterior mean around 0.8962. Regarding other parameters, differences between the two estimation results are most noticeable in terms of the degree of nominal rigidity in the domestic market for home goods and the persistence of markup shocks as in the case of Australia. The joint estimation results suggest a low degree of nominal rigidity coupled with highly persistent markup shocks, but the macro estimation results imply a high degree of nominal rigidity with moderately persistent markup shocks. Monetary policy reaction coefficients

[19] We find a very weak response to exchange rate depreciation in the joint estimation and a small response in the macro estimation.

are largely similar across the two estimation results and the central bank does not have a significant concern for exchange rate fluctuations like Australia.

4.4.3 Impulse Response and Variance Decomposition

Justiniano and Preston (2010) find that foreign shocks explain only small portions of inflation and output in Australia. Similarly, variance decomposition results reported in Tables 9 - 14 show that foreign shocks do not explain much of the fluctuations of output and inflation while they are more important in explaining the short-term interest rate. This finding suggests that the financial linkage through the international risk sharing conditions may be the most important transmission channel through which foreign shocks affect domestic variables in the context of the estimated DSGE model.

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. Similarly, markup shocks either in imports (Australia) or exports (Canada and New Zealand) account for the substantial portion of the variation in the terms of trade growth when term structure data are used in estimation.

Variance decomposition results provide information on the dominant shock explaining the variation of each observed variable, but do not identify dynamics of observed variables conditional on a given shock. We look at impulse response plots to identify the pattern that dominant shocks propagate into endogenous variables. We look at dominant shocks for observed variables in the joint estimation. We start from a technology shock that explains a substantial portion of the variation of output growth in Australia and Canada.

Figure 1 shows impulse responses to a positive technology shock using the posterior mode estimates in Australia. As expected, there is a big initial impact for output growth that dies out relatively quickly over time. However, the technology shock has small and temporary impacts on other variables. In particular, its impacts on long-term interest rates are very small with the peak impact less than a 1 basis point. In New Zealand, a government spending shock drives the variation of output growth as shown in Figure 2. Given our assumption that government spending uses only domestically produced goods, it reallocates resources from the export market to the domestic market. Hence, the terms of trade improves and the exchange rate appreciates on impact. The exchange rate appreciation reduces import prices and domestic CPI inflation. However, it has only small impacts on interest rates.

Next we turn to inflation target shock that explains most variations in inflation and interest rates in all the three countries. Figure 3 shows impulse responses to a positive inflation target shock again using the posterior mode estimates in Australia. Since the inflation target shock is highly persistent, it has long-lasting impacts on nominal variables. In particular, it shifts the level of interest rates of different maturities. However, it has very little impact on output growth because the estimated degree of nominal rigidity is small. In all three countries, a domestic markup shock seems to be a dominant factor in explaining nominal exchange rate fluctuations. Figure 4 shows responses to a positive domestic markup shock. By increasing the profit margin in the domestic market for home goods, it increases the opportunity cost of exports and pushes up export prices. As a result, terms of trade temporarily improves. Peak responses happen on impact or the early stage after a shock occurs, but die out quickly, while interest rates show small but gradually decaying responses.

For Australia, an import markup shock is the dominant shock in explaining terms of trade growth. Figure 5 shows responses to a positive import markup shock. As import prices increase, inflation and the short-term interest rate increase on impact, resulting in the immediate appreciation of domestic currency to satisfy the international risk sharing condition.[20] Otherwise, this shock has small impacts on output growth and interest rates. For Canada and New Zealand, an export markup shock is driving terms of trade growth. Figure 6 shows response to a positive export markup shock. Since export prices increase, terms of trade improves, but this shock has little impacts on all other variables quantitatively.

4.4.4 Policy Expectations Implied by the Term Structure Data

Since no-arbitrage conditions imply that long-term interest rates are risk-neutral expectations of future short-term interest rates, using the term structure data may provide some information about expected interest rates in the future. This would be the case unless the persistence of long-term interest rates entirely comes out of the persistence of term premia and the short-term interest rate is predictable under the risk-neutral measure, but not in the physical probability measure. To check if long-term interest rates embed information about future short-term interest rates, it is useful to compare the model implied expected interest rate with the realized data for both macro and joint estimation results 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 correlation coefficients between the model implied expected interest rate and the ex-post realized one are higher in the joint estimation than in the macro estimation when we look at Ausutralian and Canada as shown in Table 15. In New Zealand, the macro estimation produces the model-implied expected interest rate that follows the ex-post one as closely as in the joint estimation. The finding suggests that 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.[21] Therefore, the current level of the short-term interest rate contains sufficient information about the future value. In Australia and Canada, the joint estimation produces model-implied expected interest rates much better aligned with ex-post realized ones when we extend the horizon from one-year to five-year.

One caveat in our finding is that 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. Although we model a time-varying inflation target shock in the Taylor rule of our model, it does not show up

[20] A higher domestic interest rate can be supported in a rational expectations equilibrium only if investors expect the depreciation. To induce the expected depreciation, the domestic currency should appreciate on impact.

[21] 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 anwid 0.8002 in Australia and Canada, respectively.

in any other equation and it can be any factor that affects the level of interest rates. Indeed, the correlation between the model-implied inflation expectation and the realized average inflation rate is much weaker compared to the corresponding correlation in the interest rate as shown in Table 15. This may cast doubt on the interpretation of the estimated π_t^* in our model as a time-varying inflation target. However, the estimated π_t^* is significantly correlated with survey data evidence on long-run inflation expectations in the U.S. available from Wright (2011). Surprisingly, the magnitude of correlation is even stronger than with the domestic long-run inflation expectations, in particular for Canada and New Zealand. Hence, it is possible to interpret our inflation target shock not literally in terms of shifts in domestic policy stance, but a missing foreign shock shifting the level of interest rates.

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, even though long-term interest rates are still determined by future expectations of the domestic short-term interest rate. Similarly, we find that time-varying inflation target implicitly captures a missing foreign shock driving the level of interest rates in advanced economies. However, our inflation target is not that much correlated with foreign macro variables and in this sense distinguished from persistent foreign macro shocks emphasized by Kulish and Rees (2011).[22] Given the fact that it is more highly correlated with the U.S. long-run inflation expectations, it can be re-interpreted as a sort of international financial shock that affects the level of long-term interest rates in advanced economies at the same time.

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 additional information from the yield curve helps us to discriminate models with different degrees of persistence in an inflation target shock that are difficult to rank solely based on macro data.

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

[22]The correlation of the estimated inflation target with domestic and foreign macro variables is 0.38 at most, much lower than the correlation with long-term interest rates that is higher than 0.8.

presence of persistent foreign disturbances. Our results attribute most of variations in the long-end of the yield curve to a persistent inflation target shock. In addition, we find that our estimated inflation target is significantly correlated with long-horizon inflation expectations from survey data in the U.S., implying that time-varying inflation target can be a proxy for a persistent foreign shock that is missing in the model. However, the estimated target is not highly correlated with foreign macro variables and our finding is distinguished from Kulish and Rees (2011) who emphasize that foreign macro shocks drive long-term interest rates in small open economies because they are more persistent than domestic macro shocks.

There are many limitations in the current exercise because it uses a quite stylized model for small open economies for simplicity in estimation. For example, our model is silent about capital flows that may play an important role in international transmission of monetary policy as argued by Rey (2016). 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.

References

[1] Bansal, Ravi, and Amir Yaron. 2004. "Risks for the Long Run: A Potential Resolution of Asset Pricing Puzzles." *Journal of Finance*, 59: 1481-1509.

[2] Calvo, Guillermo. 1983. "Staggered Prices in a Utility-Maximizing Framework." *Journal of Monetary Economics*, 12: 983-998.

[3] Choudhri, Ehsan U., and Dalia S. Hakura. 2015. "The Exchange Rate Pass-through to Import and Export Prices: The Role of Nominal Rigidities and Currency Choice." *Journal of International Money and Finance*, 51: 1-25.

[4] Cogley, Timothy, Giorgio E. Primiceri, and Thomas J. Sargent. 2010. "Inflation-Gap Persistence in the U.S." *American Economic Journal: Macroeconomics*, 2(1): 43-69.

[5] Debelle, Guy. 1999. "Inflation Targeting and Output Stabilization in Australia" in *Inflaiton Targeting in Practice: Strategies and Operational Issues and Application to Emerging Market Economies*, edited by Mario I. Blejer et al. Washington, DC: International Monetary Fund.

[6] De Grave, Ferre, Marian Emiris, and Raf Wouters. 2009. "A Structural Decomposition of the US Yield Curve." *Journal of Monetary Economics*, 56(4): 545-559.

[7] Del Negro, Marco, and Frank Schorfheide. 2011. "Bayesian Macroeconometrics." in *The Oxford Handbook of Bayesian Econometrics* ed. John Geweke, Gary Koop and Herman van Dijk, 293-389, USA: Oxford University Press.

[8] Doh, Taeyoung. 2012. "What Does the Yield Curve Tell Us about the Federal Reserve's Implicit Inflation Target?." *Journal of Money, Credit and Banking*, 44(2-3): 469-486.

[9] Fischer, Andreas. 1995. "New Zealand's Experiece with Inflation Targets" in *Inflation Targets*, edited by Leonardo Leiderman et al. London, UK: Center for Economic Policy Research.

[10] Gali, Jordi, and Tommaso Monacelli. 2005. "Monetary Policy and Exchange Rate Volatility in a Small Open Economy." *Review of Economic Studies*, 72(3): 707-734.

[11] Geweke, John. 1999. "Using Simulation Methods for Bayesian Econometric Models: Inference, Development, and Communication." *Econometric Reviews*, 18(1): 1-73.

