Small Open Economy DSGE Models: Estimation and Model Fit*

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Abstract

This paper estimates various specifications of a small open economy model in order to determine which model assumptions provide a better fit of inflation, output, interest rates and exchange rate data from Australian, Canada and New Zealand. The specifications considered differ in a number of important dimensions including currency invoicing assumptions, the presence or absence of endogenous persistence mechanisms as well as the characterization of the foreign block. Using model averaging techniques to assess the evidence in favor of a given modeling assumption, limited evidence is found for the assumption of local currency pricing. Similarly, only for Australia is evidence found supporting the presence of habit formation, while for all countries there is no evidence supporting the presence of price indexation. Evidence is also adduced suggesting that the incorporation of habit formation may have undesirable consequences for properties of some second-order moments of the model.

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1 Introduction

The seminal contribution of Obstfeld and Rogoff (1995) has engendered a large literature on open economy dynamic stochastic general equilibrium (DSGE) models. However, the various assumptions adopted in these models can result in important differences in the dynamic properties of model variables. For instance, pricing-to-market assumptions can have crucial implications for the optimal degree of exchange rate flexibility as shown by Devereux and Engel (2003). Similarly, the inclusion of ad hoc endogenous persistence mechanisms, such as habit formation and price indexation, can considerably alter the dynamic behavior of model variables. However, despite this burgeoning theoretical literature, until recently, there has been little work on directly evaluating the ability of these DSGE models to fit open economy macroeconomic data. This paper therefore attempts to contribute to this empirical literature by providing a systematic evaluation of a range of modeling assumptions in explaining the behavior of macroeconomic times series in a simple small open economy model using Australian, Canadian and New Zealand data.

To investigate the role of various assumptions in the fit of a small open economy model, this paper estimates generalizations of the models proposed by Gali and Monacelli (2002) and Monacelli (2003). The former develops an elegant small open economy model incorporating many of the microfoundations appearing in the closed economy New Keynesian framework (see, for instance, Clarida, Gali, and Gertler (1999) and Woodford (2003)) that has recently been used for the analysis of monetary policy. The open economy model allows for the possibility that international trade in final goods and financial assets affect the evolution of the domestic economy giving rise to richer dynamics. The latter paper, building directly on the former, allows for local currency pricing of traded goods and nests its precursor as a special case. This modeling assumption admits deviations from the law of one price and, therefore, presents a mechanism for limited pass-through of exchange rate movements to consumer prices.

The present analysis generalizes these two models by allowing for a more general specification of dynamics. First, following much recent literature that attempts to fit closed economy DSGE models to the data, we allow for habit formation on the part of consumers and also the possibility that prices set by firms are indexed to past inflation. Second, while Monacelli (2003) proposes a particular structural model of the world economy, we also allow for the possibility that the evolution of the world economy variables are described by an unrestricted atheoretical VAR.

Following the contributions of Schorfheide (2000) and Smets and Wouters (2002) the paper adopts a Bayesian methodology. Relative to other recent approaches for inference in DSGE models this allows for a characterization of all uncertainty surrounding the estimates of the structural parameters by simulating the posterior distributions. Importantly, in using posterior odds Bayesian methods facilitate formal model comparisons regardless of whether the competing models are nested or not. The approach allows us, therefore, to formally asses the importance of pricing-to-market assumptions and the exact specification of the world economy in explaining observed data.

We emphasize that while assessing the fit of alternative models may be of interest for the purpose of policy evaluation or forecasting our goal of investigating the impact of contrasting specifications also is motivated by methodological considerations in the construction of posterior model odds. More precisely, our focus on various alternative modeling assumptions seeks to address some of the concerns with Bayesian model comparisons pointed out by Sims (2002a). In particular, our work aims to control and highlight the pitfalls of comparing a particular model characteristic when the set of competing frameworks is "too sparse". Our examples serve to highlight how model comparisons may be sensitive to small changes in specification, as underscored by Sims, and how to control for this problem by averaging across models.

Thus in addition to considering the relative fit of any two models, we also consider the evidence in favor of a given model assumption as determined by the weight of evidence provided by all models maintaining that assumption relative to all models that do not. We do this in the following way. Take the case of the pricing to market assumption. We compute posterior odds for all models as other model characteristics – such as the inclusion of habit formation or price indexation – are allowed to vary. The evidence in favor of a given pricing assumption is then determined by averaging over all models with the maintained pricing assumption using the posterior odds as weights. Our model comparison results are therefore based on a "model averaging" using the posterior odds as weights. To our knowledge this is the first application of such model selection/evaluation procedures in the recent DSGE literature.

Several key results are worthy of note. First, this paper builds on recent work on estimating New Open Economy Macroeconomic models by Bergin (2003), Dib (2003), DelNegro (2003) and Ghironi (2000). However, the present analysis is most closely related to the analysis of Lubik and

Schorfheide (2003a) which estimates a simplified version of the Gali and Monacelli (2002) model. Our empirical analysis extends theirs by exploiting the structural model proposed by Monacelli (2003), therefore allowing for the possibility of producer or local currency pricing (and consequently deviations from the law of one price). Moreover, we enrich model dynamics by allowing for habit formation, indexation of prices to past inflation, and a more flexible specification of the laws of motion describing the world economy.

Second, estimation yields plausible estimates for most structural parameters of the models under consideration (though there is some sensitivity to the specification as will be discussed). In the preferred models, the intertemporal elasticity of substitution, the elasticity of substitution between foreign and domestic goods and the import share as well as parameters governing the degree of price stickiness and policy parameters are estimated reasonably precisely and largely accord with previous findings in the closed-economy literature.

Third, for Australia and Canada, posterior model odds averaged across different specifications, reveal that the assumption of local currency pricing and the concomitant departure from the law of one price assumption does not provide a better description of the data than an otherwise identical model with producer currency pricing. For New Zealand, evidence in this respect is dependent on the characterization of the foreign block.

Our results should not be considered as suggesting deviations from full pass-through are absent from the data. This is particularly true since, as explained latter, in estimation we do not exploit all cross-equation restrictions that are relevant for pass-through dynamics. These observations, however, do suggest that for the fit of these class of small open economy DSGE models with respect to inflation, interest rates, output and the real exchange rate, deviations from the law of one price are not as important as one may have previously thought.

Interestingly, cross-validation exercises reveal that in the case of New Zealand the preferred model provides a fit that is almost comparable to a Bayesian vector autoregression (BVAR). For the case of Australia and Canada the model performs worse than a BVAR, indicating that changes in dimensions other than pricing assumptions or the presence of endogenous persistence mechanisms are needed to improve its fit. Importantly, it casts doubt on the usefulness of such small scale models for policy evaluation.

Fourth, careful analysis of the consequences of including habit formation on model dynamics reveals a number of pathologies. Habit formation has significant and substantive implications for the magnitudes of other model parameter estimates. Perhaps most importantly, calibration exercises indicate possible counter-factual properties for the model's second-order moments. For instance, the first-order serial correlation of inflation is declining as habit persistence increases, and can be negative for large values. An analysis analogous to Lettau and Uhlig (2000) indicates that an open economy setting produces differing implications for model variables' second-order moments in response to a technology shock than does a closed economy. Indeed, in contrast to the closed economy version of the model, habit formation leads to greater volatility in consumption and output and can lead to implausible variation in real wages and therefore marginal costs.

The paper proceeds as follows. Section 2 sketches the derivation of key structural equations implied by the microfoundations presented by Gali and Monacelli (2002) and Monacelli (2003) allowing for habit formation and price indexation. Section 3 details the estimation methodology and model selection techniques. Section 4 discusses the data and specification of the priors. Section 5 discusses the estimation and model selection results, and explores some implications of the models favored by the data. Section 6 investigates the implications of habit formation for model dynamics. Section 7 concludes and discusses some related ongoing research.

2 A Simple Small Open Economy Model

The following section sketches the derivation of key structural equations implied by the model proposed by Monacelli (2003) and its closely related precursor Gali and Monacelli (2002) when allowing for habit formation and indexation of prices. These papers extend the microfoundations of the kind described by Clarida, Gali, and Gertler (1999) and Woodford (2003) for analyzing monetary policy in a closed-economy setting to an open economy context. For additional detail the reader is encouraged to consult Monacelli (2003).

2.1 Households

Households are assumed to maximize

$$E_0 \sum_{t=0}^{\infty} \beta^t \tilde{\varepsilon}_{g,t} \left[\frac{(C_t - H_t)^{1-\sigma}}{1-\sigma} - \frac{N_t^{1+\varphi}}{1+\varphi} \right]$$

where N_t is the labor input; $H_t \equiv hC_{t-1}$ is an external habit taken as exogenous by the household; $\sigma, \varphi > 0$ are the inverse elasticities of intertemporal substitution and labor supply respectively; and $\tilde{\varepsilon}_{g,t}$ is a preference shock. C_t is a composite consumption index

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

where $C_{H,t}$ and $C_{F,t}$ are Dixit-Stiglitz aggregates of the available domestic and foreign produced goods given by

$$C_{H,t} = \left[\int_0^1 C_{H,t}(i)^{\frac{\varepsilon-1}{\varepsilon}} di \right]^{\frac{\varepsilon}{\varepsilon-1}} \quad \text{and} \quad C_{F,t} = \left[\int_0^1 C_{F,t}(i)^{\frac{\varepsilon-1}{\varepsilon}} di \right]^{\frac{\varepsilon}{\varepsilon-1}}.$$

$\eta > 0$ therefore gives the elasticity of substitution between domestic and foreign goods and $\varepsilon > 1$ is the elasticity of substitution between types of differentiated domestic or foreign goods. Optimization occurs subject to the flow budget constraint

$$\int_0^1 [P_{H,t}(i) C_{H,t}(i) + P_{F,t}(i) C_{F,t}(i)] \, di + E_t[Q_{t,t+1} D_{t+1}] \leq D_t + W_t N_t + T_t$$

for all $t > 0$, where W_t is the nominal wage rate, T_t lumpsum taxes and transfers, $P_{H,t}(i)$ and $P_{F,t}(i)$ the domestic price of home and foreign goods respectively, $Q_{t,t+1}$ the stochastic discount factor and D_{t+1} payments arising from the portfolio held at the end of period t. Given the assumption of complete domestic and international financial markets, this portfolio may comprise an arbitrary set of contingent claims at each state and date.

The household optimization problem requires allocation of expenditures across all types of domestic and foreign goods both intratemporally and intertemporally. This yields the following set of optimality conditions. The demand for each category of consumption good is

$$C_{H,t}(i) = (P_{H,t}(i) / P_{H,t})^{-\varepsilon} C_{H,t} \quad \text{and} \quad C_{F,t}(i) = (P_{F,t}(i) / P_{F,t})^{-\varepsilon} C_{F,t}$$

for all i with associated price indexes for the domestic and foreign consumption bundles given by

$$P_{H,t} \equiv \left[\int_0^1 P_{H,t}(i)^{1-\varepsilon} di \right]^{\frac{1}{1-\varepsilon}} \quad \text{and } P_{F,t} \equiv \left[\int_0^1 P_{F,t}(i)^{1-\varepsilon} di \right]^{\frac{1}{1-\varepsilon}}.$$

The optimal allocation of expenditure across domestic and foreign goods implies the demand functions

$$C_{H,t} = (1-\alpha) (P_{H,t}/P_t)^{-\eta} C_t \quad \text{and} \quad C_{F,t} = \alpha (P_{F,t}/P_t)^{-\eta} C_t$$

where α is the share of foreign goods in the domestic consumption bundle and $P_t = \left[(1-\alpha)P_{H,t}^{1-\eta} + \alpha P_{F,t}^{1-\eta}\right]^{\frac{1}{1-\eta}}$ is the consumer price index. The final intratemporal optimality condition follows from the households labor/leisure choice and is given by

$$\frac{N_t^{\varphi}}{(C_t - H_t)^{-\sigma}} = \frac{W_t}{P_t}. \tag{1}$$

Intertemporal optimization implies

$$Q_{t,t+1} = \beta \frac{\lambda_{t+1}}{\lambda_t} \cdot \frac{P_t}{P_{t+1}} \tag{2}$$

for all states and dates, where $\lambda_t = \tilde{\varepsilon}_{g,t}(C_t - H_t)^{-\sigma}$ is the marginal utility of income and $\tilde{\imath}_t$ the period nominal interest rate. Taking expectations results in the expression

$$\frac{1}{1+\tilde{\imath}_t} = \beta E_t[\frac{\lambda_{t+1}}{\lambda_t} \cdot \frac{P_t}{P_{t+1}}] \tag{3}$$

where the period nominal interest rate, i_t, is defined by the pricing equation $E_t Q_{t,t+1} = (1+\tilde{\imath}_t)^{-1}$.

The foreign economy is similarly described and assumed to have identical preferences. Thus a similar set of optimality conditions hold. However, because the foreign economy is approximately closed (the influence of the domestic economy is negligible), the available consumption bundle comprises the continuum of foreign produced goods $C_{F,t}^*(j)$ for $j \in [0,1]$. Foreign households need only decide how to allocate expenditures across these goods in any time period t and also over time. Conditions (1) and (2) continue to hold with all variables taking superscript "*".

2.2 International Risk Sharing and Prices

Under the maintained assumption that the foreign economy has identical preferences to the domestic economy, complete markets imply the following condition must be satisfied

$$\beta \frac{\lambda_{t+1}}{\lambda_t} \cdot \frac{P_t}{P_{t+1}} = Q_{t,t+1} = \beta \frac{\lambda_{t+1}^*}{\lambda_t^*} \cdot \frac{P_t^*}{P_{t+1}^*} \cdot \frac{\tilde{e}_t}{\tilde{e}_{t+1}} \tag{4}$$

where $\tilde{e}_t$ is the nominal exchange rate. Furthermore, from the asset pricing conditions that determine the domestic currency price of a bond purchased either in the domestic or foreign economy, the uncovered interest rate parity condition

$$E_t Q_{t,t+1}[\tilde{\imath}_t - \tilde{\imath}_t^*(\tilde{e}_{t+1}/\tilde{e}_t)] = 0$$

follows, placing a restriction on the relative movements of the domestic and foreign interest rate, and changes in the nominal exchange rate.

The real exchange rate is defined as $\tilde{q}_t \equiv \tilde{e}_t P_t^* / P_t$. Since $P_t^* = P_{F,t}^*$, when the law of one price fails to hold, we have $\tilde{\Psi}_{F,t} \equiv \tilde{e}_t P_t^* / P_{F,t} \neq 1$, which defines what Monacelli calls the law of one price gap. The models of Gali and Monacelli (2002) and Monacelli (2003) are respectively characterized by whether or not $\tilde{\Psi}_{F,t} = 1$.

