Monetary Policy and Uncertainty in an Empirical Small Open Economy Model*

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June 22, 2006

PRELIMINARY

Abstract

This paper explores optimal policy design in an estimated model of three small open economies: Australia, Canada and New Zealand. Within a class of generalized Taylor rules, we show that to stabilize of a weighted objective of output, consumer price inflation and nominal interest variation optimal policy does not respond to the nominal exchange. This is despite the presence of local currency pricing. Optimal policies that account for the uncertainty of model estimates, as captured by the parameters' posterior distrbution, give remarkably similar inference. In contrast to Brainard (1967), the presence of parameter uncertainty need not lead to attenuated policy responses. However, if the Central Bank has an incorrect estimate of key structural parameters, such as the frequency of price setting in goods markets, then significant welfare losses may result when using either the optimal policy rule or the empirical policy rule.

*This is a significantly revised version of a paper circulated under the title "Small Open Economy DSGE Models: Specification, Estimation and Model Fit". The views expressed in this paper are those of the authors' and should not be interpreted as reflecting the views of the Board of Governors or any person associated with the Federal Reserve. The usual caveat applies.

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1 Introduction

Recent theoretical analyses have emphasized the importance of pricing to market assumptions for optimal exchange rate policy, monetary policy and macroeconomic dynamics. Whether a country has producer currency pricing or local currency pricing can give rise to rather different policy recommendations, even when the sole of objective of policy is to stabilize the domestic inflation rate. For instance, Devereux and Engel (2003) show in a two country model with local currency pricing that optimal monetary policy stipulates stabilization of the nominal exchange rate.[1] Similarly, Monacelli (2003) shows that local currency pricing induces a trade-off in stabilizing domestic price inflation and the output gap that is not present when the law of one price holds.

Despite these theoretical contributions there has been relatively little work on policy evaluation in empirical small open economy models. This paper seeks to fill this gap by exploring optimal policy design within an estimated structural model using data for Australia, Canada and New Zealand. Of particular interest is whether policies in a class of generalized Taylor rule optimally respond to exchange rate variations as predicted by theory. Moreover, we assess the consequence of various sources of model uncertainty for the design of optimal monetary policy. To our knowledge, this is the first such study in a fully estimated small open economy model.[2]

The analysis is pursued using generalizations of the small open economy framework proposed by Gali and Monacelli (2005) and Monacelli (2003), in which a small and large country each specialize in the production of a continuum of goods subject to imperfect competition and price rigidities.[3] Following the latter, imports are subject to local currency pricing (through what could be considered a retail sector providing distribution services) giving rise to deviations from the law of one price. We depart from their framework, by considering incomplete asset markets, the addition of other nominal rigidities — such indexation and habits — as well as a large set of disturbances which have been found crucial in taking closed economy models to the data as documented by, inter alia, Christiano, Eichenbaum, and Evans (2005) and Smets and Wouters (2003).

Using the empirical model we determine the optimal policy rule within a generalized class of Taylor-type rule that minimizes, subject to the constraints imposed by the estimated model, a weighted objective function in the variance of domestic consumer price inflation, output and interest rates. The Taylor rule posits that nominal interest rates are adjusted in response to output, output

[1] See also XXXX, XXXX and XXXX.

[2] Levin, Onatski, Williams, and Williams (2005) pursue a similar analysis for the closed economy case.

[3] The model is technically a semi-small open economy model, as domestic goods producers have some market power. The model shall nonetheless be referred to as a small open economy. Note also that our analysis appeals to an earlier interpretation of the Gali and Monacelli (2005) of a small-large country pair, rather than as an analysis of a continuum of small open economies.

growth, inflation, nominal exchange rate growth and past interest rates. Optimization occurs subject to several assumptions about central bank knowledge of the economy. In particular, we initially posit that policy is determined assuming that model estimated parameters are known with certainty to take their median values. Then, following Levin, Onatski, Williams, and Williams (2005), the performance in terms of the policy maker's loss of both the optimal policy rule and the estimated policy rule under specific parameter perturbations is evaluated. That is, we ask what are the welfare consequences of having an incorrect estimate of a particular parameter. This permits an assessment of whether uncertainty in specific components of the transmission mechanism are more important than others. Finally, we consider the optimal policy that results from taking into account all uncertainty regarding model parameters by using the posterior distribution of our estimates. This is rendered feasible by adopting a Bayesian approach to inference.