[12] Gopinath, Gita. 2015. "The International Price System." *Working Paper*, National Bureal of Economic Research.

[13] Justiniano, Alejandro, and Bruce Preston. 2010. "Monetary Policy and Uncertainty in an Empirical Small Open Economy Model." *Journal of Applied Econometrics*, 25(1): 93-128.

[14] Kam, Timothy, Kirdan Lees, and Philip Liu. 2009. "Uncovering the Hit List for Small Inflation Targeters: A Bayesian Structural Analysis." *Journal of Money, Credit, and Banking*, 41(4): 583-618.

[15] Kulish, Mariano, and Daniel Rees. 2011. "The Yield Curve in a Small Open Economy" *Journal of International Economics*, 85: 268-279.

[16] Lubik, Thomas A., and Frank Schorfheide. 2007. "Do Central Banks Respond to Exchange Rate Movements? A Structural Investigation." *Journal of Monetary Economics*, 54(4): 1069-1087.

[17] Monacelli, Tommaso. 2005. "Monetary Policy in a Low Pass-Through Environment." *Journal of Money, Credit and Banking*, 37(6): 1047-1066.

[18] Rey, Hélène. 2015. "International Channels of Transmission of Monetary Policy and the Mundellian Trilemma." *Working Paper*, National Bureal of Economic Research.

[19] Schmitt-Grohe, Stephanie, and Martın Uribe. 2003. "Closing Small Open Economy Models." *Journal of International Economics*, 61(1): 163-185.

[20] Sims, Christopher A. 2002. "Solving Linear Rational Expectations Models." *Computational Economics*, 20(1-2): 1-20.

[21] Woodford, Michael. 2003. *Interest and Prices: Foundations of a Theory of Monetary Policy*, Princeton, NJ: Princeton University Press.

[22] Wright, Jonathan H. 2011. "Term Premia and Inflation Uncertainty: Empirical Evidence from an International Panel Dataset." *American Economic Review*, 101(4): 1514-1534.

[23] Yun, Tack. 1996. "Nominal Price Rigidity, Money Supply Endogeneity, and Business Cycles." *Journal of Monetary Economics*, 37(2): 345-370.

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. Details of the derivation are provided in the technical appendix which is available upon request.

- [1] Consumption Euler equation

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

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

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

- [2] Aggregate consumption

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

- [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

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

- [6] Foreign final good price

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

- [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

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

$$+\frac{(1-\theta_H\beta)(1-\theta_H)}{\theta_H}\left[\varphi\left(\hat{y}_{H,t}+\hat{y}^*_{H,t}\right)+\frac{1}{\bar{u}_z-h}\left(\bar{u}_z\hat{c}_t-h\hat{c}_{t-1}+h\hat{u}_{z,t}\right)-\hat{p}_{H,t}\right]+\hat{\hat{u}}_{\epsilon_H,t},.$$

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

$$\hat{\hat{u}}_{\epsilon_H,t}=\frac{(1-\theta_H\beta)(1-\theta_H)}{\theta_H}\hat{u}_{\epsilon_H,t}.$$

- [10] NK Phillips curve for foreign inflation of the exported goods

$$\begin{aligned}\left(\hat{\pi}^*_{H,t}-\gamma^*_H\hat{\pi}^*_{H,t-1}\right) &= \beta\left(E_t\hat{\pi}^*_{H,t+1}-\gamma^*_H\hat{\pi}^*_{H,t}\right)\\ &\quad+\frac{(1-\theta^*_H\beta)(1-\theta^*_H)}{\theta^*_H}\left[\varphi\left(\hat{y}_{H,t}+\hat{y}^*_{H,t}\right)+\frac{1}{\bar{u}_z-h}\left(\bar{u}_z\hat{c}_t-h\hat{c}_{t-1}+h\hat{u}_{z,t}\right)-\hat{e}_t-\hat{p}^*_{H,t}\right]+\hat{\hat{u}}_{\epsilon^*_H,t},\end{aligned}$$

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

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

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

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

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

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

- [12] Terms of trade

$$\hat{\tau}_t=\hat{p}^*_{H,t}+\hat{e}_t-\hat{p}_{F,t}$$

- [13] Real exchange rate

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

- [14] Law of one price gap

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

- [15] Monetary policy rule

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

- [16-18] 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 $\hat{\xi}^*_t=\left(\hat{y}^*_t,\hat{\pi}^*_t,\hat{r}^*_{1,t}\right)'$.

- [19] Exports

$$\hat{y}^*_{H,t}=-\eta\hat{p}^*_{H,t}+\hat{y}^*_t$$

- [20] Foreign price of the exported goods

$$\hat{p}^*_{H,t} = \hat{p}^*_{H,t-1} + \hat{\pi}^*_{H,t} - \hat{\pi}^*_t$$

- [21] Domestic final good

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

- [22] Gross domestic product

$$\hat{y}_t = \frac{\bar{y}_H}{\bar{y}}\left(\hat{p}_{H,t} + \hat{y}_{H,t}\right) + \frac{\bar{y}^*_H}{\bar{y}}\left(\hat{p}^*_{H,t} + \hat{y}^*_{H,t}\right) + \frac{\bar{y}_F}{\bar{y}}\hat{p}_{F,t}$$

- [23-29] Exogenous shock processes

$$\begin{aligned}
\hat{\tilde{u}}_{b,t} &= \rho_b \hat{\tilde{u}}_{b,t-1} + \varepsilon_{b,t},\\
\hat{u}_{\phi,t} &= \rho_\phi \hat{u}_{\phi,t-1} + \varepsilon_{\phi,t},\\
\hat{\tilde{u}}_{\epsilon_H,t} &= \rho_{\epsilon_H} \hat{\tilde{u}}_{\epsilon_H,t-1} + \varepsilon_{\epsilon_H,t},\\
\hat{\tilde{u}}_{\epsilon^*_H,t} &= \rho_{\epsilon^*_H} \hat{\tilde{u}}_{\epsilon^*_H,t-1} + \varepsilon_{\epsilon^*_H,t},\\
\hat{\tilde{u}}_{\epsilon_F,t} &= \rho_{\epsilon_F} \hat{\tilde{u}}_{\epsilon_F,t-1} + \varepsilon_{\epsilon_F,t},\\
\hat{u}_{z,t} &= \rho_z \hat{u}_{z,t-1} + \varepsilon_{z,t},\\
\hat{u}_{g,t} &= \rho_g \hat{u}_{g,t-1} + \varepsilon_{g,t},\\
\hat{\tilde{\pi}}_t &= \rho_\pi \hat{\tilde{\pi}}_{t-1} + \varepsilon_{\tilde{\pi},t},
\end{aligned}$$

where we reparameterize the standard deviation of $\varepsilon_{b,t}$, $\varepsilon_{\epsilon_H,t}$, $\varepsilon_{\epsilon^*_H,t}$, and $\varepsilon_{\epsilon_F,t}$ according to the reparameterization of $\hat{\tilde{u}}_{b,t}$, $\hat{\tilde{u}}_{\epsilon_H,t}$, $\hat{\tilde{u}}_{\epsilon^*_H,t}$, and $\hat{\tilde{u}}_{\epsilon_F,t}$, 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_H}	Beta	0.6	0.2
γ_H^*	Beta	0.6	0.2	$\rho_{\epsilon_H^*}$	Beta	0.6	0.2
γ_F	Beta	0.6	0.2	ρ_{ϵ_F}	Beta	0.6	0.2
θ_H	Beta	0.6	0.2	ρ_g	Beta	0.6	0.2
θ_H^*	Beta	0.6	0.2	ρ_z	Beta	0.6	0.2
θ_F	Beta	0.6	0.2	ρ_π	Beta	note 3	0.05
ψ_π	Gamma	1.75	0.3	σ_R	Inv-Gamma	0.01	0.02
ψ_Y	Gamma	0.3	0.1	σ_b	Inv-Gamma	0.01	0.02
ψ_S	Normal	0.0	0.1	σ_ϕ	Inv-Gamma	0.01	0.02
$\log \bar{u}_z$	Gamma	note 1	0.002	σ_{ϵ_H}	Inv-Gamma	0.01	0.02
$\log \bar{\Pi}$	Gamma	note 1	0.002	$\sigma_{\epsilon_H^*}$	Inv-Gamma	0.01	0.02
$\log \tilde{\Delta} s$	Normal	note 1	0.002	σ_{ϵ_F}	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	2207.8	**2215.2**	2182.3
	(0.03)	(0.07)	(0.4)
Macro data-only estimation	1220.4	1216.2	**1223.1**
	(0.2)	(0.02)	(0.07)
Canada			
Joint estimation	2344.9	**2352.7**	2328.6
	(0.11)	(0.15)	(0.41)
Macro data-only estimation	1294.5	**1295.2**	1293.7
	(0.05)	(0.04)	(0.05)
New Zealand			
Joint estimation	2827.4	**2846.0**	2808.8
	(0.05)	(0.14)	(0.1)
Macro data-only estimation	**1562.7**	1561.8	1561.7
	(0.16)	(0.06)	(0.26)

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: Model 2 (joint estimation)