2.3 Domestic Producers

There are a continuum of monopolistically competitive domestic firms producing differentiated goods. Calvo-style price-setting is assumed allowing for indexation to past domestic goods price inflation. Hence, in any period t, a fraction $1 - \theta_H$ of firms set prices optimally, while a fraction $0 < \theta_H < 1$ of goods prices are adjusted according to the indexation rule

$$\log P_{H,t}(i) = \log P_{H,t-1}(i) + \delta \pi_{H,t-1} \tag{5}$$

where $0 \leq \delta \leq 1$ measures the degree of indexation to the previous period's inflation rate and $\pi_{H,t} = \log(P_{H,t}/P_{H,t-1})$. Since all firms having the opportunity to reset their price in period t face the same decision problem, they set a common price $P_{H,t}^{'}$. The Dixit-Stiglitz aggregate price index therefore evolves according to the relation

$$P_{H,t} = \left[(1 - \theta_H) P_{H,t}^{'(1-\varepsilon)} + \theta_H \left(P_{H,t-1} \left(\frac{P_{H,t-1}}{P_{H,t-2}} \right)^{\delta} \right)^{1-\varepsilon} \right]^{1/(1-\varepsilon)}. \tag{6}$$

Firms setting prices in period t face a demand curve

$$y_{H,T}(i) = \left(\frac{P_{H,t}(i)}{P_{H,T}} \cdot \left(\frac{P_{H,T-1}}{P_{H,t-1}} \right)^{\delta} \right)^{-\varepsilon} \left(C_{H,T} + C_{H,T}^* \right) \tag{7}$$

for all t and take aggregate prices and consumption bundles as parametric. Good i is produced using a single labor input $N_t(i)$ according to the relation $y_{H,t}(i) = \tilde{\varepsilon}_{a,t} N_t(i)$ where $\tilde{\varepsilon}_{a,t}$ is an exogenous technology shock.

The firm's price-setting problem in period t is to maximize the expected present discounted value of profits

$$E_t \sum_{T=t}^{\infty} \theta_H^{T-t} Q_{t,T} y_{H,T}(i) \left[P_{H,t}(i) \left(\frac{P_{H,T-1}}{P_{H,t-1}} \right)^{\delta} - P_{H,T} MC_T \right]$$

where $MC_T = W_T/(P_{H,T}\tilde{\varepsilon}_{a,T})$ is the real marginal cost function for each firm, assuming homogenous factor markets, subject to the demand curve, (7). The factor θ_H^{T-t} in the firm's objective function is the probability that the firm will not be able to adjust its price in the next $(T-t)$ periods. The firm's optimization problem implies the first order condition

$$E_t \sum_{T=t}^{\infty} \theta_H^{T-t} Q_{t,T} y_{H,T}(i) \left[P_{H,t}(i) \left(\frac{P_{H,T-1}}{P_{H,t-1}} \right)^{\delta} - \frac{\theta_H}{\theta_H - 1} P_{H,T} MC_T \right] = 0. \tag{8}$$

Foreign firms face an analogous problem and are assumed to have the same production technology. Thus the optimality condition takes an identical form, with all variables taking the superscript "*" and the subscript H being changed to F. Note also that the small open economy assumption implies that P_t^* is equivalent to $P_{F,t}^*$.

2.4 Retail Firms

Retail firms import foreign differentiated goods for which the law of one price holds at the docks. However, in determining the domestic currency price of the imported good they are assumed to be monopolistically competitive. This small degree of pricing power leads to a violation of the law of one price in the short run.

In determining prices, retail firms face a Calvo-style price-setting problem allowing for indexation to past inflation. Hence, in any period t, a fraction $1 - \theta_F$ of firms set prices optimally, while a fraction $0 < \theta_F < 1$ of goods prices are are adjusted according to an indexation rule analogous to (5). The Dixit-Stiglitz aggregate price index consequently evolves according to the relation

$$P_{F,t} = \left[(1-\theta_F) P_{F,t}^{\prime(1-\varepsilon)} + \theta_F \left(P_{F,t-1} \left(\frac{P_{F,t-1}}{P_{F,t-2}} \right)^{\delta} \right)^{1-\varepsilon} \right]^{1/(1-\varepsilon)} \tag{9}$$

and firms setting prices in period t face a demand curve

$$C_{F,T}(i) = \left(\frac{P_{F,t}(i)}{P_{F,T}} \cdot \left(\frac{P_{F,T-1}}{P_{F,t-1}} \right)^{\delta} \right)^{-\varepsilon} C_{F,T} \tag{10}$$

for all t and take aggregate prices and consumption bundles as parametric. The firm's price-setting problem in period t is to maximize the expected present discounted value of profits

$$E_t \sum_{T=t}^{\infty} \theta_H^{T-t} Q_{t,T} C_{F,T}(i) \left[P_{F,t}(i) \left(\frac{P_{F,T-1}}{P_{F,t-1}} \right)^{\delta} - \tilde{e}_T P_{F,T}^*(i) \right]$$

subject to the demand curve, (10). The factor θ_F^{T-t} in the firm's objective function is the probability that the firm will not be able to adjust its prices in the next $(T-t)$ periods. The firm's optimization problem implies the first order condition

$$E_t \sum_{T=t}^{\infty} \theta_F^{T-t} Q_{t,T} \left[P_{F,t}(i) \left(\frac{P_{F,T-1}}{P_{F,t-1}} \right)^{\delta} - \frac{\theta_H}{\theta_H - 1} \tilde{e}_T P_{H,T}^* (i) \right] = 0.$$

Note that in the foreign economy there is no analogous optimal pricing problem. Because imports form a negligible part of the foreign consumption bundle variations in the import price have negligible effect on the evolution of the foreign price index, P_t^*, and therefore need not be analyzed.

2.5 General Equilibrium

Equilibrium requires that all markets clear. In particular goods market clearing requires

$$Y_{H,t} = C_{H,t} + C_{H,t}^* \quad \text{and} \quad Y_t^* = C_t^* \tag{11}$$

in the domestic and foreign economies respectively. The analysis considers a symmetric equilibrium in which all domestic producers setting prices in period t set a common price $P_{H,t}$. Similarly, all domestic retailers and foreign firms each choose a common price $P_{F,t}$ and P_t^* respectively. Finally households are assumed to have identical initial wealth, so that each faces the same period budget constraint and therefore makes identical consumption and portfolio decisions.

Monacelli (2003) is a clear and elegant generalization of the closed-economy New Keynesian framework that has be used extensively in recent analyses of monetary policy. Indeed, it nests this model as a special case. Assuming that the law of one price holds, so that $\tilde{\psi}_{F,t} = 1$ for all t, delivers the model of Gali and Monacelli (2002).[1] Foreign disturbances still affect the domestic economy, through market clearing and international risk sharing, but producer currency pricing is assumed. Furthermore, assuming the limiting value of $\alpha = 0$, so that foreign goods are no longer part of the domestic consumption bundle, delivers the familiar closed-economy New Keynesian model as explicated in Clarida, Gali, and Gertler (1999) and Woodford (2003), though modified to allow habit formation and price indexation.

[1] Note that the specific assumption that the law-of-one-price holds is not nested within in the more general model parametrically.

2.6 Log-linear approximation to the model

For the purpose of the empirical analysis, a log-linear approximation of the model's optimality conditions around a non-stochastic steady state is employed. Details are found in the appendix. We here discuss the key structural equations that emerge from this analysis. All variables are properly interpreted as log deviations from their respective steady state values. Relations pertaining to the domestic economy are discussed first followed by those for the foreign economy.

A log linear approximation to the domestic household's Euler equation (3) provides

$$c_t - hc_{t-1} = E_t(c_{t+1} - hc_t) - \sigma^{-1}(1-h)(i_t - E_t\pi_{t+1}) + \sigma^{-1}(1-h)\left(\varepsilon_{g,t} - E_t\varepsilon_{g,t+1}\right).$$

In the absence of habit formation, when $h = 0$, the usual Euler equation obtains. Consumption depends not only on expectations about next period's consumption and real interest rates, but also on consumption obtained at time $t-1$. To derive a relationship in terms of domestic output, a log-linear approximation to the goods market clearing condition implies:

$$(1-\alpha)\,c_t = y_t - \alpha\eta\,(2-\alpha)\,s_t - \alpha\eta\psi_{F,t} - \alpha y_t^*. \tag{12}$$

where

$$\psi_{F,t} \equiv (e_t + p_t^*) - p_{F,t}$$

denotes the law of one price gap, the difference between the world currency price and the domestic currency price of imports, and $s_t = p_{F,t} - p_{H,t}$ gives the terms of trade. Time differencing the terms of trade definition implies

$$\Delta s_t = \pi_{F,t} - \pi_{H,t}. \tag{13}$$

Thus, equilibrium domestic consumption depends on domestic output and three sources of foreign disturbance: the terms of trade, deviations from the law of one price and foreign output. From these equations a relation describing the evolution of domestic output is immediate, which, in contrast to the usual closed economy expression, necessarily depends on these three sources of foreign disturbance.

The terms of trade and the real exchange rate are related according to:

$$q_t = e_t + p_t^* - p_t = \psi_{F,t} + (1-\alpha)\,s_t \tag{14}$$

so that the real exchange rate varies with deviations from the law of one price and also differences in the consumption bundles across the domestic and foreign economies.

A log-linear approximation to domestic firms' optimality conditions for price setting and the price index, (6), imply the relation

$$\pi_{H,t} - \delta\pi_{H,t-1} = \theta_H^{-1}\left(1-\theta_H\right)\left(1-\theta_H\beta\right)mc_t + \beta E_t\left(\pi_{H,t+1} - \delta\pi_{H,t}\right) \tag{15}$$

where

$$mc_t = \varphi y_t - (1+\varphi)\,\varepsilon_{a,t} + \alpha s_t + \sigma\left(1-h\right)^{-1}\left(c_t - hc_{t-1}\right)$$

is the real marginal cost function of each firm. Thus domestic price inflation, $\pi_{H,t} = p_{H,t} - p_{H,t-1}$, is determined by current marginal costs, expectations about inflation in the next period and the most recent observed inflation rate. The latter appears as a result of price indexation. In the case of zero indexation to past inflation, $\delta = 0$, the usual forward looking Phillips curve arises. Marginal costs depend on the technology disturbance, $\varepsilon_{a,t}$, as well as domestic consumption. In contrast to a closed-economy setting, domestic goods price inflation depends on three sources of foreign disturbance. There is a direct and indirect effect of the terms of trade on firms' marginal costs, with the latter operating through the terms of trade implications for equilibrium consumption. There are also the effects of foreign output and deviations from the law of one price (recall relation (12)).

The optimality conditions for the retailers' pricing problems yields

$$\pi_{F,t} - \delta\pi_{F,t-1} = \theta_F^{-1}\left(1-\theta_F\right)\left(1-\theta_F\beta\right)\psi_{F,t} + \beta E_t\left(\pi_{F,t+1} - \delta\pi_{F,t}\right). \tag{16}$$

Here, inflation in the domestic currency price of imports, $\pi_{F,t} = p_{F,t} - p_{F,t-1}$, is determined by current marginal cost conditions given by $\psi_{F,t}$ and expectations about next period's inflation rate. Again, that prices are indexed to past inflation induces a history dependence on the most recent observed inflation rate.

Following the arguments of Chari, Kehoe, and McGrattan (2002) and Gali and Monacelli (2002), the complete markets assumption and condition (4) imply the following approximate relation is satisfied:

$$c_t - hc_{t-1} = y_t^* - hy_{t-1}^* + \sigma^{-1}(1-h)[\psi_{F,t} + (1-\alpha)\,s_t] + \sigma^{-1}(1-h)\varepsilon_{g,t}. \tag{17}$$

Complete markets therefore forge a link between foreign and domestic consumption levels. They differ insofar as there are departures from the law of one price and differences in the domestic and foreign consumption bundle (reflected in the final term). The uncovered interest-rate parity condition gives

$$i_t - i_t^* = E_t \Delta e_{t+1}.$$

Note that from the definition of the real exchange rate we have $\Delta e_t = \Delta q_t + \pi_t - \pi_t^*$ providing

$$(i_t - E_t \pi_{t+1}) - \left(i_t^* - E_t \pi_{t+1}^*\right) = E_t \Delta q_{t+1} + \varepsilon_{s,t} \tag{18}$$

where a risk premium shock, $\varepsilon_{s,t}$, has been added for reasons that will be clear when the estimation approach is discussed.

Conditional on the evolution of the world economy and other exogenous disturbances, to close this model of the economy we need to specify monetary policy. It will be assumed that monetary policy is conducted according to the Taylor-type rule

$$i_t = \rho i_{t-1} + \psi_\pi \pi_t + \psi_x x_t + \varepsilon_{M,t} \tag{19}$$

so that the nominal interest rate is determined by past interest rates and also responds to the current CPI inflation rate and output gap, $x_t = y_t - y_t^n$, where y_t^n corresponds to the level of output that would obtain in the presence of fully flexible prices in both domestic and retail sectors. The final term, $\varepsilon_{M,t}$, is a monetary policy shock or implementation error in the conduct of policy. Note that the CPI and domestic goods prices are related according to

$$\pi_t = \pi_{H,t} + \alpha \Delta s_t. \tag{20}$$

The domestic block of the economy is therefore given by equations (12)-(20) in the 9 unknowns $\left\{c_t,\ y_t,\ i_t,\ q_{t,}\ s_t,\ \pi_t,\ \pi_{H,t},\ \psi_{H,t},\ \pi_{F,t}\right\}$. Given processes for the exogenous disturbances $\{\varepsilon_{a,t},\ \varepsilon_{M,t},\ \varepsilon_{g,t},\ \varepsilon_{s,t}\}$ and $\{\pi_t^*,\ x_t^*,\ i_t^*\}$ this linear rational expectations model can be solved using standard methods. The disturbances $\{\varepsilon_{a,t},\ \varepsilon_{g,t},\ \varepsilon_{s,t}\}$ are assumed to be independent AR(1) processes and $\{\varepsilon_{M,t}\}$ an i.i.d. process. The determination of the foreign block $\{\pi_t^*,\ x_t^*,\ i_t^*\}$ is discussed in the subsequent section. In estimation, we only make use of observable series for $\{y_t,\ i_t,\ q_t,\ \pi_{H,t}\}$ and therefore exploit only a subset of cross-equation restrictions implied by the model.