The central insights from our analysis are as follows. Optimal policies rules within the adopted class of Taylor type rules do not respond to the nominal exchange rate. This is true regardless of whether parameter uncertainty is taken into account or not. Furthermore, this result is robust to considering a wide range of weight combinations for the components of the loss function. This finding contrasts with Smets and Wouters (2002) who provide evidence that optimal policies stipulate a response to exchange rate variations. Given the broad similarity of the models in these two studies, the difference in conclusions may originate from the fact that we estimate a large number of parameters using likelihood-based inference rather than matching impulse response functions to estimate a small subset of model parameters and calibrating the remainder. We suspect that these two approaches to estimation give rise to distinct second order moments for model time series.

Overall, optimal policies stabilize inflation to a large degree. In the case of Australia the optimal policy gives rise to a standard deviation for inflation of 0.1, far below the historical average. This is despite the presence of local currency pricing, which, as shown by Monacelli (2003) — in a model nested by our estimating framework — and others, induces a trade-off in stabilizing inflation and output. This suggests, at least in the context of this model, deviations from the law of one price may not be too important in characterizing stabilization trade-offs and optimal monetary policy. Another characteristic shared by all countries is that optimal policies are highly inertial and respond strongly to growth in output. In the latter case, the strength of the response to output growth depends, not surprisingly, on the weight assigned to output stabilization relative to the other components of the loss function.

Analysis of individual parameter uncertainty reveals that having precise estimates of the degree of price stickiness in the domestic goods sector, the elasticity of labor supply and the degree of habit formation are important to welfare outcomes. Taking as given either the estimated policy rule or the above determined optimal policy, and holding fixed all other model parameters, deviations of any one of these structural parameters can lead to significant losses. That these parameters emerge as being particularly important follows directly from the fact that: the degree of price stickiness interacts with strategic complementarities to give rise to more persistent and variable inflation; habit formation in large part determines the dynamic properties of output; and the elasticity of labor supply regulates the effects of technology innovations on marginal costs and, therefore, the time series properties of inflation. Interestingly, the open economy parameters do not give rise to variations in losses of the same magnitudes.

Despite large fluctuations in welfare losses arising from variations in individual parameters, simultaneously accounting for uncertainty in all model coefficient estimates results in negligible changes in optimal policy relative to the case when parameters are known with certainty. Notwithstanding the small differences in the coefficients of the optimized Taylor-type rule, it is interesting to note that in some cases uncertainty leads to slightly more aggressive responses to output. This result stands in contrast to the classic attenuation result of Brainard (1967), though is consistent with multivariate generalizations of that analysis as shown by Chow (1975). Similar findings have also been documented for the closed economy case in the robust control literature — see Giannoni (2002).

A number of robustness exercises are conducted. As shown by Justiniano and Preston (2006), open economy DSGE models of the kind analyzed here have difficulty accounting for the transmission of international disturbances. To allay concern that our results are driven by this lack of transmission, we estimate an alternative model that accounts better for foreign influences on the evolution of the domestic economy. Rather than assuming the foreign block of the model is proxied by U.S. data and treated as observed variables in estimation, we instead assume that foreign output, inflation and interest rates are unobserved exogenous autoregressive processes. This permits an agnostic view of the precise nature of these shocks and also addresses possible concern that the U.S. may not be not provide an accurate representation of foreign trade in goods and assets for these small open economies. While the resulting model gives rise to a substantially greater role of foreign sourced disturbances in the dynamics of domestic variables, our broad conclusions regarding optimal policy design are virtually identical.