Parameters	mean	90% HPD interval	Parameters	mean	90% HPD interval
$-\log(\beta)$	0.0019	[0.0008, 0.0030]	ρ_R	0.7505	[0.6750 ,0.8278]
h	0.2543	[0.0792, 0.4227]	ρ_b	0.3634	[0.1842 ,0.5378]
η	1.0781	[0.9854,1.1732]	ρ_ϕ	0.5753	[0.4434 ,0.7055]
γ_H	0.2751	[0.0332, 0.5181]	ρ_{ϵ_H}	0.9947	[0.9922,0.9973]
γ_F	0.3382	[0.0529,0.6189]	ρ_{ϵ_F}	0.9941	[0.9885 ,0.9998]
γ_H^*	0.5415	[0.2198,0.8723]	$\rho_{\epsilon_H^*}$	0.6607	[0.3740 ,0.9484]
θ_H	0.3498	[0.2689,0.4299]	ρ_g	0.9424	[0.9209,0.9659]
θ_F	0.1426	[0.0660, 0.2199]	ρ_z	0.3385	[0.0949 ,0.5614]
θ_H^*	0.4059	[0.2305 ,0.5742]	ρ_π	0.995	n/a
ψ_π	2.0623	[1.6605 ,2.4536]	σ_R	0.0031	[0.0021 ,0.0042]
ψ_Y	0.2603	[0.1542 ,0.3623]	σ_b	0.0050	[0.0030 ,0.0070]
ψ_S	0.0263	[-0.0283 , 0.0832]	σ_ϕ	0.0444	[0.0237 ,0.0650]
$\log \bar{u}_z$	0.0062	[0.0048,0.0075]	σ_{ϵ_H}	0.1077	[0.0433 ,0.1733]
$\log \bar{\Pi}$	0.0060	[0.0033,0.0086]	σ_{ϵ_F}	0.0084	[0.0029,0.0140]
$\log \tilde{\Delta s}$	-0.0013	[-0.0042 ,0.0017]	$\sigma_{\epsilon_H^*}$	0.0052	[0.0034 ,0.0071]
$\log \tilde{\tau}$	0.0080	[0.0054, 0.0106]	σ_g	0.0024	[0.0018,0.0029]
$\log \bar{u}_{z^*}$	0.0051	[0.0044 ,0.0059]	σ_z	0.0134	[0.0086 ,0.0179]
$\log \bar{\Pi}^*$	0.0062	[0.0045 ,0.0079]	σ_π	0.0007	[0.0006, 0.0009]
$\log \bar{R}_1^*$	0.0107	[0.0084 ,0.0129]	σ_{r_8}	0.0006	[0.0004 ,0.0008]
$\tilde{\phi}_a$	0.0009	[0.0002 ,0.0016]	$\sigma_{r_{12}}$	0.0008	[0.0006 ,0.0009]
			$\sigma_{r_{20}}$	0.0004	[0.0003 , 0.0005]
			$\sigma_{r_{40}}$	0.0007	[0.0005,0.0008]

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 4: Posterior distribution of the structural parameters for Australia: Model 3 (macro data only)

Parameters	mean	90% HPD interval	Parameters	mean	90% HPD interval
$-\log(\beta)$	0.0024	[0.0013, 0.0035]	ρ_R	0.8312	[0.7916 ,0.8714]
h	0.4613	[0.1484, 0.7650]	ρ_b	0.5177	[0.2836 ,0.7472]
η	1.0284	[0.9873,1.0715]	ρ_ϕ	0.4027	[0.167 ,0.6368]
γ_H	0.097	[0.0235, 0.1671]	ρ_{ϵ_H}	0.1081	[0.0298,0.1845]
γ_F	0.4158	[0.0839,0.7376]	ρ_{ϵ_F}	0.6212	[0.3127 ,0.9584]
γ_H^*	0.194	[0.025,0.3612]	$\rho_{\epsilon_H^*}$	0.6151	[0.2203 ,0.9542]
θ_H	0.9936	[0.9918,0.9954]	ρ_g	0.5658	[0.2644,0.8858]
θ_F	0.1157	[0.0372, 0.1969]	ρ_z	0.3503	[0.1013 ,0.5882]
θ_H^*	0.6962	[0.4412 ,0.9433]	ρ_π	n/a	n/a
ψ_π	2.2499	[1.8044 ,2.6662]	σ_R	0.0055	[0.0029 ,0.0081]
ψ_Y	0.2797	[0.1827 ,0.3841]	σ_b	0.0033	[0.0021 ,0.0044]
ψ_S	0.1265	[0.0571 , 0.1975]	σ_ϕ	0.0087	[0.0069 ,0.0106]
$\log \bar{u}_z$	0.0055	[0.0044,0.0067]	σ_{ϵ_H}	0.0089	[0.0026 ,0.0154]
$\log \bar{\Pi}$	0.0057	[0.0032,0.0082]	σ_{ϵ_F}	0.0219	[0.0088,0.0393]
$\log \tilde{\Delta} s$	-0.001	[-0.0038 ,0.0018]	$\sigma_{\epsilon_H^*}$	0.0041	[0.0025 ,0.0056]
$\log \tilde{\tau}$	0.0075	[0.0054, 0.0095]	σ_g	0.002	[0.0016,0.0024]
$\log \bar{u}_{z^*}$	0.0048	[0.0042 ,0.0055]	σ_z	0.007	[0.0035 ,0.0101]
$\log \bar{\Pi}^*$	0.0065	[0.0049 ,0.0081]	σ_π	n/a	[n/a]
$\log \bar{R}_1^*$	0.0102	[0.0081 ,0.0125]			
$\tilde{\phi}_a$	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
$-\log(\beta)$	0.0026	[0.0012, 0.0040]	ρ_R	0.8730	[0.8437 ,0.9030]
h	0.3487	[0.1713, 0.5326]	ρ_b	0.3468	[0.1516 ,0.5267]
η	1.1370	[0.9958,1.2784]	ρ_ϕ	0.8382	[0.7982 ,0.8795]
γ_H	0.3310	[0.1227, 0.5260]	ρ_{ϵ_H}	0.3981	[0.2193,0.5742]
γ_F	0.1637	[0.0369,0.2821]	ρ_{ϵ_F}	0.2389	[0.0594 ,0.4103]
γ_H^*	0.5114	[0.1827,0.8485]	$\rho_{\epsilon_H^*}$	0.7473	[0.6016 ,0.8975]
θ_H	0.9836	[0.9763,0.9930]	ρ_g	0.6449	[0.3657,0.9535]
θ_F	0.6990	[0.5812, 0.8239]	ρ_z	0.6108	[0.4415 ,0.7935]
θ_H^*	0.2993	[0.1558 ,0.4403]	ρ_π	0.995	n/a
ψ_π	2.1447	[1.7200 ,2.5695]	σ_R	0.0038	[0.0022 ,0.0054]
ψ_Y	0.1125	[0.0415 ,0.1773]	σ_b	0.0031	[0.0021 ,0.0040]
ψ_S	0.2622	[0.1495 , 0.3793]	σ_ϕ	0.0068	[0.0036 ,0.0098]
$\log \bar{u}_z$	0.0083	[0.0066,0.0099]	σ_{ϵ_H}	0.0100	[0.0072 ,0.0127]
$\log \bar{\Pi}$	0.0043	[0.0018,0.0068]	σ_{ϵ_F}	0.1175	[0.0442,0.1868]
$\log \tilde{\Delta s}$	0.0000	[-0.0026 ,0.0026]	$\sigma_{\epsilon_H^*}$	0.0042	[0.0030 ,0.0053]
$\log \tilde{\tau}$	0.0034	[0.0017, 0.0050]	σ_g	0.0023	[0.0019,0.0027]
$\log \bar{u}_{z^*}$	0.0049	[0.0045 ,0.0053]	σ_z	0.0052	[0.0027 ,0.0075]
$\log \bar{\Pi}^*$	0.0062	[0.0050 ,0.0074]	σ_π	0.0005	[0.0004, 0.0007]
$\log \bar{R}_1^*$	0.0110	[0.0087 ,0.0132]	σ_{r_8}	0.0006	[0.0004 ,0.0008]
$\tilde{\phi}_a$	0.0004	[0.0001 ,0.0007]	$\sigma_{r_{12}}$	0.0008	[0.0006 ,0.0009]
			$\sigma_{r_{20}}$	0.0005	[0.0004 , 0.0006]
			$\sigma_{r_{40}}$	0.0006	[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: Model 2 (macro data only)