2.7 The Foreign Economy

In Monacelli (2003) the foreign economy is specified as the closed-economy variant of the model described above. Thus, the economy is given by the structural relations:

$$y_t^* - hy_{t-1}^* = E_t(y_{t+1}^* - hy_t^*) - \sigma^{-1}(1-h)\left(i_t^* - E_t\pi_{t+1}^*\right) \tag{21}$$

and

$$\pi_t^* - \delta\pi_{t-1}^* = \beta E_t(\pi_{t+1}^* - \delta\pi_t^*) + \theta^{-1}(1-\theta)(1-\theta\beta)\,mc_t^* \tag{22}$$

where

$$mc_t^* = \varphi y_t^* - (1+\varphi)\,\varepsilon_{a,t}^* - \sigma(1-h)^{-1}(y_t^* - hy_{t-1}^*)$$

where all parameters take identical values to those in the domestic economy (preferences and technology being assumed identical). These expressions are log-linear approximations to the household and firm optimality conditions (2) and (8) with all variables appended by "$*$". Note that under the assumption that the world economy is approximately closed there is no distinction between the foreign CPI and foreign goods price inflation and also $c_t^* = y_t^*$. The foreign block of the model is closed by specifying monetary policy. Analogous to the domestic economy, the nominal interest rate is assumed to be determined according to a Taylor rule:

$$i_t^* = \rho_{i^*} i_{t-1}^* + \psi_{\pi^*}\pi_t^* + \psi_{x^*}x_t^* + \varepsilon_{i,t}^*. \tag{23}$$

The foreign block therefore comprises the three equations (21)-(23) in the unknowns $\{x_t^*, \pi_t^*, i_t^*\}$ and is exogenous to the domestic economy. Application of standard solution methods determines the paths $\{x_t^*, \pi_t^*, i_t^*\}$ as a linear function of $\left\{i_{t-1}^*,\ \varepsilon_{a,t}^*,\ \varepsilon_t^*,\ \varepsilon_{i,t}^*\right\}$.

Because the foreign economy is exogenous to the domestic economy, we have some flexibility in specifying the determination of foreign variables. Rather than take a literal interpretation of the Monacelli model, we instead assume that the paths of $\{x_t^*, \pi_t^*, i_t^*\}$ are determined by an unrestricted vector autoregression.[2] Hence, defining $z_t^* = [x_t^*, \pi_t^*, i_t^*]'$ as the vector of foreign variables, the data generating process is assumed to take the form:

$$z_t^* = Az_{t-1}^* + \varepsilon_t^* \tag{24}$$

[2] Clearly if the true model is one that has the domestic and foreign economies both having the same preference and technology, estimation would be more efficient by imposing this restriction. Note also that the structural relations derived for the domestic economy in large part depended on the assumption that the foreign economy is populated with households and firms with identical preferences and technology. The assumption of a VAR therefore is not fully consistent with the structural equations presented.

where A is a coefficient matrix of appropriate dimension and ε_t^* an error vector with the usual properties. This specification has the advantage of not imposing the assumption that domestic and foreign preferences and technology are identical and also allows for a more flexible representation of the reduced form dynamics of these variables. Moreover the dynamics of the VAR nest those implied by the structural model of the foreign block. We consider both possibilities in estimation, though only report results for the latter.[3]

3 Estimation Methodology

Our objective is to estimate variants of the model specified in Section 2 using Bayesian methods. The Bayesian approach has the advantages of facilitating comparison of models that are non-nested and taking explicit account of all uncertainty (related to unobservables or models) surrounding parameter estimates. This section sketches our approach to inference and model comparisons, leaving details to an appendix.

We wish to estimate each DSGE model, denoted m_K, and associated parameters $\theta_k \in \Theta_k$. Given a prior $p(\theta_k)$, the posterior density of the model parameters, θ_k, is given by

$$p\left(\theta_k|Y^T, m_K\right) = \frac{L\left(\theta_k|Y^T, m_K\right)p(\theta_k)}{\displaystyle\int L\left(\theta_k|Y^T, m_K\right)p(\theta_k)d\theta_k}$$

where $L\left(\theta_k|Y^T, m_K\right)$ is the likelihood conditional on observed data, Y^T, and model, m_K. The likelihood function is computed under the assumption of normally distributed disturbances by combining the state-space representation implied by the solution of the linear rational expectations model and the Kalman filter.[4] Posterior draws are obtained using Markov Chain Monte Carlo methods. After obtaining an approximation to the mode of the posterior, we rely on a Random Walk Metropolis algorithm to generate posterior draws, as discussed in Schorfheide (2000). Point estimates of θ_k can be obtained from the generated values by using various location measures, such as the mean or median. Similarly, measures of uncertainty follow from computing the percentiles of the draws.

[3] The results under the former assumption were somewhat implausible. In ongoing work we are estimating a related model which allows for the domestic and foreign economies to have differing structural parameters.

[4] It is worth highlighting that the employed estimation methodology does not allow the linear rational expectations model to have either a non-existent or indeterminate solution. Empirical research of closed economy models suggests that monetary policy has been conducted over the sample period of interest in such a way to ensure determinacy of rational expectations equilibrium. Nonetheless, an important step would be to generalize the analysis here to allow for indeterminacy along the lines proposed by Lubik and Schorfheide (2003b).

Having applied this procedure to different models $m_K \neq m_H$, the DSGE models are compared in their ability to fit the data. Model comparisons are based on the ratio of the posterior model densities $p(m_K|Y^T)$ and $p(m_H|Y^T)$, known as the Posterior Odds $(PO_{K,H})$, which summarize the evidence provided by the data, Y^T, in favor of model K over model H:

$$PO_{K,H} = \frac{p(m_K|Y^T)}{p(m_H|Y^T)} = \frac{f(Y^T|m_K)}{f(Y^T|m_H)} \frac{\pi(m_K)}{\pi(m_H)}. \tag{25}$$

The expression on the right follows directly from Bayes theorem. The density

$$f(Y^T|m_K) = \int L\left(\theta_k|Y^T, m_K\right) p(\theta_k)$$

is known as the marginal likelihood. When competing models are assigned equal prior probabilities, so that $\pi(m_K) = \pi(m_H)$, posterior odds are equivalent to the ratio of the marginal likelihoods. In this paper, we estimate the marginal likelihood using the simulation-based modified Harmonic mean proposed by Geweke (1998). Furthermore, we follow an alternative approach that treats the model indicator as an additional parameter to be estimated. By running the product space search method of Dellaportas, Forster, and Ntzoufras (2002) – a hybrid of a Reversible Jump and a Metropolis algorithm – it is possible to obtain the posterior model probabilities directly without having to estimate the marginal likelihood.

4 Data and Priors

For all three countries, Australia, Canada and New Zealand, we estimate all models using quarterly data on output, inflation, interest rates and the real exchange rate. GDP is per-capita in log deviations from a linear trend. The real exchange rate is also in log-deviations from a linear trend. The inflation series corresponds to the annualized quarterly log-difference in the GDP deflator. For the case of Australia, an adjustment is made to the GDP deflator series to take into account the effects of the introduction of the GST in 2000-2001. Finally, we use the cash rate in Australia and for Canada and New Zealand averages of 3-month bank rates (all expressed in annualized percentages) for interest rates. All Australian data was downloaded from the Statistical Tables published by the Reserve Bank of Australia (RBA). For Canada and New Zealand all data were obtained from Data Stream International.

For specifications in which the foreign block is observable we assume it to be reasonably proxied by US data. The US series are the annualized quarterly log percentage change in the CPI, the log deviations of per capita GDP from a linear trend and the Fed Funds rate (annualized percentage), all taken from the Database at the Federal Reserve Bank of St. Louis. Our samples run from 1984:I until 2002:IV for Australia, and 1988:III-2003:IV for New Zealand, following the move in each country towards a flexible exchange rate regime. For Canada, the sample covers the period 1982:I-2003:IV, to coincide with the abandonment of targeting monetary targeting with the Bank of Canada.[5]

The priors for the parameters are specified in Table 1, which reports the distribution, the mean and 99% probability bands for each of the elements of the parameter vector θ_k. The prior distributions are assumed to be independent across parameters, and were formulated to give due regard to earlier work estimating closed-economy versions of the DSGE model considered in this paper, and also the extensive literature on estimating monetary policy rules. Identical priors are used for all countries. Our priors are similar to those of Lubik and Schorfheide (2003a), although we consider a wider set of apriori values particularly for the inverse intertemporal elasticity of substitution, as well as the response to the output gap in the Taylor rule. In contrast, our prior specification is somewhat tighter for the smoothing coefficient in the Taylor rule. As a robustness check, we try an alternative set of looser priors.

5 Estimation Results

The central question of interest for the empirical analysis is the ability of different specifications of a small open economy model to explain the time series properties of macroeconomic data from three small open economies: Australia, Canada and New Zealand. Two characteristics on which we wish to focus across specifications are the degree of pass-through from exchange rate movements as well as the presence or absence of endogenous persistence mechanisms: (external) habit formation and price indexation. We seek to analyze how varying both of these model assumptions affect parameter estimates, as well as provide an assessment of how important each of these specifications is for model fit. To this end, we estimate the model laid out in Section 2 under the alternative assumptions of

[5] We use four observations before the start of the sample dates above listed to deal with the initialization of the Kalman filter. These four initial data points are excluded from the computation of the likelihood and consequently from our estimates. Note that this does not represent the use of a training sample prior.

producer currency and local currency pricing for each country. For each of these models we report results with and without habit formation and price indexation and also models with either habit formation or price indexation.

An agnostic stance on the determination of the foreign block is adopted. Two alternative specifications of the foreign block are considered: unobserved – as in Lubik and Shorfheide – and observed, proxied for with US data. This yields a total of sixteen DSGE models to be estimated per country. Once again, our aim is to highlight how varying different underlying assumptions of the model (as well as the data in the observability of the foreign block) may affect inference on the parameters and the role each of these characteristics plays in fitting the model to the data.

Tables 2, 3 and 4 present parameter estimates for the Australian, Canadian and New Zealand data respectively. Tables marked 'a' give estimates when the foreign block is observed and tables marked 'b' denote the corresponding unobserved cases. In each table, the first four columns of results pertain to the model with producer currency pricing (with and without habit and price indexation) while the second four detail those for the model with local currency pricing. Parameter estimates are presented in three groups: preference and technology parameters; policy parameters; and those of the exogenous disturbances.[6]

5.1 Australia

When the foreign block is observable (Table 2.a) with the exception of the LCP model with inflation indexation, estimates are remarkably stable across models. Inferred median values for σ and φ imply elasticities of intertemporal substitution and labor supply well within the ranges found by earlier studies – $0.4 - 0.5$ and $0.66 - 1.0$ respectively. The degree of price stickiness suggests prices are changed every 2.5 quarters on average. The share of imported goods in the domestic consumption bundle is estimated to be around 0.1, somewhat below the estimate implied by national accounts data. Of particular interest is the posterior for η. Looking at the posterior percentiles reported in Table 2.a it is easy to see that this density is tightly concentrated (despite a fairly non-informative prior) around a median value of 0.3.[7] The inferred range of values for η is robust across all specifications and implies a low elasticity of substitution between domestic and foreign goods particularly

[6] The parameter estimates pertaining to the foreign block are available on request.

[7] Plotting our prior against the inferred posterior density reveals that the likelihood is quite informative about this parameter.

compared to calibration values available in the literature. Indeed, it has implications for papers such as Obstfeld and Rogoff (2001) which proposes a model in which large values of the elasticity of substitution between domestic and foreign goods and transaction cost stories help explain a number of prominent puzzles in international macroeconomics. The policy parameters are consistent with single equation GMM estimates from de Brouwer and Gilbert (2003). Of the disturbances, domestic technology and demand shocks are most important, having the largest standard deviations and the latter being most persistent.

Reflecting the stability of estimates across models it is clear that the addition of price indexation does not have a great impact on the model parameters. The most significant change is the fall in θ. This stems from indexation raising the degree of inflation inertia, while lower degrees of price stickiness are associated with less serial correlation in inflation. The introduction of habit also has little impact on the estimates. θ rises somewhat relative to the indexation model. Similarly, the assumption of PCP versus LCP has little effect on the estimates. θ_F is inferred to be between 0.3 and 0.5 implying that the domestic price of imported goods are changed every $1.4 - 2$ quarters, so that deviations from the law of one price are fairly short lived. We emphasize that the low degree of price rigidity for foreign goods (especially compared to domestically produced goods) is one characteristic of the model estimates that is robust to alternative specifications.

Finally note that the LCP model with inflation indexation is very much an outlier amongst the models. We explored the possibility of this being a result of a convergence failure in the Markov Chains. However, longer chains as well as alternative priors produced very similar estimates for this specification.

When the foreign block is unobserved, coefficient estimates exhibit less stability across models.[8] This is a consequence of the fact that when the foreign block is unobserved the model need no longer be constrained to fit US data, leaving the exogenous foreign disturbance terms free to soak up variation in domestic variables. Thus, when habit and indexation are introduced – frictions which, as explained later, can have important and substantial implications for the second moments implied by the model – the foreign shocks combined with structural parameters can change more dramatically in order to fit the data.

[8] In estimating models with the foreign block unobserved we drop the foreign exchange risk premium shock – otherwise the model would have 7 shocks for the 4 observable series.

Taking a look first at the PCP models (columns 1-4 , Table 2.b) note that σ and φ are again plausible. Of particular interest however is the instability of θ, η, α, the policy response to inflation and the volatility of foreign output and technology, especially when habit is introduced. These three models (1 through 3) differ only by the sequential inclusion of indexation and habit formation which begs the question of what can be driving the differences in parameter estimates? As underscored by Chari, Kehoe, and McGrattan (2002), recall that the models of the kind being examined are attempting to fit two important characteristics of the data: the volatility and persistence of the real exchange rate. To match these characteristics we require price stickiness and also inflation persistence. With this in mind, consider the PCP model with inflation indexation. The degree of indexation, δ, is estimated to be 0.33 and θ and η shift by significant amounts – falling and rising, respectively – relative to the no indexation case. The reasoning is as follows: greater indexation (larger values of δ) increase the persistence of inflation substantially, thus enabling a better fit of the persistence in the real exchange rate. However, it also eases constraints on other model parameters. Since lower price stickiness implies reduced inflation inertia in the context of this model and higher substitutability between domestic and foreign goods leads to reductions in domestic goods price inflation inertia – since domestic consumers more readily switch to foreign goods in response to domestic goods price increases – as δ rises lower values of θ and higher η are permitted while nonetheless matching the inflation inertia observed in the data.[9]

The introduction of habit has more dramatic implications than does indexation. θ jumps to a large value of 0.9, η falls to zero, α doubles in size and σ increases. Moreover, the policy coefficients shift, with policy exhibiting a diminished long-run response to inflation and output. Meanwhile, the persistence of foreign output shocks declines together with the standard deviation of its innovations. Finally, there is a dramatic increase in the volatility of technology shocks of nearly an order of magnitude. A similar pattern can be seen in the models that allow for LCP by comparing the estimates in columns 5 and 7 corresponding to the specifications with and without habit.

To interpret these changes, keep in mind the risk sharing relationship, (17), the definition of the real exchange rate, (14), and the UIP condition, (18). Habit increases the volatility of domestic output and therefore better matches real exchange rate volatility. As a result, foreign output

[9] It is not obvious that the magnitude of θ should have consequences for the degree of inflation inertia. Indeed, in a closed economy version of the model presented here, with only a preference shock, the serial correlation properties are independent of the frequency of price changes. Extensive calibration exercises were used to check the model's dynamics properties as various model parameters changed.

shocks become less volatile from the risk sharing relationship. However, increasing habit formation significantly lowers the degree of persistence of inflation in this model. Matching the persistence of the real exchange rate therefore requires changes in other model parameters (driven both by the definition of the real exchange rate and the UIP conditions) to induce appropriate persistence in other model variables. As already noted increases in θ and declines in η are both associated with greater inflation persistence. Therefore the jump in these coefficients (upwards and downwards respectively) relative to the model without habit serves to prevent large declines in the autocorrelation of the real exchange rate and inflation. In section 6, we discuss in greater detail certain pathologies in model dynamics arising from the introduction of habit formation, particularly for the persistence of inflation.