The second key robustness exercise focuses on the choice of prior and model identification. A number of recent papers have raised concerns about identification in DSGE models — see Lubik and Schorfheide (2005) and Justiniano and Preston (2006) for discussions in the context of open economy models. More specifically, Canova and Sala (2005) and Fukac, Pagan, and Pavlov (2006) explore implications of identification problems for inference and speculate on consequences for policy evaluation. We connect to this discussion by considering a more agnostic prior on two key parameters: the degree of price indexation and habit formation. The resulting estimates are revealed to parameterize persistence with a different configuration of parameter values having a very low degree of price indexation and a greater degree of rigidity in price setting in domestic and imported goods sectors relative to the benchmark prior. However, the second moments implied by the model are largely unchanged as are our conclusions on policy design.

This paper most closely relates to Smets and Wouters (2002) and the references therein on policy evaluation in empirical small open economy models. Lubik and Schorfheide (2003) also consider whether there is evidence that Australia, Canada, New Zealand and the United Kingdom have had monetary policies that depend on nominal exchange variations. However, they do not address the question of optimal policy or the consequences of model uncertainty. It is also builds on the ever growing literature on estimating small open economy models using Bayesian methods — see Ambler, Dib, and Rebei (2004), Bergin (2003, 2004), Del Negro (2003), Dib (2003), Ghironi (2000), Justiniano and Preston (2004, 2006), Lubik and Schorfheide (2003, 2005), Lubik and Teo (2005) and Rabanal and Tuesta (2005).

The paper proceeds as follows. Section 2 lays out the theoretical model. Section 3 discusses the data, estimation methodology, the prior and identification. Section 4 presents the baseline estimation results and properties of the model implied second order moments. Section 5 presents the optimal policy exercises and assesses the implications of parameter uncertainty for policy design. Section 6 analyzes the robustness of our conclusions to the specification of the foreign block. Section 7 returns to our choice of priors and a set of identification issues and implications for policy inference. Finally, Section 8 concludes.

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 (2005) when allowing for habit formation and indexation of prices to past inflation. 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

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

where α is the share of foreign goods in the domestic consumption bundle; $\eta > 0$ 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.

Assuming the only available assets are one period domestic and foreign bonds, optimization occurs subject to the flow budget constraint

$$P_t C_t + D_t + e_t B_t = D_{t-1}(1 + \tilde{\imath}_{t-1}) + e_t B_{t-1}\left(1 + i_{t-1}^*\right)\phi_t(A_t) + P_t^H Y_t^H + \left(P_t^F - \tilde{e}_t P_t^*\right) C_t^F + T_t$$

for all $t > 0$, where D_t denotes the household's holding of one period domestic bonds, and B_t one period foreign bonds with corresponding interest rates i_t and $\tilde{\imath}_t$. The price indices P_t, $P_{H,t}$ and P^* correspond to the domestic CPI, domestic goods prices and foreign prices respectively and are formally defined below. T_t denotes taxes and transfers. Following Benigno (2001), Kollmann (2002) and Schmitt-Grohe and Uribe (2003), the function $\phi_t(\cdot)$ is interpretable as a debt elastic interest rate premium given by

$$\phi_t = \exp\left[-\chi \left(A_t + \tilde{\phi}_t \right) \right]$$

where

$$A_t \equiv \frac{\tilde{e}_{t-1} B_{t-1}^f}{\bar{Y} P_{t-1}}$$

is the real quantity of outstanding foreign debt expressed in terms of domestic currency as a fraction of steady state output and $\tilde{\phi}_t$ a risk premium shock. The adopted functional form ensures stationarity of the foreign debt level.

Implicitly underwriting this expression for the budget constraint is the assumption that all households in the domestic economy receive an equal fraction of both domestic and retail firm profits. Hence the final two terms in the flow budget constraint represent the income received from operation of the domestic and imported goods sector firms discussed below (both taken as given in the optimization problem). Absent this assumption, which imposes complete markets within the domestic economy, the analysis would require modeling the distribution of wealth across agents. That same assumption also ensures that households face identical decision problems and therefore choose identical state-contingent plans for consumption.