Parameters	mean	90% HPD interval	Parameters	mean	90% HPD interval
$-\log(\beta)$	0.0018	[0.0007, 0.0028]	ρ_R	0.8034	[0.7497 ,0.8579]
h	0.7274	[0.5392, 0.9154]	ρ_b	0.5863	[0.3408 ,0.8336]
η	1.3568	[1.1903,1.5243]	ρ_ϕ	0.4138	[0.154 ,0.6763]
γ_H	0.194	[0.0473, 0.3316]	ρ_{ϵ_H}	0.2506	[0.0833, 0.4077]
γ_F	0.259	[0.0537,0.4542]	ρ_{ϵ_F}	0.7612	[0.4137, 0.9967]
γ_H^*	0.5742	[0.2515,0.9057]	$\rho_{\epsilon_H^*}$	0.606	[0.3018, 0.9309]
θ_H	0.9856	[0.9751,0.9962]	ρ_g	0.6218	[0.3293, 0.9251]
θ_F	0.3867	[0.2746, 0.5023]	ρ_z	0.5114	[0.3403 ,0.6798]
θ_H^*	0.1969	[0.0523, 0.3378]	ρ_π	0.995	n/a
ψ_π	2.3162	[1.8794 ,2.7575]	σ_R	0.0046	[0.0023 ,0.0069]
ψ_Y	0.1801	[0.0942 ,0.2644]	σ_b	0.0039	[0.0024 ,0.0054]
ψ_S	0.216	[0.111 , 0.3204]	σ_ϕ	0.0123	[0.0079 ,0.0166]
$\log \bar{u}_z$	0.0059	[0.0043,0.0075]	σ_{ϵ_H}	0.0066	[0.003 ,0.01]
$\log \bar{\Pi}$	0.0044	[0.0018,0.0069]	σ_{ϵ_F}	0.02	[0.0022,0.0626]
$\log \tilde{\Delta} s$	-0.0007	[-0.0034 ,0.0020]	$\sigma_{\epsilon_H^*}$	0.0059	[0.0044 ,0.0074]
$\log \tilde{\tau}$	0.0021	[0.0005, 0.0036]	σ_g	0.0027	[0.0021, 0.0032]
$\log \bar{u}_{z^*}$	0.0052	[0.0046 ,0.0059]	σ_z	0.0055	[0.0027, 0.0083]
$\log \bar{\Pi}^*$	0.0061	[0.005 ,0.0073]	σ_π	0.0006	[0.0004, 0.0009]
$\log \bar{R}_1^*$	0.0102	[0.0074 ,0.0129]			
$\tilde{\phi}_a$	0.01	[0.0091 ,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
$-\log(\beta)$	0.0026	[0.0011, 0.0040]	ρ_R	0.7378	[0.6668 ,0.8128]
h	0.1122	[0.0202, 0.1989]	ρ_b	0.6593	[0.5258 ,0.7955]
η	1.3231	[1.1686,1.4810]	ρ_ϕ	0.6234	[0.5389 ,0.7040]
γ_H	0.3957	[0.1093, 0.6736]	ρ_{ϵ_H}	0.9942	[0.9907,0.9979]
γ_F	0.3602	[0.0605,0.6586]	ρ_{ϵ_F}	0.5731	[0.2550 ,0.9119]
γ_H^*	0.3936	[0.0772,0.7098]	$\rho_{\epsilon_H^*}$	0.9725	[0.9598 ,0.9856]
θ_H	0.1720	[0.0830,0.2508]	ρ_g	0.9464	[0.9273,0.9665]
θ_F	0.1120	[0.0387, 0.1826]	ρ_z	0.2940	[0.0326 ,0.8460]
θ_H^*	0.1034	[0.0431 ,0.1571]	ρ_π	0.995	n/a
ψ_π	2.5115	[2.0622 ,2.9538]	σ_R	0.0023	[0.0017 ,0.0028]
ψ_Y	0.2113	[0.1231 ,0.2937]	σ_b	0.0035	[0.0026 ,0.0044]
ψ_S	-0.0089	[-0.0697 , 0.0515]	σ_ϕ	0.3275	[0.1076 ,0.5646]
$\log\bar{u}_z$	0.0088	[0.0069,0.0106]	σ_{ϵ_H}	0.0107	[0.0025 ,0.0217]
$\log\bar{\Pi}$	0.0059	[0.0031,0.0085]	σ_{ϵ_F}	0.4028	[0.1469,0.6649]
$\log\tilde{\Delta s}$	0.0002	[-0.0028 ,0.0031]	$\sigma_{\epsilon_H^*}$	0.0092	[0.0031 ,0.0130]
$\log\tilde{\tau}$	0.0019	[-0.0003, 0.0039]	σ_g	0.0033	[0.0025,0.0040]
$\log\bar{u}_{z^*}$	0.0050	[0.0044 ,0.0056]	σ_z	0.0366	[0.0233 ,0.0508]
$\log\bar{\Pi}^*$	0.0068	[0.0055 ,0.0081]	σ_π	0.0009	[0.0007, 0.0010]
$\log\bar{R}_1^*$	0.0104	[0.0085 ,0.0123]	σ_{r_4}	0.0009	[0.0005 ,0.0013]
$\tilde{\phi}_a$	0.0005	[0.0001 ,0.0009]	σ_{r_8}	0.0012	[0.0009 ,0.0014]
			$\sigma_{r_{20}}$	0.0007	[0.0005 , 0.0010]
			$\sigma_{r_{40}}$	0.0007	[0.0005,0.0010]

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: Baseline (macro data only)

Parameters	mean	90% HPD interval	Parameters	mean	90% HPD interval
$-\log(\beta)$	0.003	[0.0014, 0.0046]	ρ_R	0.8099	[0.7655 ,0.8552]
h	0.5542	[0.1868, 0.8627]	ρ_b	0.5445	[0.2595 ,0.8178]
η	1.1696	[1.0109,1.3308]	ρ_ϕ	0.4694	[0.2325 ,0.711]
γ_H	0.1763	[0.0488, 0.2968]	ρ_{ϵ_H}	0.2154	[0.0739, 0.3528]
γ_F	0.2986	[0.0705,0.5226]	ρ_{ϵ_F}	0.6012	[0.2919, 0.9342]
γ_H^*	0.4183	[0.0752,0.7539]	$\rho_{\epsilon_H^*}$	0.677	[0.3778, 0.9709]
θ_H	0.9874	[0.9813,0.9938]	ρ_g	0.4376	[0.1373, 0.7308]
θ_F	0.2473	[0.1204, 0.3681]	ρ_z	0.3157	[0.0272 ,0.626]
θ_H^*	0.287	[0.054, 0.4949]	ρ_π	0.8962	[0.8321, 0.9608]
ψ_π	2.333	[1.7884 ,2.8376]	σ_R	0.0057	[0.0027 ,0.0087]
ψ_Y	0.2065	[0.091 ,0.3178]	σ_b	0.0039	[0.0024 ,0.0054]
ψ_S	0.0538	[-0.0162 , 0.1243]	σ_ϕ	0.0209	[0.014 ,0.0279]
$\log \bar{u}_z$	0.0078	[0.0061,0.0095]	σ_{ϵ_H}	0.0072	[0.0028 ,0.0119]
$\log \bar{\Pi}$	0.0054	[0.0029,0.0078]	σ_{ϵ_F}	0.0744	[0.0025,0.1719]
$\log \tilde{\Delta s}$	0.0001	[-0.0026 ,0.0027]	$\sigma_{\epsilon_H^*}$	0.0088	[0.0033 ,0.0149]
$\log \tilde{\tau}$	0.0011	[-0.0002, 0.0024]	σ_g	0.0027	[0.0022, 0.0033]
$\log \bar{u}_{z^*}$	0.0049	[0.0042, 0.0056]	σ_z	0.0259	[0.0042, 0.0384]
$\log \bar{\Pi}^*$	0.0069	[0.0057 ,0.0081]	σ_π	0.0006	[0.0003, 0.0008]
$\log \bar{R}_1^*$	0.0106	[0.0087 ,0.0124]			
$\tilde{\phi}_a$	0.012	[0.0004 ,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*. Note that Model 3 is a specification where the inflation target is assumed constant (zero).

Table 9: Forecast error variance decomposition for Australia: Model 2 (joint estimation)

	pref	risk	dom markup	imp markup	exp markup	tech	money policy	gov't spend	inf target	me2	me3	me5	me10	foreign
1 quarter ahead														
output growth	0.02	0.02	0.01	0.02	0.00	0.59	0.00	0.32	0.00	0.00	0.00	0.00	0.00	0.02
inflation	0.06	0.15	0.06	0.06	0.02	0.01	0.29	0.06	0.22	0.00	0.00	0.00	0.00	0.07
short term interest rates	0.12	0.25	0.04	0.08	0.02	0.01	0.09	0.04	0.23	0.00	0.00	0.00	0.00	0.12
exchange rate depreciation	0.00	0.05	0.86	0.01	0.00	0.00	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.05
terms of trade growth	0.01	0.00	0.01	0.90	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03
2-year yields	0.01	0.06	0.07	0.05	0.05	0.00	0.00	0.10	0.52	0.01	0.00	0.00	0.00	0.13
3-year yields	0.01	0.03	0.07	0.05	0.03	0.00	0.00	0.09	0.60	0.00	0.01	0.00	0.00	0.11
5-year yields	0.00	0.01	0.07	0.05	0.01	0.00	0.00	0.07	0.70	0.00	0.00	0.00	0.00	0.09
10-year yields	0.00	0.00	0.05	0.06	0.00	0.00	0.00	0.04	0.80	0.00	0.00	0.00	0.01	0.04
40 quarters ahead														
output growth	0.03	0.02	0.01	0.02	0.01	0.58	0.01	0.30	0.00	0.00	0.00	0.00	0.00	0.02
inflation	0.02	0.05	0.04	0.05	0.01	0.00	0.09	0.08	0.62	0.00	0.00	0.00	0.00	0.04
short term interest rates	0.01	0.03	0.05	0.05	0.02	0.00	0.01	0.05	0.72	0.00	0.00	0.00	0.00	0.06
exchange rate depreciation	0.00	0.06	0.81	0.01	0.00	0.00	0.01	0.01	0.05	0.00	0.00	0.00	0.00	0.05
terms of trade growth	0.01	0.03	0.29	0.59	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04
2-year yields	0.00	0.00	0.05	0.05	0.01	0.00	0.00	0.04	0.81	0.00	0.00	0.00	0.00	0.04
3-year yields	0.00	0.00	0.04	0.06	0.00	0.00	0.00	0.03	0.83	0.00	0.00	0.00	0.04	0.11
5-year yields	0.00	0.00	0.04	0.06	0.00	0.00	0.00	0.02	0.86	0.00	0.00	0.00	0.00	0.02
10-year yields	0.00	0.00	0.02	0.06	0.00	0.00	0.00	0.01	0.90	0.00	0.00	0.00	0.00	0.01