The changes in η, θ and α in the model with habit (relative to the model without it), combined with a fall in the volatility of foreign output shocks, all help to curb the importance of foreign shocks. This is especially true for foreign output shocks particularly for the real exchange rate and output. [10] However, these changes in parameters lead as well to a decline in the overall standard deviation of several series owing to a lesser role of technology shocks. Consequently, matching the volatility of the data requires a substantial increase in the standard deviation of the innovations to the technology process. These observations rationalize the large differences in estimates of this coefficient across specifications.

5.2 Canada

Many of the above comments for the case of Australia apply equally well to the Canadian results. When the foreign block is observable, model estimates are stable across specifications varying the degree of pass-through and the degree of inflation persistence (columns 1-2 and 5-6). For these models the elasticity of intertemporal substitution and labor supply are both around unity. The degree of price stickiness implies prices are changed on average a little more than every two quarters. The import share, α, like the Australian models implies a value roughly half that given by national accounts data. Again, policy parameters are sensible. Note that domestic demand shocks are relatively volatile in this case, while innovations in technology exhibit smaller standard deviations than for Australia.

[10] These observations can be clearly seen by contrasting the the variance decompositions for the PCP models with and without habit, as well as by perturbing the degree of habit for a given set of estimated coefficients.

The introduction of habit once again yields substantial changes in the coefficients (columns 3-4 and 7-8). Discrepancies across models with and without habit persistence are well in line with those described for Australia. In this respect the jump in σ and θ, decline in η and particularly the increase in the volatility of technology shocks matches well those effects of introducing habit documented above. Regarding models where the foreign block is unobservable, remarks on the estimates are similar to those made for Australia. The inferred posteriors for the parameters are less stable across specifications than when using US data. Moreover, coefficient discrepancies owing to the introduction of habit persistence can be seen once again.

An important feature of Canada's estimates (shared by Australia) is the robustness on the estimates for $\theta_{\dot{F}}$ across all specifications, regardless of the assumptions for the foreign block and endogenous persistence mechanisms. Posterior densities for this parameter suggest substantial flexibility in foreign goods prices. As for the case of Australia, these estimates indicate short lived deviations from the law of one price in the model. In light of these results, there would seem to be little flexibility added to these models in fitting Australian and Canadian data when the assumption of full pass-though does not hold. We subsequently explore this issue formally through model comparisons.

5.3 New Zealand

Finally consider Table 4 which details the New Zealand results. Parameter estimates are reasonably stable across models, particularly – and somewhat surprisingly – when the foreign block is unobserved. The elasticity of substitution between domestic and foreign goods, η, is substantially higher than for various specifications in Canada and especially across all models in Australia. σ is lower for New Zealand that in the case of Australian and Canadian data, as well as the frequency of price changes θ which if anything is on the low side. These estimates likely reflect the relative importance of inflation inertia in the New Zealand data and the associated larger values of δ, the degree of price indexation. Other estimates are reasonably similar. Demand shocks are again crucial to the model's fit with standard deviations in the neighborhood of 4-6, highlighting the difficulty the model has in fitting all aspects of the data.

In contrast to Australia and Canada, the above discussed effects of introducing price indexation appear to be stronger than those associated with habit formation. When the foreign block is not observable, the relative importance of price indexation over habit is very clear. Parameter estimates are remarkably stable across models with some of the effects documented for the introduction of indexation appearing in muted form. The most significant changes occur in the properties of the shocks. Demand shocks become relatively less important while foreign output shocks become highly relevant.

5.4 Model Comparisons

In a Bayesian framework, model comparisons are based on posterior model probabilities, denoted by $p(m_K|Y^T)$ for some model K. Given alternative models K and H, the posterior odds given by (26) tell us how likely it is that the data came from one as opposed to another model. When all models are assigned equal prior probabilities, then the posterior odds boil down to the ratios of the marginal likelihood that we compute using the modified harmonic mean of Geweke (1998). The marginal likelihoods for each model are summarized in Table 5.

Suppose we wish to assess, for instance, how important deviations from the law of one price are for fitting this type of models. One approach would be to do a pair-wise comparison of models with and without full pass-through for each specification exhibiting or lacking habit and/or price indexation. Assigning all models equal prior probability, this would simply require looking at the differences of the log-marginal likelihoods as presented in Table 5. For the case of Canada, for instance, when the foreign block is observable the specifications without any endogenous persistence (GM and M HF-PI in Table 5) result in a marginal log-difference of $-928.89-(-935.53) = 6.64$. This translates into a posterior odds ratio greater than e^6 in favor of the model with full pass-through. However, a similar comparison when both habit and indexation are included would provide some evidence in favor of the specification exhibiting deviations from the law of one price.

Sims (2002) has recently highlighted a number of possible pitfalls in constructing posterior odds for macroeconomic models. Following the discussion in Gelman, Carlin, Stern, and Rubin (1995), Sims provides an example of how problems in model comparisons arise not from the methodology itself but rather as a result of considering "too sparse" a set of models. The Canadian example is an illustration of this observation.

In this paper we seek to investigate the fit of small open economy macro models that are allowed to differ across specifications in two important dimensions. On the one hand, we consider two competing models, one that assumes full pass-through and another that allows for deviations from the law of one price. On the other, we wish to investigate the consequences of introducing endogenous persistence through habit formation and price indication. Thus, when assessing the relevance of any particular assumption for model fit, we allow variations in other model assumptions/specifications as well. Therefore, our aim is to complete the set of competing models as well as to control for the sensitivity of results to alternative specifications, following Sims' observations.

To be somewhat formal, we use Bayesian posterior odds both to compare any two specific models and also two alternative *classes* of model – differing in some characteristic i – while averaging over a range of possible specifications (i.e. different model assumptions) in another dimension j. Suppose two classes of model, denoted $i \in \{1, 2\}$, are distinguish by the presence or absence of some characteristic (say local currency pricing). The posterior probability weight on models of class $i = 1$ is then determined as

$$p(m_1|Y) = \sum_j p(m_{ij}|Y)$$

where

$$p(m_{1j}|Y) = \frac{\exp(f(y|m_{ij}))}{\sum_i \sum_j \exp(f(y|m_{ij}))}$$

and $f(y|m_{ij})$ is the marginal likelihood. The posterior probability weight on models in class $i = 2$ is similarly determined. The posterior odds in favor of model class $i = 1$ over $i = 2$ is then computed as $p(m_1|Y)/p(m_2|Y)$.

Maintaining a given assumption on the determination of the foreign block, Table 5 shows the log marginal likelihood and the posterior model probabilities, $p(m_{ij}|Y)$, for each specific model under the alternative assumptions of producer and local currency pricing. To determine the posterior probabilities of each pricing assumption (indexed by i) simply add up the posterior probabilities for all models estimated under each pricing assumption (that is the various models with and without habit formation and price indexation which correspond to index j). The resulting two probabilities give the evidence in favor of one pricing assumption over the other. Note that one can similarly ask how important habit and price indexation are by averaging over different pricing assumptions. The analysis could also be extended to assess the relative importance of particular shocks.

For the case of Australia, when the foreign block is observed, the addition of these probabilities across the PCP and LCP specifications results in posterior probabilities of 0.981 and 0.019

respectively (last row for each group). Therefore, the data favors the model exhibiting PCP, and, consequently, no deviations from the law of one price.

We note, however, that this does not constitute a fair test of the LCP versus PCP assumptions. The estimation procedure by failing to include the terms of trade (or equivalently the nominal exchange rate) as an observable variable does not explicitly test the restriction:

$$q_t = \psi_{F,t} + (1 - \alpha)\, s_t$$

(equation (14) of the model). It is clear that when there is producer currency pricing, so that $\psi_{F,t} = 0$, the terms of trade and real exchange rate are predicted by the model to be proportional. Obviously, if we were to estimate the model using both terms of trade and real exchange rate series then the linear restriction linking these two variables in the model would not be validated by the data. In principle we could avoid this singularity by introducing measurement error or treating the terms of trade as exogenous (Lubik and Shorfheide). What the results do show is that the degree of freedom afforded by LCP does not appear to important for explaining other model relationships.

Note also that the model attaining the highest posterior weight, 0.96, has neither habit formation nor price indexation. As a result, it is not surprising that regardless of the pricing assumption – i.e. adding across the LCP and PCP specifications – posterior odds strongly imply that the inclusion of habit formation and price indexation mechanisms is not validated by the data.

Treating the foreign block as unobservable yields two somewhat different conclusions. First, evidence in favor of PCP over LCP is substantially weaker (almost $\frac{2}{3}$ and $\frac{1}{3}$ respectively). Second, the posterior probability for the specifications with habit formation only is close to 0.99 ($= 0.65 + 0.34$) suggesting a prominent role for these mechanism in explaining the data.

Turning to the case of Canada, both specifications for the foreign block lead to similar conclusions as far as the importance of allowing for deviations from the law of one price. Adding across specifications to asses the importance of pricing assumptions reveals that in both cases the posterior probabilities strongly favor the PCP over the LCP assumption. Regarding the particular specification of endogenous persistence the evidence is somewhat mixed. When US data is used for the foreign series, the model with habit attains a weight of roughly 0.3 (sum of the GM-H and M-H probabilities, although the contribution of the later is negligible). Instead, treating the foreign block as unobservable produces probabilities of 0.98. Despite the discrepancies in magnitude, overall these results only indicate a role for habit persistence in fitting the models to the data.

For New Zealand, alternative assumption on the foreign block do not alter inference on the lack of evidence in favor of any mechanism of endogenous persistence (posterior probabilities are highest for the sum of the GM no HF-PI and M no HF-PI models). On the contrary, inference on the degree of pass-through depends on whether the foreign block is observed or unobserved (posterior odds are roughly 5 to 1 in favor of LCP and 10 to 1 for PCP, respectively).

It is interesting to note that for New Zealand the posterior probabilities do not lead to results that may seem implausibly clear-cut, as pointed out by Sims in discussing model probabilities. A similar observation holds for Australia when the foreign block is unobserved, but not for Canada.

The particular interpretation of the pass-through results is left to the reader depending on her or his preferences as to how to model the foreign block. We simply note that overall the results are suggestive of a limited role of allowing deviations from the law of one price for model fit when seeking to explain the evolution of inflation, output, nominal interest rates and the real exchange rate. A robust result across specifications and countries is that the inclusion of price indexation is not validated by the data. With respect to habit formation, results are overall mixed although seem to matter in some cases, particularly Canada.

The last two observations may seem somewhat surprising considering that these mechanisms are becoming more standard in the literature of fitting closed economy models to the data. We conjecture that in this case it may be the result of fairly flexible specification of dynamics for the foreign block, modeled as an atheoretical VAR, which could be soaking up the persistence in the series.

5.4.1 Cross Validation

As a final diagnostic, for models in which the foreign block is not observable, we perform cross-validation exercises and compare the fit of the structural models to Bayesian VAR's of various lag length, reported in the last column of Table 5.[11] For Australia, comparing the marginal likelihood

[11] The BVARs are estimated using the symmetrized Minnesota prior of Sims and Zha (2001) which allows for a closed form expression for the marginal likelihood. Note also that in the case that the foreign block is observed the reduced form of the model is not a VAR, requiring development of codes for estimating BVARs that are not publicly available. We are presently working on developing such code.

across specifications with those of a BVAR (last column in Table 5) underscores that the model fit is particularly poor. For VARs having only 1 or 2 lags, the preferred structural model provides an inferior fit to the data. Additional lags in the VAR retard its fit relative to the structural model to such a degree that the preferred structural model is comparable in explaining the data.[12]

For Canada, the log-marginals of the unrestricted VAR (the preferred lag-length is 3) indicate that the structural models provide a very poor fit across all specifications. In contrast, in the case of New Zealand, a BVAR(2) achieves the highest marginal although the GM model without habit and indexation does as well as a BVAR(1) and slightly better than a BVAR(3)

It is interesting that for Australia and particularly Canada the model's ability to match the data is unsatisfactory, despite allowing for deviations from the law of price, a flexible specification of foreign variables and various endogenous persistence mechanisms. This observation suggests that even though overall the model yields plausible parameter estimates, it is necessary to improve the building blocks of these models if they are to match the data, particularly if they are to be used for policy evaluation and forecasting. Natural candidates in this respect include the addition of frictions in labor markets, trade in intermediate goods, as well as perhaps non-tradables. Some of these are being addressed in on-going work.

6 Implications of Habit Formation

As already mentioned, in order to match the hump-shaped responses of output and consumption to monetary shocks, estimated from structural VARs, in recent years it has become customary to allow for external habit persistence in DSGE models – see, for instance, Boivin and Giannoni (2004), Christiano, Eichenbaum, and Evans (2003) and McCallum and Nelson (2000). While the evidence on the importance of habit formation in the previous section was mixed, a key emerging result in estimating various specifications of the models at hand, was that the inferred parameters were often not robust to the inclusion of (external) habit persistence mechanisms. This short digression highlights some of our findings after further exploring the consequences of allowing for habit persistence in open economy models, with particular emphasis on contrasting results to the closed economy case.

[12] Although we have considered up to six lags when estimating the BVAR, the model with one lag attains the greatest marginal likelihood.

In broad terms, we find that allowing for habit can have drastic implications for the dynamics of small open economy models. For instance, for certain parameter values, habit formation can significantly alter the autocorrelation of some series. To illustrate this point, we take as a benchmark the parameter estimates of the model for Australia without habit formation (or price indexation) when the foreign block is not observed. The model is solved keeping all parameters at their estimated (median) values, but allowing h – which governs the degree of habit persistence – to vary from 0 to 0.9. As shown in Table 8, as the degree of habit rises, the first order autocorrelation of home goods and final goods inflation gradually declines, and for values of h in excess of 0.8, the autocorrelation coefficient becomes negative! A similar pattern of declining persistence is observed in other series as well, most notably the real exchange rate, wages and marginal costs, although these do not become negative as in the previous case.

We must stress that the estimated models with habit do not exhibit these anomalies in dynamics. Following the discussion in section 5, recall some coefficients – particularly the degree of price rigidity, θ, elasticity of substitution for home and foreign goods, η, as well as the volatility of innovations to technology – adjusted significantly when habit was introduced, and indeed these parameter adjustments happen precisely to prevent these pathologies. For instance, calibrating the model with the median estimates for Australia (foreign block not observed) with habit, but with θ and η at their (median) values for the model without intrinsic persistence, we find that the autocorrelation of inflation declines to zero once again as h rises. In contrast using the median estimates of θ and η for the specification with habit leads to reasonably high degrees of persistence in all series, even when $h = 0.7$. Our point is not to suggest that posterior model probabilities may favor a specification with implausible autocorrelations. Rather we intend to more broadly highlight the consequences including habit persistence might have in these models and to illustrate how these changes in dynamics may differ from a framework in which open economy elements are absent. Moreover, it highlights possible difficulties for researchers choosing to calibrate models rather than estimate them .

In a closed economy setting, Lettau and Uhlig (2000) analyze the implications of habit persistence in real business cycle models. The main conclusion from their analysis is that habit induces a dramatic decline in the volatility of consumption (of an order of magnitude) making consumption implausibly smooth. They conclude that while habit formation may help explain asset pricing puzzles such as the equity premium puzzle, it may also have important and undesirable consequences for a DSGE model's ability to fit other dimensions of the data.

To investigate the verity of this observation in an open economy model, an analogous exercise to Lettau and Uhlig (2000) is pursued. The model's dynamic properties in response to a technology shock are considered as habit is varied over the range 0 to 0.9. As a benchmark, we considered the nested special case of a closed economy that obtains when $\alpha = 0$ and $\eta = 0$. The first two rows of Table 8 display the standard deviations of consumption and output for this closed economy case when $h = 0$, 0.4 and 0.9 in response to a technology shock. As in the Lettau and Uhlig (2000), the volatility of both series declines with increasing habit. Repeating this exercise for a finer grid of values of h (not shown), demonstrates this mitigating effect on the volatility of both consumption and output is monotonic in h. It is important to note, however, that the effect is not an order of magnitude smaller as in Lettau and Uhlig: clearly the models are not identical and differ in a number of important dimensions – most notably in the absence of physical capital in the Gali-Monacelli framework and also the assumed parameter values in the calibration. Therefore, this discussion does not seek to emphasize differences in magnitude but rather to contrast the results qualitatively.

To recover the open economy dimension, η and α are set equal to their median estimated values of 0.39 and 0.08 respectively. Note that these values entail neither a very large share of foreign goods in final consumption, nor a great degree of substitutability between domestic and foreign goods. In this case, however, the remaining rows of Table 8 show the volatility of both consumption and output increase, rather than decline, with increasing levels of habit. Once again, a finer grid of values for the degree of habit shows that this effect is monotonic, and the rise in standard deviation holds true for both the domestic and foreign components of final consumption.

Since these results contrast with the effects of habit emphasized by Lettau and Uhlig and the closed economy calibration of Gali-Monacelli it is worth pursuing this discussion further to isolate to source of the differing conclusions. The open economy dimension introduces, amongst other things, the foreign demand (foreign output) component to the model, which also has important implications for the international risk sharing condition. This implies that foreign output plays a major role in the determination of marginal costs through the risk sharing and labor demand effects on wages. When domestic and foreign goods are substitutes ($\eta > 0$) then any shock that implies a movement in the real exchange rate automatically translates into higher (lower) foreign demand for domestic goods when the real exchange rate depreciates (appreciates).

It follows that a positive domestic technology shock induces a real depreciation and consequently higher demand for domestic goods.[13] As emphasized by Lettau and Uhlig in their closed economy analysis, households can adjust their labor supply in order to smooth consumption. Even though the technology shock induces an increased desired labor supply due to the higher real wage, because agents are locally highly risk averse they choose not to increase labor supply too much, therefore smoothing consumption extremely. In contrast to the closed economy setting, the foreign demand channel induced by the technology shock places sufficient upward pressure on wages that households are willing to substantially increase labor supply. The resulting wealth effect leads to an adjustment in consumption levels despite households strong desire for smooth consumption. In the presence of habit persistence, domestic agents are less willing to adjust their consumption in response to the shock (compared to the $h = 0$ case) and therefore require a larger adjustment in wages to supply labor. Figure 1 displays the impulse responses of real wages to a technology shock for various degrees of habit persistence. It is clear from these graphs that the positive response of wages is exacerbated the greater the degree of habit in the economy.

The impulse responses for marginal costs to a positive technology further reinforce this point. Indeed, while marginal costs, as expected, declines on impact in response to positive innovations in technology, as h rises, the impact effect eventually become positive! An analysis similar to the one for consumption and output, in rows 5 through 6 of table 8, reveals precisely that the volatility of marginal costs and real wages increase dramatically with habit (by an order of magnitude for the former). The degree of substitution between domestic and foreign goods, η, is crucial in determining the magnitude of these effects. Higher values of eta imply an even greater amplification of the volatilities of output, consumption, marginal cost and wages as a function of the degree of habit in the economy.

7 Conclusions

This paper investigates whether macroeconomic data from several small open economies are better explained by models that allow for either producer currency or local currency pricing. Estimating

[13] Note that the response of the foreign demand component is independent of the degree of habit.

generalized versions of the models proposed by Gali and Monacelli (2002) and Monacelli (2003), parameter estimates take plausible values and are often precisely estimated. Mixed evidence is found for the two alternative pricing-to-market assumptions. For New Zealand, evidence is found in favor local currency pricing, while the data favor producer currency pricing in Australia and Canada. Cross-validation exercises, which compare the fit of the structural model to Bayesian VAR's of various lag length, demonstrate that the models provide an almost passable fit to the data in the case of New Zealand. In contrast, for the cases of Australia and Canada the restrictions inherent in the DSGE modeling framework appear to be strongly rejected by the data.

It is important to underscore that while evidence is adduced in favor of producer currency pricing, this should not be interpreted as indicating that there are not important and persistent deviations from the law of one price. What these results do suggest, is that at least from a macroeconomic modelling perspective, the additional degree of freedom gained by allowing for deviations from the full pass-through assumption is not as important as one might have expected.

In addition to contributing to the recent literature on estimating DSGE models, this paper also explores the effects of habit formation on the model's statistical properties. It is shown that habit formation can introduce a number of pathologies in the model's second-order moments. For instance, high values of habit can induce negative first-order serial correlation in domestic goods price and CPI inflation. In contrast to the closed economy analysis of Lettau and Uhlig (2000), this paper shows habit formation typically increases the volatility of consumption and output. Moreover, for series such as real wages and real marginal costs high levels of habit can induce implausibly large variation in these series. Taken together, these findings highlight that further work is required to fully understand implications of incorporating ad hoc devices such as habit formation to improve model fit.

In ongoing work the effects of model/parameter uncertainty on the design of simple optimal policy rules by exploiting the estimated posterior distribution of model parameters afforded by the Bayesian methodology. Within a class of Taylor-type rules, it is found that parameter uncertainty may lead to more or less aggressive policy relative to the case when parameters are known with certainty. It follows that model uncertainty of this kind, at least in the class of forward-looking DSGE models under consideration, does not lead to unambiguous implications for the design of simple optimal policy rules.

A Appendix

A.1 The Steady State and Log-linear model

To obtain a log-linear approximation to the model presented in Section 2, define the linearization point to the steady state characterized by $\tilde{\varepsilon}_{a,t} = \tilde{\varepsilon}_{M,t} = \tilde{\varepsilon}_{g,t} = 0$ and $\tilde{\varepsilon}^*_{a,t} = \tilde{\varepsilon}^*_{M,t} = \tilde{\varepsilon}^*_{g,t} = 0$ for all t. Standard arguments establish the existence of a steady state with $Y_t = \bar{Y}$, $\pi_t = P_t/P_{t-1} = P_{H,t}/P_{H,t-1} = P_{F,t}/P_{F,t-1} = 1$, $\bar{\imath} = \beta^{-1} - 1$ and analogously defined variables for the foreign economy. Furthermore, $S_t = P_{F,t}/P_{H,t} = 1$. For any variable Z_t or $\tilde{z}_t$, define the log-deviation as $z_t \equiv \log\left(Z_t/\bar{Z}\right)$ and $z_t \equiv \log\left(\tilde{z}_t/\bar{Z}\right)$ respectively, except for the nominal interest rate for which $i \equiv \log[(1+\tilde{\imath}_t)\,/\,(1+\bar{\imath})]$, where $\bar{Z}$ is the associated steady state value of Z_t or $\tilde{z}_t$. Given these definitions standard methods yield to the log-linear approximation detailed in the text. Calculations are available on request.

A.2 Inference on the Parameters and Model Selection

We briefly describe the methods for estimation and model comparison for DSGE models applied in this paper. We begin with a log-linearized DSGE model, denoted by m_K, with associated parameters $\theta_k \in \Theta_k$. Our main task is to estimate the parameters θ_k as well as to formally compare different DSGE models, m_H and m_K for $H \neq K$.

Regarding inference on the parameters first, the Bayesian methods described below were proposed in an influential paper by **?**. Therefore only a brief description of these techniques is presented and the interested reader is referred to that paper for further details.

Our goal is to characterize the posterior distribution of the parameters $p(\theta_k|Y^T, m_K)$ (the target density) where Y^T is the observed data set (note that the model indicator m_K is introduced explicitly). Given the prior densities $\pi(\theta_k|m_K)$,for model k, a maximization algorithm is used to find the posterior mode by combining the likelihood $\mathcal{L}(Y^T|\theta_k, m_K)$ with the prior. For each θ_k the model is solved using the solution method proposed by Sims (2002b).

The posterior mode obtained from this first step is used as the starting value (θ_k^0) of a Random Walk metropolis algorithm. This Markov Chain Monte Carlo (MCMC) method allows us to generate draws from the posterior density $p(\theta_k|Y^T, m_K)$. At each step i of the Markov Chain, the proposal density used to draw a new candidate parameter θ_k^* is a $N(\theta_k^i, c\Sigma_k)$. The new draw is then accepted with probability

$$\alpha = \min(1, \frac{\mathcal{L}(Y^T|\theta_k^*, m_K)\pi(\theta_k^*|m_K)}{\mathcal{L}(Y^T|\theta_k^i, m_K)\pi(\theta_k^i|m_K)})$$

If accepted, $\theta_k^{i+1} = \theta_k^*$; otherwise, $\theta_k^{i+1} = \theta_k^i$. We generate chains of 30,000 draws in this manner discarding the first 5,000 iterations.

In contrast to other authors, we use a two step procedure which updates the variance covariance matrix $\Sigma_{k.}$ of the proposal density. In the first step we use the inverse Hessian from the maximization algorithm above mentioned. As suggested by Gelman, Carlin, Stern, and Rubin (1995) in discussing efficient algorithms (Ch.11.5) we generate a couple thousand iterations and then update the proposal density (in the second stage) using the variance covariance matrix of these draws. In our experience this updating stage results in acceptance rates of the Random walk Metropolis in the range of 30-50% even for very large values of c. We adjust c however, to obtain an acceptance rate of between 25% and 35%. With the generated draws moments of the posterior distribution are obtained as medians and percentiles of the simulated values.

Having repeated the above procedure for different models $m_K \neq m_H$, we proceed to compare the DSGE models in their ability to fit the data. In a Bayesian framework, as mentioned briefly in the text, the *Posterior Odds* $(PO_{K,H})$ summarizes the evidence provided by the data (Y^T) in favor of model K over model H

$$PO_{K,H} = \frac{p(m_K|Y^T)}{p(m_H|Y^T)} = \frac{f(Y^T|m_K)}{f(Y^T|m_H)} \frac{\pi(m_K)}{\pi(m_H)} \tag{26}$$

The expression on the right follows directly from Bayes theorem. The marginal density $f(Y^T|m_K)$ is known as the marginal likelihood. When, as here, competing models are assigned equal prior probabilities, $\pi(m_K) = \pi(m_H) = \frac{1}{Number\ of\ Competing\ Models}$, posterior odds are equivalent to the ratio of the marginal likelihoods. It is not surprising therefore that the literature on DSGE models has focused on the estimation of $f(Y^T|m_K)$ for model comparisons. In this paper, we follow this approach using two alternative simulation based methods for obtaining the marginal likelihood. In addition, however, we consider a product space search algorithm that explicitly introduces the model indicator in addition to the parameters.

The first method for computing $f(Y^T|m_K)$ is the Metropolis-Laplace approximation of DiCiccio, Kass, Raftery, and A.L.Wasserman (1997) and Kass and Raftery (1995), that is of the form

$$\widehat{f}(Y^T|m_K) = (2*pi)^{W/2}|\Sigma_{\widehat{V_K}}|^{1/2}\mathcal{L}(Y^T|m_K,\widehat{\theta_K})\pi(\widehat{\theta_K}|m_K) \tag{27}$$

where W stands for the dimension of the parameter space.

We also compute the modified Harmonic mean proposed by Geweke (1998) and Fernandez-Villaverde and Rubio-Ramirez (2003)

$$\widehat{f}(Y^T|m_K) = \{\frac{1}{M}\sum_{g=1}^{G}\frac{s(\Gamma_K^g)}{L(Y^T|m_K,\Gamma_K^g)\pi(\Gamma_K^g|m_K)}\}^{-1} \tag{28}$$

where for the reciprocal importance sampling density, $s(\cdot)$ we construct the set

$$\widehat{\Xi}_k = \{\theta_K|(\theta_K - \widehat{\theta_K})'\widehat{\Sigma}_{\theta_K}^{-1}(\theta_K - \widehat{\theta_K}) \leq \chi_{1-\lambda(W)}\}$$

$\chi_{1-\lambda}$ is a chi-square distribution with W degrees of freedom. $s(\cdot)$ is then taken to be

$$s(\Gamma_K) = \frac{1}{C(2\pi)^{\frac{w}{2}}}|\widehat{\Sigma}_{\theta_K}|^{-1}\exp\left[-\frac{1}{2}(\theta_K - \widehat{\theta_K})'\widehat{\Sigma}_{\theta_K}^{-1}(\theta_K - \widehat{\theta_K})\right]I_{\theta_K\cap\widehat{\Xi}_k}$$

Note that both the Metropolis-Laplace and the modified Harmonic Mean require a measure of center and scatter of the posterior density. To this end we let $\widehat{\theta}_k$ equal the mode, mean or median computed from the draws, and $V_{\widehat{\theta}_k}$ the corresponding variance covariance matrix. Raftery (1996) suggests, however, that these measures can be susceptible to "distant excursions" of the Markov Chains. He proposes using measures that are robust to outliers. We therefore also consider measures of center and scatter with high breakdown point as suggested by Rousseeuw (1983) and in particular the Minimum Covariance Determinant (MCD) method of Rousseeuw and Driessen (1999). The results reported in this paper are robust to this modification, even for different values of the fraction of observations to consider in the MCD.

Our final approach to model comparison is to rely on simulation methods that include the model indicator (m) as part of the parameter space. Consequently these algorithms operate over the product space $\mu \times \Pi_{K=1}^{K_{\max}} \Gamma_K$, (with μ defined as the set of all possible models) to take into account both model and parameter uncertainty. In particular, we apply the Reversible Jump Markov Chain Monte Carlo (RJMCMC) method of Dellaportas, Forster, and Ntzoufras (2002). A description of their method and product space search algorithms is beyond the scope of this paper and the interest reader is refereed to their paper for further details as well as Justiniano (2003) for a comparison of the performance of alternative methods for model selection.. For our purpose it is enough to note that rather than computing the marginal likelihood, the RJMCMC directly provides us with the posterior model probabilities, $p(m_K|Y^T)$.