Notes: pref- preference shock, risk- risk premium shock, dom markup- domestic goods mark-up shock, imp markup- imported goods mark-up shock,exp marku- exported goods mark-up, 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: Forecast error variance decomposition for Australia: Model 3(macro estimation)

	pref	risk	dom markup	imp markup	exp markup	tech	money policy	gov't spend	foreign
1 quarter ahead									
output growth	0.24	0.00	0.03	0.00	0.00	0.36	0.00	0.30	0.07
inflation	0.02	0.03	0.10	0.00	0.01	0.00	0.56	0.02	0.26
short term interest rates	0.13	0.09	0.00	0.00	0.01	0.00	0.04	0.01	0.72
exchange rate depreciation	0.01	0.01	0.68	0.00	0.00	0.00	0.20	0.01	0.09
terms of trade growth	0.01	0.00	0.02	0.00	0.91	0.00	0.00	0.00	0.06
40 quarters ahead									
output growth	0.27	0.00	0.03	0.00	0.00	0.34	0.00	0.30	0.06
inflation	0.03	0.02	0.30	0.00	0.00	0.00	0.35	0.01	0.29
short term interest rates	0.19	0.01	0.38	0.00	0.01	0.00	0.07	0.00	0.34
exchange rate depreciation	0.01	0.02	0.67	0.00	0.00	0.00	0.20	0.01	0.09
terms of trade growth	0.01	0.00	0.18	0.00	0.72	0.00	0.04	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, exp markup- exported goods mark-up, tech- technology shock, money policy- monetary policy shock, gov't spend- government spending 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	exp markup	tech	money policy	gov't spend	inf target	me2	me3	me5	me10	foreign
1 quarter ahead														
output growth	0.02	0.03	0.05	0.11	0.01	0.64	0.01	0.07	0.03	0.00	0.00	0.00	0.00	0.03
inflation	0.00	0.08	0.18	0.53	0.00	0.00	0.07	0.00	0.07	0.00	0.00	0.00	0.00	0.07
short term interest rates	0.00	0.18	0.00	0.25	0.00	0.00	0.37	0.00	0.06	0.00	0.00	0.00	0.00	0.14
exchange rate depreciation	0.00	0.22	0.38	0.00	0.00	0.00	0.18	0.00	0.06	0.00	0.00	0.00	0.00	0.16
terms of trade growth	0.01	0.03	0.13	0.11	0.58	0.01	0.12	0.00	0.00	0.00	0.00	0.00	0.00	0.01
2-year yields	0.08	0.22	0.04	0.07	0.00	0.00	0.06	0.00	0.23	0.01	0.00	0.00	0.00	0.29
3-year yields	0.05	0.20	0.03	0.05	0.00	0.00	0.04	0.00	0.33	0.00	0.01	0.00	0.00	0.28
5-year yields	0.02	0.14	0.02	0.02	0.00	0.00	0.02	0.00	0.52	0.00	0.00	0.01	0.00	0.25
10-year yields	0.01	0.06	0.00	0.01	0.00	0.00	0.01	0.00	0.77	0.00	0.00	0.00	0.01	0.13
40 quarters ahead														
output growth	0.02	0.03	0.08	0.08	0.01	0.64	0.01	0.06	0.03	0.00	0.00	0.00	0.00	0.04
inflation	0.00	0.07	0.13	0.23	0.00	0.00	0.06	0.00	0.43	0.00	0.00	0.00	0.00	0.08
short term interest rates	0.00	0.12	0.03	0.05	0.00	0.00	0.05	0.00	0.56	0.00	0.00	0.00	0.00	0.19
exchange rate depreciation	0.00	0.21	0.36	0.00	0.00	0.00	0.17	0.00	0.09	0.00	0.00	0.00	0.00	0.17
terms of trade growth	0.01	0.06	0.14	0.10	0.52	0.01	0.11	0.00	0.01	0.00	0.00	0.00	0.00	0.04
2-year yields	0.01	0.08	0.02	0.01	0.00	0.00	0.01	0.00	0.72	0.00	0.00	0.00	0.00	0.15
3-year yields	0.00	0.05	0.01	0.01	0.00	0.00	0.01	0.00	0.79	0.00	0.00	0.00	0.00	0.13
5-year yields	0.00	0.03	0.01	0.00	0.00	0.00	0.00	0.00	0.87	0.00	0.00	0.00	0.00	0.09
10-year yields	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.94	0.00	0.00	0.00	0.00	0.04

Notes: pref- preference shock, risk- risk premium shock, dom markup- domestic goods mark-up shock, imp markup- imported goods mark-up shock,exp marku- exported goods mark-up, 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: Forecast error variance decomposition for Canada: Model 2 (macro estimation)

	pref	risk	dom markup	imp markup	exp markup	tech	money policy	gov't spend	inf target	foreign
1 quarter ahead										
output growth	0.00	0.00	0.19	0.00	0.00	0.70	0.00	0.06	0.00	0.05
inflation	0.00	0.07	0.02	0.06	0.00	0.00	0.34	0.00	0.17	0.34
short term interest rates	0.00	0.13	0.04	0.03	0.00	0.00	0.14	0.00	0.15	0.51
exchange rate depreciation	0.00	0.05	0.66	0.01	0.00	0.00	0.14	0.00	0.04	0.10
terms of trade growth	0.75	0.00	0.04	0.13	0.00	0.03	0.02	0.00	0.00	0.03
40 quarters ahead										
output growth	0.02	0.00	0.2	0.01	0.00	0.68	0.01	0.05	0.01	0.02
inflation	0.01	0.02	0.27	0.03	0.00	0.00	0.11	0.00	0.44	0.12
short term interest rates	0.03	0.01	0.29	0.04	0.00	0.00	0.02	0.00	0.40	0.21
exchange rate depreciation	0.00	0.05	0.62	0.02	0.00	0.00	0.13	0.00	0.09	0.09
terms of trade growth	0.60	0.01	0.18	0.09	0.00	0.02	0.05	0.00	0.01	0.04

Notes: pref- preference shock, risk- risk premium shock, dom markup- domestic goods mark-up shock, imp markup- imported goods mark-up shock, exp markup- exported goods mark-up, 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: Forecast error variance decomposition for New Zealand: Model 2 (joint estimation)

	pref	risk	dom markup	imp markup	exp markup	tech	money policy	gov't spend	inf target	me2	me3	me5	me10	foreign
1 quarter ahead														
output growth	0.00	0.00	0.02	0.00	0.02	0.16	0.00	0.78	0.00	0.00	0.00	0.00	0.00	0.02
inflation	0.01	0.21	0.04	0.00	0.00	0.02	0.39	0.07	0.16	0.00	0.00	0.00	0.00	0.10
short term interest rates	0.02	0.42	0.04	0.00	0.00	0.05	0.03	0.04	0.18	0.00	0.00	0.00	0.00	0.22
exchange rate depreciation	0.00	0.02	0.86	0.00	0.07	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.01
terms of trade growth	0.02	0.02	0.03	0.00	0.70	0.14	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.04
1-year yields	0.06	0.21	0.01	0.00	0.01	0.05	0.00	0.07	0.30	0.01	0.00	0.00	0.00	0.28
2-year yields	0.03	0.10	0.00	0.00	0.01	0.05	0.00	0.08	0.43	0.00	0.02	0.00	0.00	0.28
5-year yields	0.01	0.03	0.01	0.00	0.02	0.03	0.00	0.07	0.69	0.00	0.00	0.01	0.00	0.13
10-year yields	0.00	0.01	0.01	0.00	0.01	0.02	0.00	0.03	0.86	0.00	0.00	0.00	0.01	0.05
40 quarters ahead														
output growth	0.00	0.00	0.02	0.00	0.01	0.26	0.00	0.69	0.00	0.00	0.00	0.00	0.00	0.02
inflation	0.00	0.08	0.03	0.00	0.00	0.01	0.15	0.09	0.58	0.00	0.00	0.00	0.00	0.06
short term interest rates	0.00	0.07	0.01	0.00	0.01	0.03	0.00	0.05	0.71	0.00	0.00	0.00	0.00	0.12
exchange rate depreciation	0.00	0.02	0.83	0.00	0.07	0.01	0.01	0.01	0.03	0.00	0.00	0.00	0.00	0.02
terms of trade growth	0.02	0.02	0.11	0.00	0.62	0.14	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.04
1-year yields	0.01	0.03	0.01	0.00	0.01	0.02	0.00	0.04	0.79	0.00	0.00	0.00	0.00	0.09
2-year yields	0.00	0.01	0.01	0.00	0.01	0.02	0.00	0.04	0.85	0.00	0.00	0.00	0.00	0.06
5-year yields	0.00	0.00	0.01	0.00	0.01	0.01	0.00	0.02	0.93	0.00	0.00	0.00	0.00	0.02
10-year yields	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.01	0.96	0.00	0.00	0.00	0.00	0.01

Notes: pref- preference shock, risk- risk premium shock, dom markup- domestic goods mark-up shock, imp markup- imported goods mark-up shock,exp marku-exported goods mark-up, 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 14: Forecast error variance decomposition for New Zealand: Baseline (macro estimation)

	pref	risk	dom markup	imp markup	exp markup	tech	money policy	gov't spend	inf target	foreign
1 quarter ahead										
output growth	0.03	0.00	0.05	0.00	0.00	0.90	0.00	0.01	0.00	0.01
inflation	0.00	0.14	0.00	0.03	0.00	0.00	0.35	0.00	0.20	0.28
short term interest rates	0.00	0.20	0.02	0.03	0.00	0.00	0.15	0.00	0.20	0.40
exchange rate depreciation	0.00	0.04	0.78	0.00	0.00	0.00	0.08	0.00	0.04	0.10
terms of trade growth	0.96	0.00	0.00	0.01	0.00	0.00	0.02	0.00	0.00	0.01
40 quarters ahead										
output growth	0.05	0.00	0.06	0.00	0.00	0.87	0.00	0.01	0.00	0.01
inflation	0.06	0.06	0.39	0.01	0.00	0.00	0.17	0.00	0.15	0.16
short term interest rates	0.20	0.03	0.42	0.01	0.00	0.01	0.02	0.00	0.14	0.17
exchange rate depreciation	0.01	0.04	0.77	0.00	0.00	0.00	0.08	0.00	0.04	0.06
terms of trade growth	0.76	0.01	0.16	0.01	0.00	0.00	0.03	0.00	0.01	0.02

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 15: Correlation between model implied factors and counterparts in data

	$\mathbf{Corr}(\frac{\sum_{j=1}^{4} E_t(r_{t+j})}{4}, \frac{\sum_{j=1}^{4} r_{t+j}}{4})$	$\mathbf{Corr}(\frac{\sum_{j=1}^{4} E_t(\pi_{t+j})}{4}, \frac{\sum_{j=1}^{4} \pi_{t+j}}{4})$	$\mathbf{Corr}(\pi_t^*, \frac{\sum_{j=21}^{40} E_t^{survey}(\pi_{t+j})}{20})/\mathbf{Corr}(\pi_t^*, \frac{\sum_{j=21}^{40} E_t^{survey}(\pi_{US,t+j})}{20})$
Australia			
Joint estimation (M2)	0.898	0.4273	0.8855/0.9007
Macro estimation (M3)	0.4673	0.1617	N/A
Canada			
Joint estimation (M2)	0.8069	-0.1484	0.4948/0.9106
Macro estimation (M2)	0.5967	0.0561	0.3211/-0.3338
New Zealand			
Joint estimation (M2)	0.8906	0.3021	-0.6890/0.7223
Macro estimation (M1)	0.8909	0.2734	0.2918/-0.4163

Notes: The last column uses the five-to-ten year inflation expectation from survey data used in Wright (2011). The survey data are available on semi-annual frequency. We use data from April 1994 to October 2006 for Australia, from October 1992 to October 2006 for Canada, and from October 1995 to October 2006 for New Zealand. Model-implied estimates are computed at the posterior mode.

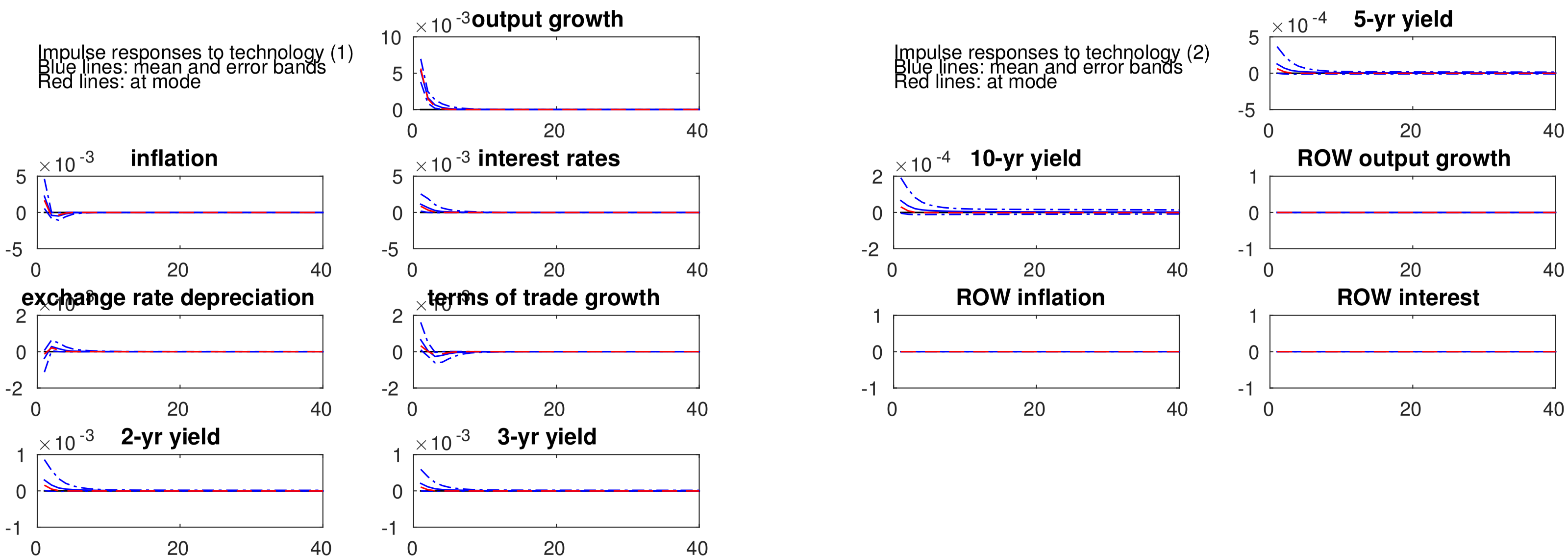

Figure 1: Impulse responses to a positive technology shock in Australia: M2 (joint estimation)

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.

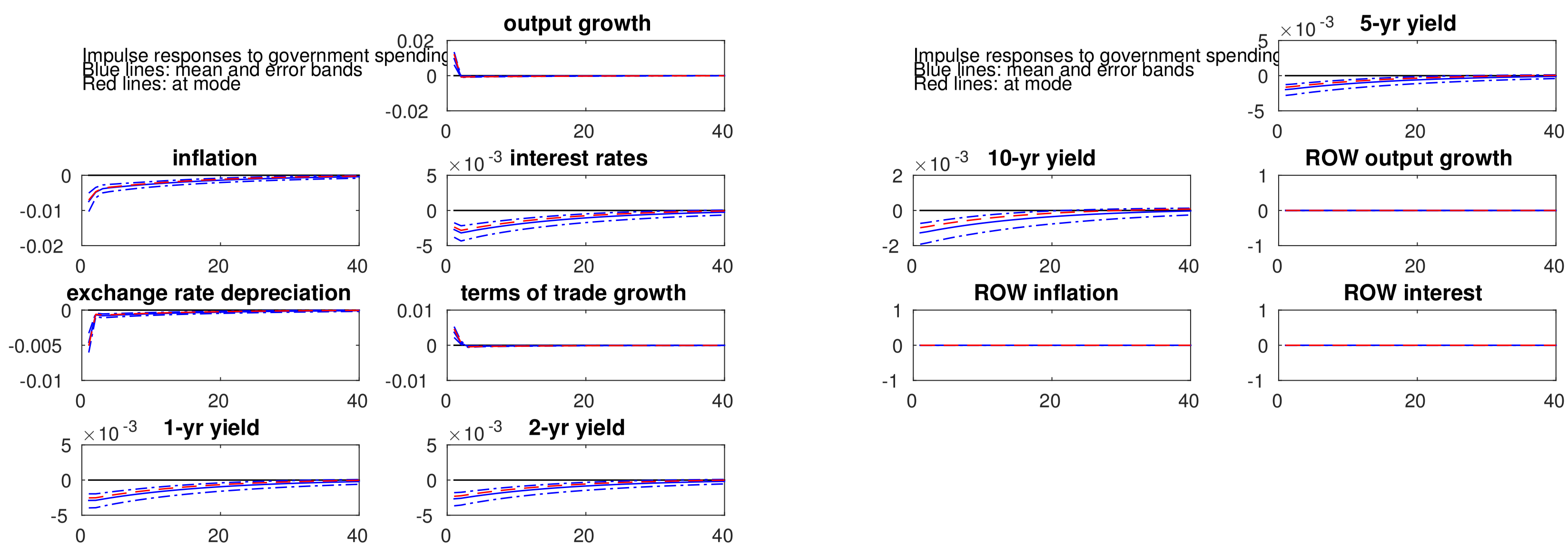

Figure 2: Impulse responses to a positve government spending shock in New Zealand: Model 2(joint estimation)

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.

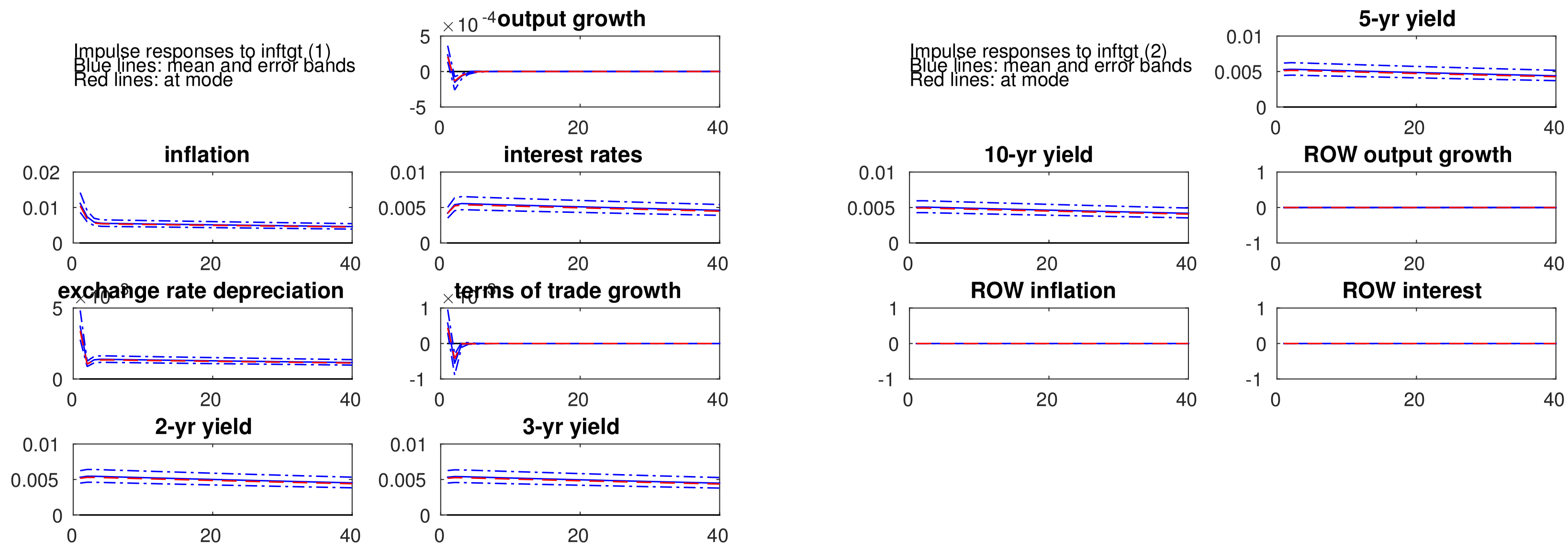

Figure 3: Impulse responses to a positive inflation target shock in Australia: M2 (joint estimation)

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.