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Table1 : Priors for GM and M when the foreign block is a VAR

Coefficient		Distribution	Mean	Percentiles 1%	99%
σ	inverse elasticity of substitution	G	1.2	0.247	3.014
φ	inverse elasticity of labor supply	G	1.5	0.309	3.767
θ	Calvo-pricing, home goods	B	0.5	0.172	0.828
θ_F	Calvo-pricing, foreign goods	B	0.5	0.172	0.828
α	Degree of openess	B	0.3	0.103	0.554
η	Elasticity of substituion H,F	G	1.5	0.267	3.952
h	Degree of habit formation	B	0.5	0.172	0.828
δ	Degree of price indexation	B	0.5	0.172	0.828
ρ_i	Interest rate smoothing, Taylor Rule	B	0.7	0.446	0.897
ψ_π	Response on inflation, Taylor Rule	G	1.5	0.585	2.900
ψ_y	Response on output, Taylor Rule	G	0.5	0.103	1.256
ρ_z	AR(1) technology	B	0.7	0.446	0.897
ρ_s	AR(1) Exchange rate risk premium	B	0.7	0.446	0.897
ρ_g	AR(1) IS/Utility shock	B	0.7	0.446	0.897
ω_{11}	Foreign VAR	N	0.4	-0.996	1.796
ω_{12}	Foreign VAR	N	0	-1.628	1.628
ω_{13}	Foreign VAR	N	0	-1.628	1.628
ω_{21}	Foreign VAR	N	0	-1.628	1.628
ω_{22}	Foreign VAR	N	0.4	-0.996	1.796
ω_{23}	Foreign VAR	N	0	-1.628	1.628
ω_{31}	Foreign VAR	N	0	-1.628	1.628
ω_{32}	Foreign VAR	N	0	-1.628	1.628
ω_{33}	Foreign VAR	N	0.4	-0.996	1.796
νy_*	SD Foreign output shock	IG1	1	0.260	5.620
ν_{p*}	SD Foreign Inflation shock	IG1	1	0.260	5.620
ν_{i*}	SD Foreign interest rate shock	IG1	1	0.260	5.620
ν_{z*}	SD Technology	IG1	1	0.260	5.620
ν_i	SD Monetary Policy shock	IG1	1	0.260	5.620
ν_s	SD Exchange rate risk premium	IG1	1	0.260	5.620
ν_g	SD IS/Utility shock	IG1	1	0.260	5.620

For all models, β is calibrated at 0.99. Distributions: G (Gamma), B (Beta), N (Normal), IG (Inverse Gamma-1). ρ corresponds to the autoregressive coefficient of an AR(1) process. Subindices are as follow: i (nominal interest rate), z (technology), g (preference or government), s (risk premium) . As throughout the paper, * denotes a foreign variable, ωij corresponds to the row i, column j coefficients of a first order atheoretical VAR with rows (1 to 3) corresponding to foreign inflation, foreign output and foreign interest rate. Note that foreign standard deviations correspond to the distrubances of the VAR. Last two columns, inverse cd for percentiles 0.01 and 0.99.

Table 2a: Australian results with Foreign block Observable

Producer Currency Pricing (PCP)

Model Version	1 No habit or indexation			2 Indexation			3 Habit			4 Indexation and Habit		
	10%	Median	90%	10%	Median	90%	10%	Median	90%	10%	Median	90%
σ	2.46	2.65	2.85	2.07	2.33	2.63	1.80	2.07	2.27	1.93	2.33	2.56
φ	0.58	1.10	1.71	0.73	1.35	2.20	0.89	1.27	1.60	1.09	1.61	2.47
θ	0.56	0.64	0.70	0.37	0.48	0.59	0.60	0.66	0.70	0.52	0.61	0.67
θ_F												
α	0.07	0.10	0.12	0.06	0.08	0.11	0.06	0.09	0.12	0.06	0.08	0.11
η	0.14	0.29	0.49	0.16	0.31	0.53	0.14	0.29	0.50	0.17	0.32	0.52
h							0.21	0.28	0.35	0.19	0.26	0.33
δ				0.16	0.32	0.52				0.14	0.26	0.41
ρ_i	0.79	0.83	0.86	0.78	0.83	0.86	0.81	0.84	0.87	0.81	0.84	0.86
ψ_π	2.05	2.19	2.53	2.33	2.76	2.95	2.50	2.59	2.66	2.40	2.53	2.73
ψ_y	0.25	0.50	0.87	0.21	0.45	0.78	0.13	0.26	0.45	0.14	0.29	0.54
ρ_z	0.85	0.89	0.93	0.87	0.91	0.94	0.83	0.88	0.92	0.84	0.89	0.93
ρ_g	0.97	0.98	0.99	0.97	0.98	0.99	0.97	0.98	0.99	0.97	0.98	0.99
ρ_{fx}	0.80	0.85	0.89	0.79	0.84	0.88	0.77	0.82	0.86	0.77	0.82	0.87
ρ_{pi*}	0.41	0.50	0.58	0.40	0.48	0.57	0.42	0.49	0.56	0.42	0.51	0.58
ρ_{y*}	0.87	0.91	0.93	0.87	0.91	0.94	0.87	0.90	0.93	0.87	0.91	0.94
ρ_{i*}	0.87	0.90	0.93	0.87	0.91	0.94	0.87	0.91	0.94	0.88	0.91	0.94
sd_{pi*}	0.30	0.33	0.37	0.30	0.34	0.37	0.31	0.33	0.36	0.31	0.34	0.38
sd_{y*}	0.50	0.55	0.61	0.49	0.54	0.60	0.50	0.55	0.64	0.50	0.56	0.61
sd_{i*}	0.16	0.17	0.19	0.16	0.17	0.19	0.15	0.17	0.19	0.15	0.17	0.19
sd_z	1.45	1.77	1.92	1.12	1.40	1.64	1.52	1.71	1.88	1.34	1.63	1.84
s_i	0.31	0.35	0.40	0.32	0.37	0.44	0.31	0.35	0.41	0.31	0.35	0.40
sd_g	1.45	1.65	1.83	1.51	1.82	2.09	1.38	1.65	1.81	1.23	1.50	1.70
sd_{fx}	0.36	0.42	0.53	0.34	0.41	0.51	0.43	0.51	0.65	0.42	0.51	0.64
MHM		**-929.26**			-933.76			-934.04			-935.28	

Local Currency Pricing (LCP)

Model Version	5 No habit or indexation			6 Indexation			7 Habit			8 Indexation and Habit		
	10%	Median	90%	10%	Median	90%	10%	Median	90%	10%	Median	90%
σ	2.51	2.74	3.02	2.14	2.37	2.42	2.08	2.21	2.39	1.66	1.93	2.33
φ	0.66	1.46	2.30	2.29	2.84	2.92	0.66	1.25	2.56	0.82	1.53	1.96
θ	0.56	0.64	0.70	0.48	0.59	0.61	0.67	0.72	0.77	0.49	0.58	0.66
θ_F	0.22	0.36	0.51	0.33	0.47	0.54	0.19	0.30	0.42	0.17	0.30	0.45
α	0.07	0.11	0.14	0.08	0.11	0.12	0.08	0.11	0.15	0.07	0.10	0.12
η	0.16	0.31	0.54	0.50	0.88	0.96	0.10	0.18	0.31	0.13	0.24	0.39
h							0.24	0.34	0.42	0.20	0.28	0.35
δ				0.34	0.59	0.64				0.13	0.25	0.45
ρ_i	0.78	0.82	0.84	0.79	0.83	0.84	0.81	0.83	0.86	0.78	0.81	0.84
ψ_π	2.13	2.23	2.33	2.39	2.63	2.70	2.07	2.21	2.31	2.14	2.39	2.57
ψ_y	0.22	0.46	0.80	0.44	0.74	0.83	0.10	0.21	0.39	0.12	0.24	0.44
ρ_z	0.86	0.90	0.93	0.92	0.95	0.95	0.82	0.87	0.91	0.84	0.89	0.93
ρ_g	0.97	0.98	0.99	0.99	0.99	0.99	0.96	0.98	0.99	0.97	0.98	0.99
ρ_{fx}	0.78	0.83	0.88	0.82	0.87	0.88	0.78	0.83	0.88	0.75	0.81	0.87
ρ_{pi*}	0.45	0.52	0.59	0.47	0.55	0.58	0.44	0.51	0.57	0.39	0.48	0.57
ρ_{y*}	0.87	0.91	0.93	0.91	0.93	0.94	0.87	0.90	0.94	0.88	0.91	0.94
ρ_{i*}	0.87	0.90	0.93	0.91	0.94	0.95	0.88	0.91	0.94	0.87	0.91	0.94
sd_{pi*}	0.31	0.33	0.37	0.34	0.39	0.40	0.30	0.33	0.38	0.30	0.33	0.37
sd_{y*}	0.49	0.54	0.59	0.55	0.62	0.63	0.51	0.57	0.63	0.50	0.55	0.60
sd_{i*}	0.15	0.17	0.19	0.17	0.19	0.20	0.16	0.17	0.19	0.16	0.17	0.19
sd_z	1.21	1.58	2.06	1.11	1.31	1.36	1.98	2.20	2.36	1.35	1.58	1.83
s_i	0.30	0.35	0.39	0.37	0.42	0.44	0.29	0.32	0.37	0.31	0.35	0.40
sd_g	1.32	1.55	1.82	2.06	2.27	2.31	1.02	1.17	1.37	1.37	1.50	1.74
sd_{fx}	0.39	0.48	0.57	0.42	0.50	0.52	0.43	0.53	0.70	0.41	0.50	0.66
MHM		-933.23			-937.95			-937.68			-937.97	

Table 2b: Australian results with Foreign block Unobservable

	Producer Currency Pricing (PCP)												Local Currency Pricing (LCP)											
Model	**1**			**2**			**3**			**4**			**5**			**6**			**7**			**8**		
Version	**No habit or indexation**			**Indexation**			**Habit**			**Indexation and Habit**			**No habit or indexation**			**Indexation**			**Habit**			**Indexation and Habit**		
	10%	Median	90%	10%	Median	90%	10%	Median	90%	10%	Median	90%	10%	Median	90%	10%	Median	90%	10%	Median	90%	10%	Median	90%
σ	2.08	2.31	2.57	1.36	1.52	1.68	2.92	3.56	4.05	3.08	3.36	3.61	2.33	2.87	3.20	1.68	2.03	2.42	2.33	3.09	3.71	3.38	3.49	3.81
φ	0.57	1.05	1.83	0.84	1.29	1.80	1.05	1.71	2.88	0.60	1.15	2.52	0.70	1.41	2.69	0.82	1.52	2.66	0.84	1.47	2.43	0.68	0.84	1.58
θ	0.47	0.56	0.63	0.26	0.34	0.44	0.89	0.90	0.92	0.87	0.89	0.91	0.57	0.66	0.72	0.31	0.43	0.55	0.88	0.90	0.91	0.65	0.67	0.73
θ_F													0.19	0.31	0.45	0.18	0.31	0.48	0.19	0.31	0.44	0.15	0.17	0.29
α	0.06	0.08	0.11	0.05	0.07	0.09	0.15	0.20	0.26	0.15	0.21	0.28	0.08	0.11	0.14	0.05	0.08	0.11	0.18	0.25	0.32	0.08	0.09	0.12
η	0.22	0.39	0.61	0.44	0.71	1.03	0.02	0.05	0.08	0.02	0.04	0.08	0.20	0.34	0.62	0.22	0.45	0.73	0.02	0.04	0.07	0.06	0.08	0.16
h							0.58	0.68	0.78	0.57	0.68	0.77							0.57	0.70	0.80	0.06	0.08	0.14
δ				0.21	0.36	0.55				0.07	0.13	0.22				0.19	0.33	0.50				0.07	0.09	0.18
ρ_i	0.75	0.80	0.84	0.69	0.75	0.80	0.86	0.89	0.91	0.86	0.89	0.92	0.78	0.82	0.85	0.73	0.78	0.82	0.84	0.87	0.89	0.81	0.82	0.85
ψ_π	2.17	2.38	2.48	2.33	2.53	2.73	1.20	1.63	2.06	1.17	1.58	2.18	2.15	2.27	2.39	2.30	2.42	2.58	1.15	1.41	1.79	2.14	2.16	2.28
ψ_y	0.29	0.56	1.03	0.22	0.50	0.96	0.10	0.19	0.32	0.09	0.19	0.35	0.28	0.55	0.92	0.19	0.42	0.78	0.11	0.20	0.35	0.15	0.18	0.37
ρ_z	0.88	0.92	0.95	0.89	0.92	0.95	0.60	0.69	0.76	0.57	0.68	0.76	0.85	0.90	0.94	0.89	0.93	0.96	0.62	0.71	0.78	0.82	0.83	0.87
ρ_g	0.65	0.79	0.89	0.66	0.79	0.88	0.72	0.79	0.86	0.72	0.79	0.85	0.63	0.77	0.88	0.66	0.78	0.88	0.70	0.78	0.85	0.61	0.66	0.81
ρ_{pi*}	0.48	0.62	0.77	0.45	0.61	0.76	0.57	0.73	0.88	0.64	0.86	0.92	0.53	0.66	0.82	0.53	0.67	0.91	0.54	0.72	0.88	0.48	0.52	0.72
ρ_{y*}	0.97	0.98	0.99	0.97	0.98	0.99	0.58	0.71	0.82	0.59	0.72	0.83	0.96	0.98	0.99	0.97	0.98	0.99	0.58	0.72	0.82	0.89	0.92	0.96
ρ_{i*}	0.86	0.90	0.93	0.86	0.91	0.94	0.83	0.89	0.93	0.55	0.78	0.89	0.85	0.90	0.93	0.65	0.89	0.92	0.77	0.87	0.91	0.64	0.68	0.85
sd_{pi*}	0.28	0.40	0.62	0.25	0.33	0.45	0.35	0.55	0.90	0.41	0.63	0.89	0.29	0.40	0.60	0.27	0.36	0.48	0.37	0.62	0.98	0.36	0.40	0.57
sd_{y*}	1.66	1.86	2.15	2.83	3.09	3.33	0.37	0.46	0.55	0.38	0.47	0.56	1.43	1.66	2.26	1.81	2.13	2.42	0.39	0.50	0.61	0.82	0.88	1.07
sd_{i*}	0.25	0.30	0.38	0.22	0.27	0.34	0.43	0.57	0.68	0.50	0.75	0.91	0.28	0.35	0.44	0.24	0.30	0.37	0.49	0.68	0.94	0.45	0.48	0.57
sd_z	1.11	1.39	1.61	0.84	1.00	1.18	9.65	10.22	11.13	10.93	11.63	12.00	1.21	1.74	2.02	0.92	1.10	1.35	8.17	9.73	10.53	2.05	2.10	2.29
s_i	0.32	0.38	0.47	0.39	0.45	0.53	0.27	0.30	0.34	0.27	0.30	0.34	0.30	0.35	0.40	0.33	0.37	0.45	0.27	0.30	0.34	0.27	0.28	0.32
sd_g	0.27	0.38	0.54	0.29	0.39	0.58	0.44	0.56	0.69	0.44	0.55	0.70	0.26	0.34	0.47	0.25	0.34	0.46	0.43	0.54	0.68	0.26	0.28	0.41
MHM		**-653.15**			-659.53			-646.3794			-658.78			-657.33			-659.83			-647.0221			-674.14	