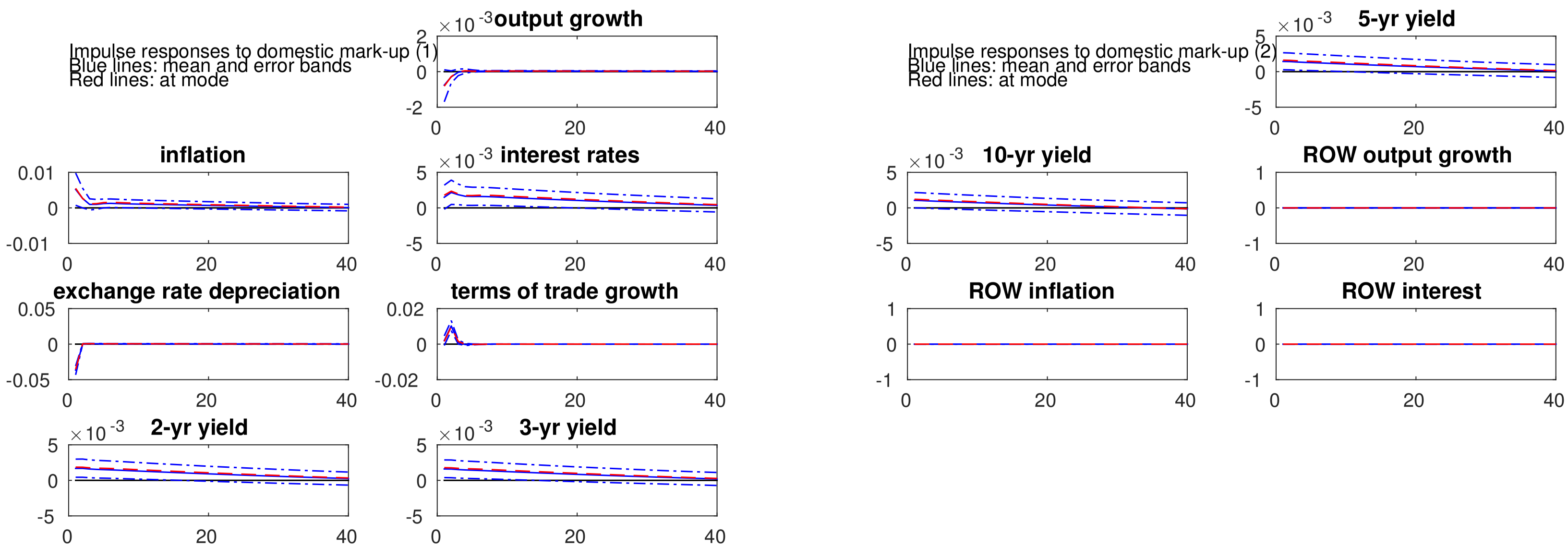

Figure 4: Impulse responses to a positive domestic markup shock in Australia: M2 (joint estimation)

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.

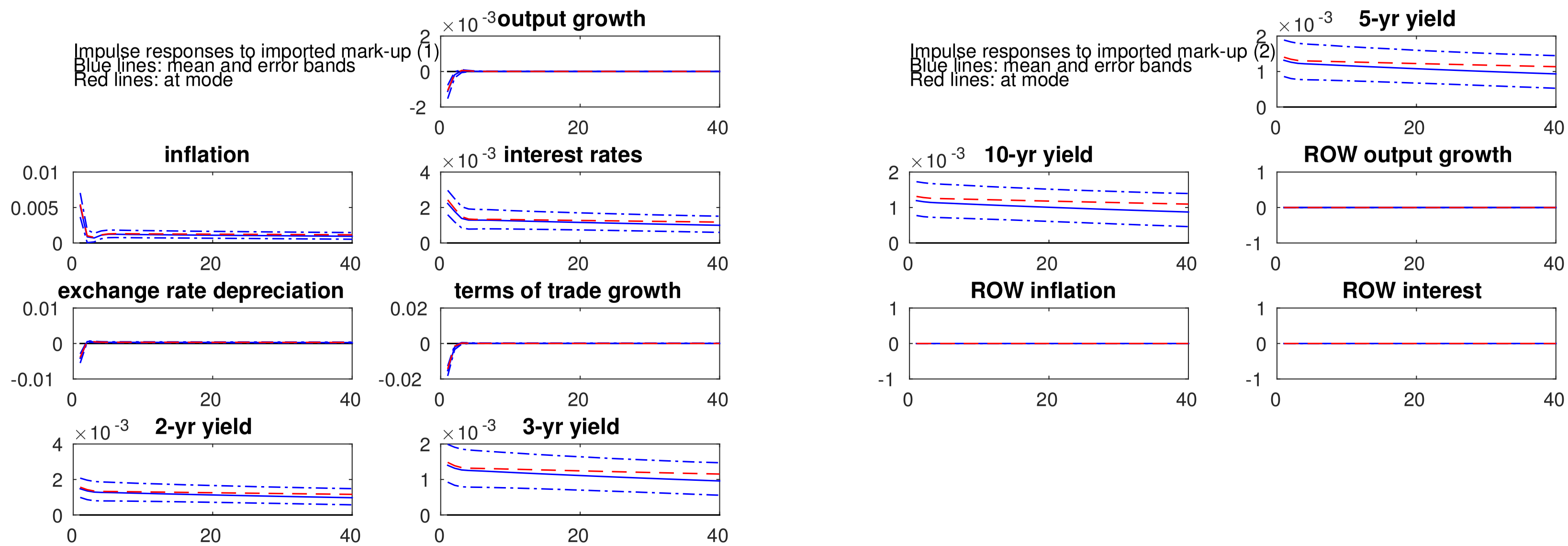

Figure 5: Impulse responses to a positive import markup shock in Australia: M2 (joint estimation)

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.

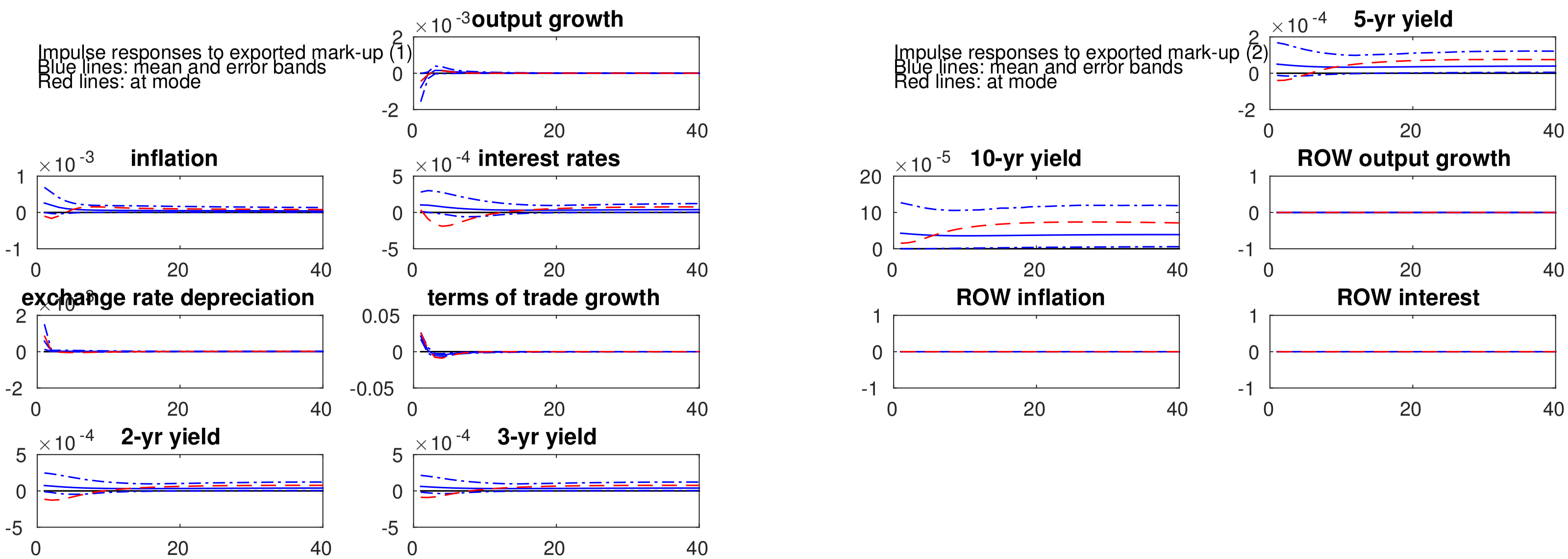

Figure 6: Impulse responses to a positve export markup shock in Canada: Model 2(joint estimation)

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.