Table 3a: Canadian results with Foreign block Observable

Model Version	Producer Currency Pricing (PCP) 1 No habit or indexation			2 Indexation			3 Habit			4 Indexation and Habit		
	10%	Median	90%	10%	Median	90%	10%	Median	90%	10%	Median	90%
σ	1.02	1.21	1.43	1.10	1.26	1.42	2.30	3.38	4.20	2.01	2.12	2.48
φ	0.90	1.63	2.29	0.62	0.98	1.33	0.73	1.57	2.45	0.61	1.08	1.69
θ	0.35	0.48	0.56	0.25	0.37	0.46	0.91	0.93	0.94	0.91	0.92	0.94
θ_F												
α	0.09	0.12	0.15	0.08	0.11	0.15	0.28	0.36	0.45	0.32	0.42	0.49
η	0.46	0.76	1.22	0.35	0.68	1.14	0.03	0.05	0.11	0.02	0.03	0.06
h							0.53	0.71	0.82	0.70	0.79	0.86
δ				0.16	0.33	0.55				0.09	0.16	0.25
ρ_i	0.81	0.85	0.88	0.81	0.84	0.87	0.92	0.94	0.95	0.90	0.92	0.94
ψ_π	2.92	3.27	3.50	2.76	2.89	3.09	1.83	2.47	2.80	1.13	1.26	1.44
ψ_y	0.24	0.47	0.83	0.29	0.57	0.97	0.05	0.11	0.24	0.05	0.10	0.21
ρ_z	0.91	0.93	0.95	0.92	0.94	0.96	0.54	0.63	0.70	0.56	0.64	0.72
ρ_g	0.98	0.98	0.99	0.97	0.98	0.99	0.42	0.62	0.86	0.35	0.50	0.68
ρ_{fx}	0.76	0.82	0.87	0.76	0.81	0.86	0.78	0.83	0.88	0.80	0.83	0.88
ρ_{pi^*}	0.31	0.37	0.44	0.30	0.36	0.43	0.42	0.50	0.57	0.40	0.49	0.60
ρ_{y^*}	0.85	0.89	0.92	0.86	0.89	0.92	0.84	0.87	0.90	0.84	0.87	0.91
ρ_{i^*}	0.88	0.91	0.94	0.88	0.91	0.94	0.91	0.94	0.96	0.90	0.92	0.94
sd_{pi^*}	0.31	0.34	0.38	0.31	0.34	0.38	0.31	0.34	0.38	0.31	0.35	0.39
sd_{y^*}	0.52	0.58	0.64	0.53	0.58	0.63	0.53	0.58	0.64	0.51	0.55	0.60
sd_{i^*}	0.15	0.17	0.19	0.15	0.17	0.18	0.15	0.17	0.18	0.15	0.17	0.18
sd_z	0.75	0.86	1.03	0.78	0.87	1.02	16.91	17.46	17.96	19.15	19.37	19.99
s_i	0.28	0.32	0.39	0.27	0.31	0.36	0.24	0.27	0.31	0.23	0.25	0.28
sd_g	2.19	2.41	2.70	1.93	2.16	2.30	0.64	0.73	0.88	0.58	0.66	0.77
sd_{fx}	0.21	0.25	0.30	0.22	0.27	0.32	0.43	0.58	0.76	0.46	0.65	0.75
MHM		-928.89			-936.98			-929.60			-943.57	

Model Version	Local Currency Pricing (LCP) 5 No habit or indexation			6 Indexation			7 Habit			8 Indexation and Habit		
	10%	Median	90%	10%	Median	90%	10%	Median	90%	10%	Median	90%
σ	1.14	1.29	1.49	1.04	1.20	1.45	1.80	2.35	2.57	0.64	0.90	1.20
φ	0.53	0.83	1.21	1.01	1.71	2.03	0.53	0.89	1.24	1.00	1.45	1.99
θ	0.39	0.47	0.54	0.32	0.41	0.49	0.90	0.92	0.93	0.33	0.45	0.59
θ_F	0.14	0.25	0.35	0.15	0.25	0.38	0.09	0.16	0.25	0.13	0.22	0.40
α	0.10	0.13	0.16	0.08	0.11	0.15	0.32	0.38	0.44	0.08	0.11	0.15
η	0.24	0.52	0.83	0.27	0.67	1.18	0.02	0.03	0.06	0.24	0.48	0.78
h							0.66	0.78	0.85	0.26	0.35	0.45
δ				0.16	0.30	0.46				0.12	0.23	0.38
ρ_i	0.83	0.86	0.88	0.81	0.85	0.87	0.90	0.92	0.93	0.82	0.86	0.89
ψ_π	3.01	3.06	3.27	2.99	3.09	3.19	1.58	1.80	1.93	3.08	3.22	3.37
ψ_y	0.29	0.54	0.86	0.17	0.36	0.72	0.05	0.10	0.18	0.13	0.31	0.57
ρ_z	0.90	0.93	0.95	0.91	0.93	0.95	0.58	0.65	0.72	0.88	0.92	0.95
ρ_g	0.98	0.98	0.99	0.98	0.98	0.99	0.38	0.52	0.67	0.97	0.98	0.99
ρ_{fx}	0.77	0.82	0.87	0.77	0.83	0.89	0.81	0.85	0.90	0.73	0.79	0.85
ρ_{pi^*}	0.30	0.38	0.45	0.34	0.42	0.48	0.46	0.54	0.63	0.35	0.42	0.50
ρ_{y^*}	0.85	0.88	0.91	0.85	0.88	0.91	0.84	0.88	0.90	0.85	0.88	0.92
ρ_{i^*}	0.88	0.91	0.94	0.89	0.92	0.94	0.91	0.93	0.95	0.89	0.92	0.95
sd_{pi^*}	0.31	0.34	0.37	0.31	0.34	0.38	0.32	0.35	0.38	0.31	0.34	0.38
sd_{y^*}	0.52	0.57	0.61	0.50	0.56	0.61	0.52	0.57	0.62	0.54	0.59	0.65
sd_{i^*}	0.15	0.17	0.18	0.15	0.16	0.18	0.15	0.17	0.18	0.15	0.17	0.19
sd_z	0.87	1.00	1.11	0.83	0.91	0.98	16.92	17.09	17.39	0.78	0.93	1.11
s_i	0.27	0.31	0.34	0.27	0.31	0.36	0.22	0.25	0.28	0.26	0.31	0.37
sd_g	1.80	1.95	2.09	2.01	2.09	2.20	0.61	0.67	0.73	1.72	2.00	2.16
sd_{fx}	0.24	0.28	0.32	0.22	0.26	0.32	0.39	0.55	0.68	0.26	0.32	0.40
MHM		-935.53			-942.98			-940.12			-941.04	

Table 3b: Canadian results with Foreign block Unobservable

Model	Producer Currency Pricing (PCP)											
	1			2			3			4		
Version	No habit or indexation			Indexation			Habit			Indexation and Habit		
	10%	Median	90%	10%	Median	90%	10%	Median	90%	10%	Median	90%
σ	1.64	1.85	2.23	1.11	1.28	1.50	2.42	2.75	3.78	1.17	1.52	1.69
φ	0.83	1.69	2.88	0.54	1.10	1.68	1.32	1.99	2.59	0.85	1.58	2.35
θ	0.51	0.63	0.73	0.31	0.41	0.50	0.88	0.89	0.91	0.87	0.89	0.91
θ_F												
α	0.12	0.16	0.22	0.08	0.11	0.14	0.23	0.28	0.35	0.23	0.35	0.46
η	0.10	0.24	0.47	0.19	0.40	0.68	0.04	0.07	0.12	0.02	0.03	0.06
h							0.66	0.75	0.82	0.76	0.82	0.87
δ				0.16	0.30	0.50				0.08	0.15	0.24
ρ_i	0.82	0.86	0.89	0.77	0.82	0.86	0.90	0.92	0.94	0.88	0.90	0.92
ψ_π	2.37	2.49	2.65	2.75	2.95	3.32	2.06	2.36	2.58	1.14	1.37	1.75
ψ_y	0.34	0.64	0.95	0.20	0.39	0.68	0.09	0.18	0.34	0.07	0.14	0.24
ρ_z	0.90	0.93	0.96	0.92	0.95	0.96	0.68	0.73	0.79	0.68	0.74	0.82
ρ_g	0.64	0.78	0.89	0.66	0.80	0.89	0.67	0.77	0.84	0.63	0.73	0.82
ρ_{pi*}	0.49	0.63	0.79	0.43	0.56	0.73	0.57	0.70	0.83	0.57	0.72	0.86
ρ_{y*}	0.94	0.97	0.98	0.96	0.97	0.98	0.56	0.67	0.78	0.59	0.71	0.83
ρ_{i*}	0.80	0.86	0.90	0.82	0.87	0.91	0.82	0.87	0.91	0.77	0.87	0.91
sd_{pi*}	0.26	0.37	0.55	0.24	0.32	0.45	0.29	0.41	0.58	0.31	0.48	0.82
sd_{y*}	1.09	1.40	1.62	1.64	1.93	2.13	0.38	0.45	0.52	0.41	0.49	0.58
sd_{i*}	0.24	0.31	0.45	0.22	0.26	0.32	0.39	0.51	0.67	0.35	0.47	0.61
sd_z	0.98	1.23	1.60	0.80	0.92	1.09	5.79	6.16	6.63	6.87	7.10	7.30
s_i	0.26	0.30	0.36	0.29	0.35	0.43	0.23	0.26	0.29	0.22	0.26	0.30
sd_g	0.27	0.37	0.53	0.27	0.36	0.48	0.40	0.52	0.64	0.36	0.45	0.56
MHM		-636.36			-638.04			-625.04			-636.82	

Model	Local Currency Pricing (LCP)											
	5			6			7			8		
Version	No habit or indexation			Indexation			Habit			Indexation and Habit		
	10%	Median	90%	10%	Median	90%	10%	Median	90%	10%	Median	90%
σ	1.10	1.26	1.42	1.06	1.33	1.59	1.59	1.88	2.32	1.41	1.78	2.29
φ	0.73	1.44	2.59	0.48	1.06	1.42	1.04	1.85	2.36	0.93	1.57	2.24
θ	0.42	0.51	0.60	0.28	0.41	0.52	0.88	0.89	0.91	0.87	0.89	0.90
θ_F	0.14	0.25	0.41	0.13	0.24	0.40	0.13	0.22	0.34	0.12	0.20	0.31
α	0.09	0.13	0.17	0.09	0.12	0.16	0.27	0.33	0.40	0.23	0.28	0.35
η	0.24	0.47	0.78	0.16	0.32	0.56	0.03	0.04	0.07	0.03	0.05	0.09
h							0.75	0.80	0.85	0.74	0.80	0.86
δ				0.16	0.30	0.49				0.08	0.14	0.22
ρ_i	0.76	0.82	0.86	0.77	0.82	0.85	0.87	0.89	0.91	0.87	0.89	0.91
ψ_π	2.54	2.67	2.77	2.69	2.78	2.95	1.45	1.60	1.72	1.54	1.76	1.88
ψ_y	0.33	0.59	0.93	0.23	0.46	0.77	0.08	0.16	0.28	0.06	0.12	0.23
ρ_z	0.92	0.94	0.96	0.93	0.95	0.97	0.70	0.75	0.80	0.65	0.71	0.77
ρ_g	0.65	0.78	0.88	0.63	0.78	0.89	0.64	0.74	0.82	0.64	0.75	0.83
ρ_{pi*}	0.46	0.60	0.74	0.50	0.67	0.87	0.56	0.75	0.88	0.57	0.79	0.88
ρ_{y*}	0.96	0.98	0.99	0.96	0.97	0.98	0.56	0.70	0.82	0.60	0.73	0.84
ρ_{i*}	0.82	0.87	0.90	0.57	0.84	0.90	0.68	0.85	0.90	0.73	0.83	0.90
sd_{pi*}	0.25	0.33	0.45	0.25	0.33	0.45	0.36	0.54	0.93	0.35	0.49	0.71
sd_{y*}	1.82	1.99	2.23	1.39	1.72	2.22	0.43	0.49	0.57	0.40	0.48	0.59
sd_{i*}	0.22	0.27	0.33	0.21	0.26	0.32	0.36	0.49	0.64	0.34	0.48	0.68
sd_z	0.80	0.93	1.04	0.81	0.98	1.09	5.65	5.93	6.43	6.43	6.78	7.05
s_i	0.27	0.32	0.40	0.29	0.34	0.40	0.22	0.25	0.28	0.22	0.25	0.28
sd_g	0.27	0.37	0.54	0.26	0.34	0.50	0.33	0.42	0.54	0.37	0.48	0.58
MHM		-638.69			-644.33			-629.18			-636.14	