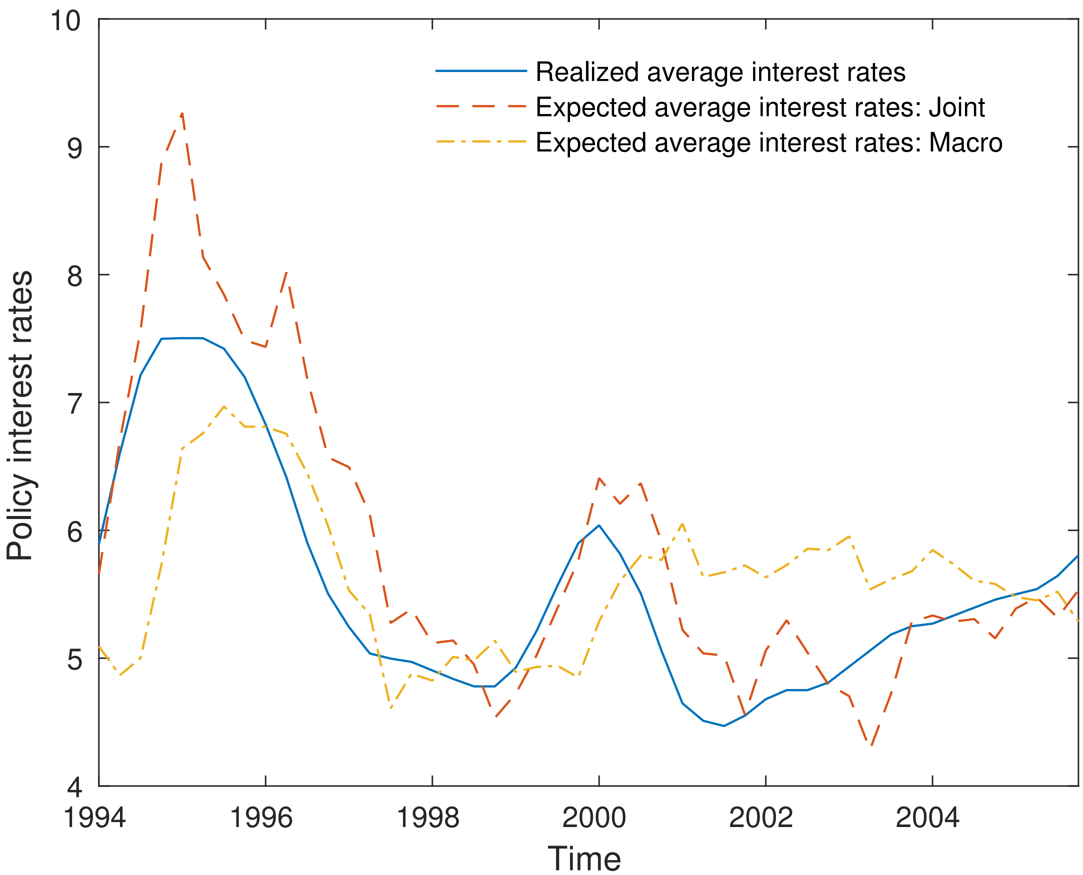

Figure 7: Expected vs. realized average policy interest rates over 1 year in Australia: best-fitting specification

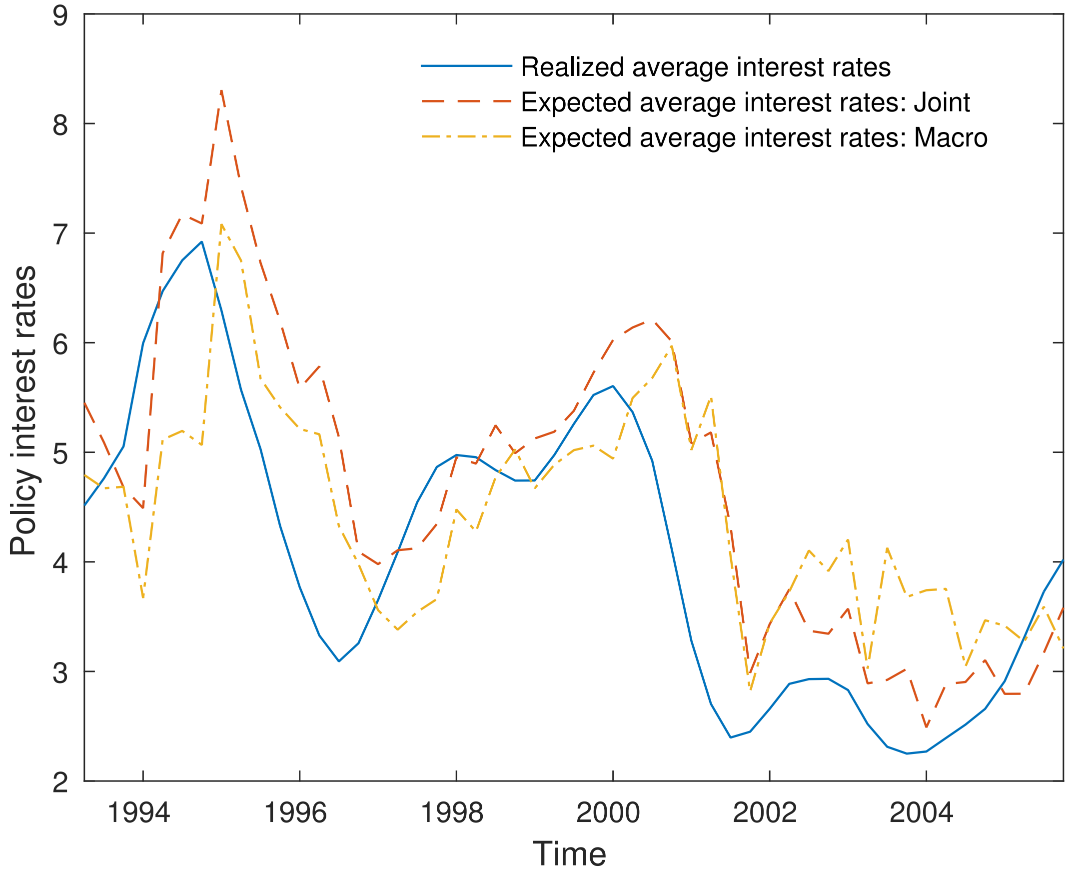

Figure 8: Expected vs. realized average policy interest rates over 1 year in Canada: best-fitting specification

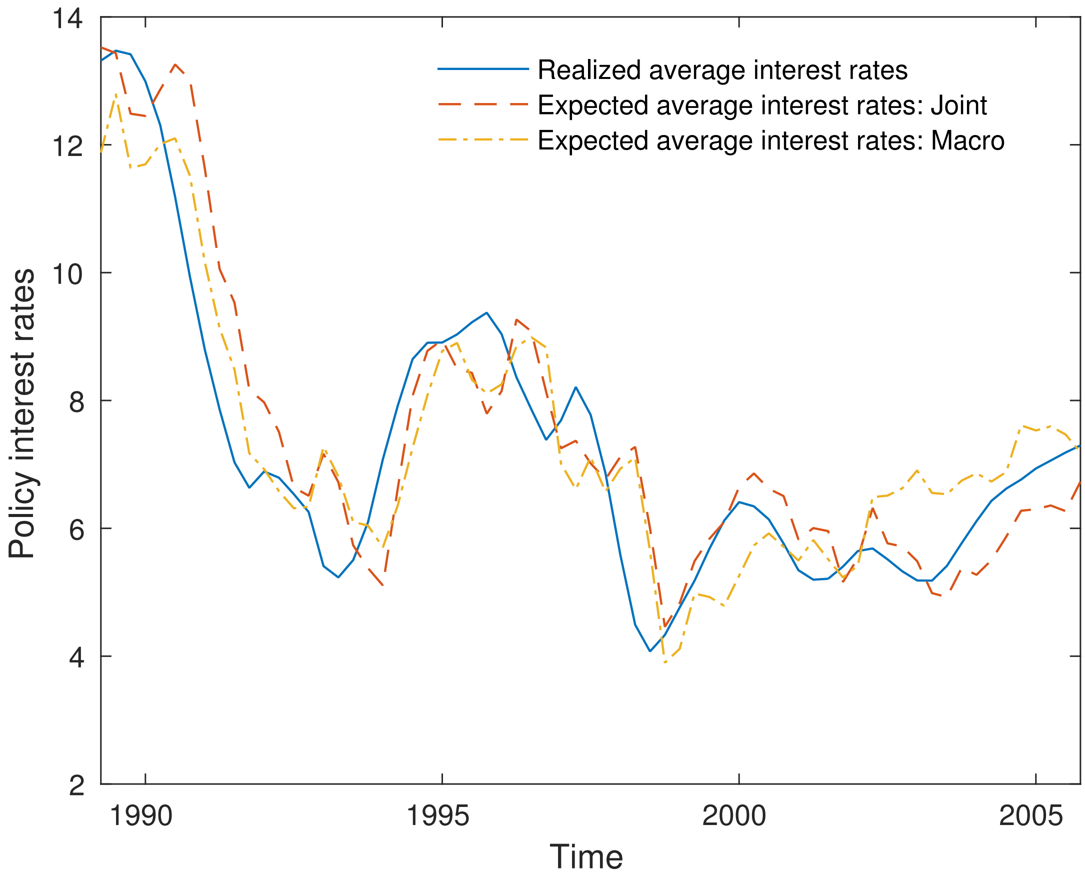

Figure 9: Expected vs. realized average policy interest rates over 1 year in New Zealand: best-fitting specification