Table 4a: New Zealand results with Foreign block Observable

Model Version	Producer Currency Pricing (PCP)												Local Currency Pricing (LCP)											
	1 No habit or indexation			2 Indexation			3 Habit			4 Indexation and Habit			5 No habit or indexation			6 Indexation			7 Habit			8 Indexation and Habit		
	10%	Median	90%	10%	Median	90%	10%	Median	90%	10%	Median	90%	10%	Median	90%	10%	Median	90%	10%	Median	90%	10%	Median	90%
σ	0.66	0.84	1.82	0.52	0.62	0.75	0.42	0.53	0.66	0.37	0.48	0.62	0.88	1.23	1.54	0.57	0.68	0.86	0.43	0.53	0.73	0.34	0.42	0.53
φ	1.31	2.30	2.98	1.35	2.82	3.90	0.76	1.24	1.90	2.10	2.56	3.09	0.96	1.46	1.97	1.09	1.77	2.31	0.64	1.21	2.01	2.21	2.67	3.41
θ	0.33	0.45	0.56	0.18	0.28	0.39	0.27	0.35	0.43	0.25	0.33	0.41	0.31	0.40	0.47	0.15	0.23	0.31	0.23	0.32	0.45	0.19	0.28	0.35
θ_F													0.38	0.69	0.88	0.33	0.68	0.89	0.28	0.49	0.77	0.26	0.45	0.64
α	0.07	0.11	0.16	0.05	0.09	0.12	0.05	0.08	0.12	0.05	0.08	0.12	0.08	0.14	0.23	0.07	0.11	0.18	0.05	0.08	0.13	0.05	0.08	0.12
η	0.60	1.25	2.19	0.41	0.89	1.43	0.38	0.76	1.27	0.55	0.98	1.62	1.52	1.78	2.19	1.52	2.08	2.56	0.60	1.29	2.55	0.53	0.97	1.69
h							0.11	0.20	0.32	0.10	0.19	0.30							0.09	0.18	0.28	0.10	0.18	0.27
δ				0.23	0.41	0.61				0.17	0.33	0.50				0.21	0.36	0.53				0.24	0.42	0.62
ρ_i	0.80	0.85	0.89	0.81	0.85	0.87	0.80	0.87	0.90	0.79	0.84	0.87	0.83	0.86	0.89	0.79	0.83	0.87	0.78	0.83	0.88	0.80	0.84	0.87
ψ_π	2.14	2.35	2.48	2.84	2.94	3.04	2.79	3.11	3.47	2.34	2.49	2.71	2.26	2.59	2.74	2.47	2.61	2.86	2.44	2.54	2.64	2.55	2.83	2.99
ψ_y	0.26	0.48	0.76	0.25	0.50	1.04	0.18	0.36	0.59	0.20	0.40	0.70	0.25	0.62	1.51	0.18	0.40	0.70	0.17	0.35	0.64	0.23	0.47	0.80
ρ_z	0.79	0.85	0.90	0.82	0.86	0.90	0.78	0.85	0.90	0.80	0.86	0.91	0.81	0.86	0.90	0.81	0.86	0.91	0.79	0.85	0.90	0.80	0.85	0.90
ρ_g	0.96	0.97	0.98	0.96	0.97	0.98	0.96	0.97	0.98	0.96	0.97	0.98	0.96	0.97	0.98	0.97	0.98	0.99	0.97	0.98	0.98	0.96	0.97	0.98
ρ_{fx}	0.72	0.78	0.84	0.70	0.76	0.82	0.68	0.75	0.82	0.69	0.77	0.84	0.69	0.76	0.83	0.72	0.77	0.83	0.69	0.77	0.83	0.68	0.75	0.83
ρ_{pi^*}	0.46	0.53	0.61	0.39	0.48	0.55	0.39	0.48	0.56	0.42	0.49	0.55	0.41	0.51	0.58	0.45	0.52	0.59	0.43	0.50	0.58	0.40	0.48	0.59
ρ_{y^*}	0.86	0.89	0.93	0.86	0.90	0.93	0.85	0.89	0.93	0.86	0.90	0.93	0.86	0.89	0.93	0.85	0.89	0.93	0.86	0.90	0.93	0.85	0.89	0.93
ρ_{i^*}	0.85	0.89	0.92	0.85	0.89	0.93	0.86	0.90	0.93	0.85	0.89	0.92	0.85	0.89	0.92	0.86	0.90	0.93	0.85	0.89	0.93	0.86	0.90	0.93
sd_{pi^*}	0.30	0.33	0.37	0.29	0.33	0.37	0.29	0.33	0.37	0.30	0.34	0.40	0.30	0.33	0.37	0.29	0.32	0.37	0.29	0.32	0.35	0.29	0.32	0.36
sd_{y^*}	0.50	0.55	0.60	0.50	0.56	0.63	0.52	0.58	0.65	0.49	0.54	0.63	0.50	0.56	0.61	0.47	0.53	0.59	0.50	0.54	0.59	0.50	0.57	0.64
sd_{i^*}	0.15	0.17	0.19	0.15	0.17	0.19	0.15	0.17	0.19	0.15	0.17	0.19	0.15	0.17	0.19	0.15	0.17	0.19	0.15	0.17	0.19	0.15	0.17	0.19
sd_z	1.16	1.40	1.82	0.92	1.03	1.11	0.97	1.14	1.27	0.97	1.15	1.33	1.09	1.27	1.45	0.96	1.07	1.23	0.89	1.10	1.31	0.97	1.05	1.11
s_i	0.37	0.45	0.55	0.43	0.51	0.65	0.40	0.49	0.72	0.40	0.50	0.63	0.36	0.41	0.47	0.37	0.45	0.58	0.35	0.51	0.67	0.40	0.49	0.61
sd_g	3.90	4.61	4.86	4.94	5.08	5.57	4.66	4.93	5.07	5.37	5.55	5.75	3.38	3.70	4.10	5.18	5.29	5.40	5.00	5.17	5.31	5.93	6.12	6.39
sd_{fx}	0.27	0.33	0.42	0.26	0.31	0.36	0.30	0.37	0.46	0.27	0.33	0.41	0.30	0.37	0.47	0.26	0.30	0.37	0.27	0.33	0.41	0.28	0.34	0.43
MHM		-796.84			-798.42			-799.47			-804.90			-794.95			-800.95			-803.40			-804.54	

Table 4b: New Zealand results with Foreign block Unobservable

Model	Producer Currency Pricing (PCP)												Local Currency Pricing (LCP)											
	1			2			3			4			5			6			7			8		
Version	No habit or indexation			Indexation			Habit			Indexation and Habit			No habit or indexation			Indexation			Habit			Indexation and Habit		
	10%	Median	90%	10%	Median	90%	10%	Median	90%	10%	Median	90%	10%	Median	90%	10%	Median	90%	10%	Median	90%	10%	Median	90%
σ	0.61	0.71	0.83	0.54	0.63	0.76	0.74	0.87	1.13	0.68	0.84	1.02	0.54	0.62	0.73	0.50	0.57	0.65	0.59	0.68	0.78	0.55	0.65	0.78
φ	0.70	1.30	2.07	1.45	2.21	3.05	0.69	1.15	1.73	0.90	2.10	3.06	0.60	1.11	1.88	0.83	1.57	2.37	0.55	1.18	1.74	0.97	1.47	1.95
θ	0.23	0.32	0.40	0.16	0.25	0.33	0.29	0.39	0.49	0.22	0.31	0.40	0.18	0.27	0.36	0.13	0.19	0.31	0.25	0.32	0.40	0.17	0.26	0.37
θ_F													0.23	0.41	0.61	0.24	0.40	0.55	0.29	0.53	0.73	0.20	0.35	0.54
α	0.07	0.10	0.14	0.06	0.09	0.13	0.07	0.11	0.15	0.06	0.10	0.14	0.06	0.10	0.13	0.06	0.09	0.13	0.05	0.09	0.12	0.06	0.09	0.13
η	0.37	0.82	1.42	0.47	0.91	1.37	0.20	0.43	0.76	0.35	0.68	1.14	0.36	0.71	1.16	0.31	0.60	1.04	0.35	0.72	0.98	0.29	0.59	0.93
h							0.03	0.06	0.10	0.03	0.05	0.08							0.03	0.05	0.09	0.03	0.05	0.08
δ				0.21	0.38	0.57				0.18	0.36	0.62				0.18	0.32	0.52				0.18	0.35	0.55
ρ_i	0.77	0.81	0.85	0.76	0.81	0.85	0.79	0.84	0.87	0.72	0.79	0.84	0.77	0.81	0.85	0.73	0.80	0.84	0.77	0.82	0.85	0.76	0.81	0.85
ψ_π	2.08	2.28	2.47	2.59	2.82	3.02	1.82	1.91	2.04	2.03	2.11	2.22	2.18	2.39	2.65	2.44	2.60	2.86	2.07	2.36	2.58	2.12	2.28	2.45
ψ_y	0.29	0.67	1.08	0.22	0.45	0.84	0.24	0.48	0.84	0.17	0.35	0.68	0.20	0.40	0.68	0.25	0.56	0.95	0.17	0.36	0.64	0.18	0.43	0.84
ρ_z	0.80	0.85	0.90	0.81	0.86	0.90	0.79	0.85	0.90	0.80	0.86	0.91	0.80	0.85	0.90	0.81	0.86	0.91	0.80	0.85	0.90	0.79	0.84	0.89
ρ_g	0.60	0.74	0.85	0.61	0.74	0.85	0.59	0.73	0.84	0.61	0.76	0.85	0.63	0.76	0.86	0.60	0.75	0.84	0.62	0.78	0.88	0.58	0.74	0.85
ρ_{pi*}	0.45	0.59	0.76	0.50	0.63	0.76	0.48	0.62	0.77	0.56	0.70	0.82	0.47	0.60	0.74	0.51	0.69	0.82	0.49	0.64	0.79	0.56	0.75	0.85
ρ_{y*}	0.96	0.97	0.98	0.96	0.97	0.98	0.96	0.98	0.98	0.96	0.97	0.98	0.96	0.97	0.98	0.96	0.97	0.98	0.97	0.98	0.99	0.97	0.98	0.98
ρ_{i*}	0.70	0.80	0.85	0.75	0.81	0.87	0.69	0.79	0.85	0.60	0.75	0.84	0.74	0.81	0.86	0.68	0.79	0.85	0.73	0.80	0.86	0.59	0.74	0.84
sd_{pi*}	0.24	0.33	0.48	0.23	0.30	0.41	0.28	0.40	0.57	0.26	0.35	0.48	0.24	0.33	0.46	0.23	0.30	0.41	0.26	0.35	0.49	0.24	0.32	0.43
sd_{y*}	4.22	4.64	4.92	4.74	5.03	5.22	3.48	3.65	3.86	3.85	4.13	4.35	4.91	5.14	5.32	5.19	5.30	5.53	4.31	4.49	4.67	4.45	4.72	4.91
sd_{i*}	0.22	0.27	0.33	0.21	0.25	0.31	0.25	0.32	0.43	0.22	0.28	0.36	0.22	0.27	0.33	0.21	0.26	0.32	0.22	0.27	0.35	0.23	0.29	0.36
sd_z	0.93	1.04	1.14	0.92	1.01	1.12	1.04	1.23	1.41	1.13	1.26	1.38	0.90	1.01	1.11	0.84	0.96	1.10	0.90	0.99	1.09	0.87	1.14	1.34
s_i	0.45	0.52	0.62	0.47	0.60	0.81	0.36	0.43	0.53	0.43	0.55	0.75	0.41	0.50	0.61	0.45	0.58	0.81	0.40	0.50	0.63	0.40	0.51	0.66
sd_g	0.33	0.51	0.81	0.31	0.46	0.74	0.29	0.41	0.61	0.30	0.43	0.66	0.35	0.54	0.87	0.31	0.49	0.72	0.35	0.59	0.97	0.30	0.44	0.65
MHM		-566.30			-569.83			-580.70			-585.90			-568.51			-572.12			-584.31			-586.53	

Table 5: Model Comparisons and Cross Validation

Panel A: Australia

	Foreign Block Observable Modified Harmonic Mean		Foreign Block NOT Observable Modified Harmonic Mean		Bayesian VAR Cross Validation	
	Log marginal	Posterior Model Probabilities	Log marginal	Posterior Model Probabilities		Log Marginal
GM (no HF-PI)	-929.26	0.96	-653.15	7.53E-04	BVAR(1)	-643.65
GM (PI)	-933.76	1.07E-02	-659.53	1.27E-06	BVAR(2)	-652.36
GM (HF)	-934.04	8.02E-03	-646.38	0.65	BVAR(3)	-658.24
GM (HF-PI)	-933.23	2.34E-03	-658.78	2.69E-06	BVAR(4)	-663.77
Sum of posterior model probs:		0.981		0.656		
M (no HF-PI)	-933.23	0.02	-657.33	1.15E-05		
M (PI)	-937.95	1.61E-04	-659.83	9.45E-07		
M (HF)	-937.68	2.12E-04	-647.02	0.34		
M (HF-PI)	-937.97	1.58E-04	-674.14	5.76E-13		
Sum of posterior model probs:		0.019		0.344		

Panel B: Canada

	Foreign Block Observable Modified Harmonic Mean		Foreign Block NOT Observable Modified Harmonic Mean		Bayesian VAR Cross Validation	
GM (no HF-PI)	-928.886	6.70E-01	-636.364	1.19E-05	BVAR(1)	-608.58
GM (PI)	-936.984	2.04E-04	-638.041	2.23E-06	BVAR(2)	-608.17
GM (HF)	-929.598	3.29E-01	-625.043	9.84E-01	BVAR(3)	-609.24
GM (HF-PI)	-943.572	2.81E-07	-636.820	7.56E-06	BVAR(4)	-608.32
Sum of posterior model probs:		0.999		0.98		
M (no HF-PI)	-935.532	8.71E-04	-638.689	1.17E-06		
M (PI)	-942.985	5.05E-07	-644.333	4.13E-09		
M (HF)	-940.123	8.83E-06	-629.177	1.58E-02		
M (HF-PI)	-941.044	3.52E-06	-636.143	1.49E-05		
Sum of posterior model probs:		0.001		0.02		

Panel C: New Zealand

	Foreign Block Observable Modified Harmonic Mean		Foreign Block NOT Observable Modified Harmonic Mean		Bayesian VAR Cross Validation	
GM (no HF-PI)	-796.84	1.27E-01	-566.30	8.75E-01	BVAR(1)	-566.28
GM (PI)	-798.42	2.59E-02	-569.83	2.59E-02	BVAR(2)	-563.85
GM (HF)	-799.47	9.07E-03	-580.70	4.89E-07	BVAR(3)	-567.33
GM (HF-PI)	-804.90	3.98E-05	-585.90	2.70E-09	BVAR(4)	-568.45
Sum of posterior model probs:		0.162		0.901		
M (no HF-PI)	-794.95	8.36E-01	-568.51	9.62E-02		
M (PI)	-800.95	2.07E-03	-572.12	2.61E-03		
M (HF)	-803.40	1.78E-04	-584.31	1.32E-08		
M (HF-PI)	-804.54	5.72E-05	-586.53	1.43E-09		
Sum of posterior model probs:		0.838		0.099		

Notes: 1) HF - habit formation and PI -- price indexation. 2) Log Marginal Likelihood obtained with a Modified-Harmonic Mean estimator. Results are insensitive to the choice of cut-off point for the reciprocal importance sampling density and correspond above to the mean of a grid of values between 0.1 and 0.9. Results are also robust to whther the density point corresponds to mean, medians of the (simulated) maximizing value of the posterior draws. Posterior odds based on all models assigned equal prior probability of 1/4. 3) Reversible jump MCMC 100,000 draws. Discarded the first 10,000. Posterior model probabilities P(m|data) based on assigning each model a prior probability of 0.25.

Table 6: Variations in the standard deviations of Consumption and Output with the degree of habit

Autocorrelations of Inflation *"Open Economy"* (eta=0.39, alpha=0.08)

	h=0	***h=0.4***	***h=0.9***
Home Goods Inflation	0.48	0.30	-0.09
CPI Inflation	0.46	0.46	-0.04

***"Closed Economy"* (eta=alpha=0). Standard deviations (sd)**

Degree of Habit	***h=0***	***h=0.4***	***h=0.9***
sd consumption	1.42	1.40	1.21
sd output	0.71	0.70	0.60

***"Open Economy"* (eta=0.39, alpha=0.08). Standard deviations (sd)**

Degree of Habit	***h=0***	***h=0.4***	***h=0.9***
sd consumption	1.92	2.10	2.93
sd output	1.95	2.08	2.76
sd marginal cost	0.34	0.72	4.61
sd real wages	2.0877	2.62	6.57