The household's 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

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

for all i with associated aggregate price indexes for the domestic and foreign consumption bundles given by $P_{H,t}$ and $P_{F,t}$. The optimal allocation of expenditure across domestic and foreign goods implies the demand functions

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

where $P_t = \left[(1-\alpha) P_{H,t}^{1-\eta} + \alpha P_{F,t}^{1-\eta}\right]^{\frac{1}{1-\eta}}$ is the consumer price index. Allocation of expenditures on the aggregate consumption bundle satisfies

$$\lambda_t = \tilde{\varepsilon}_{g,t}\left(C_t - H_t\right)^{-1/\sigma} \tag{2}$$

and portfolio allocation is determined by the optimality conditions

$$\lambda_t \tilde{e}_t P_t = E_t\left[\left(1+\tilde{\imath}_t^*\right)\beta\phi_{t+1}\lambda_{t+1}\tilde{e}_{t+1}P_{t+1}\right] \tag{3}$$

$$\lambda_t P_t = E_t\left[\left(1+\tilde{\imath}_t\right)\beta\lambda_{t+1}P_{t+1}\right] \tag{4}$$

for Lagrange multiplier λ_t. The latter condition when combined with (2) gives the usual Euler equation.

2.2 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

$$P_{H,t} = \left[(1-\theta_H) P_{H,t}^{\prime(1-\varepsilon)} + \theta_H \left(P_{H,t-1} \left(\frac{P_{H,t-1}}{P_{H,t-2}} \right)^{\delta} \right)^{1-\varepsilon} \right]^{1/(1-\varepsilon)}. \tag{6}$$

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

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

2.3 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

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

2.4 International Risk Sharing and Prices

From the asset pricing conditions that determine domestic and foreign bond holdings, the uncovered interest rate parity condition

$$E_t \lambda_{t+1} P_{t+1} [(1 + \tilde{\imath}_t) - (1 + \tilde{\imath}^*_t)(\tilde{e}_{t+1}/\tilde{e}_t)\phi_{t+1}] = 0 \tag{11}$$

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 (2003) calls the law of one price gap. The models of Gali and Monacelli (2005) and Monacelli (2003) are respectively characterized by whether or not $\tilde{\Psi}_{F,t} = 1$.

2.5 General Equilibrium

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

$$Y_{H,t} = C_{H,t} + C^*_{H,t} \tag{12}$$

in the domestic economy. The model is closed assuming foreign demand for the domestically produced good is specified as

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

where $\lambda > 0$. This demand function is standard in small open economy models (see Kollmann (2002) and McCallum and Nelson (2000)) and nests the specification in Monacelli (2003) by allowing λ to be different from η, the domestic elasticity of substitution across goods in the domestic economy, in order to give additional flexibility in the transmission mechanism of foreign disturbances to the domestic economy. However, our results are unaffected by the parametrization of this demand function.[4] Domestic debt is assumed to be in zero net supply so that $D_t = 0$ for all t.[5]

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 choose a common price $P_{F,t}$. 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.

Finally, monetary policy is assumed to be conducted according to a Taylor-type rule discussed in the subsequent section. Fiscal policy is specified as a zero debt policy, so that taxes are equal to the subsidy required to eliminate the distortion induced by imperfect competition in the domestic and imported goods markets.

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 (2005).[6] 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.

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. 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.

[4] Constraining λ to equal η results in identical insights from the estimation, and therefore we report results based on this more general specification.

[5] A similar condition holds for the foreign economy once it is noted that domestic holdings of foreign debt, B_t, is negligible relative to the size of the foreign economy.

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

A log linear approximation to the domestic household's Euler equation (4) 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. To derive a relationship in terms of domestic output, a log-linear approximation to the goods market clearing condition implies:

$$(1-\alpha)\,c_t = y_t - \alpha\eta\,(2-\alpha)\,s_t - \alpha\eta\psi_{F,t} - \alpha y_t^*. \tag{13}$$

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

$$\Delta s_t = \pi_{F,t} - \pi_{H,t}. \tag{14}$$

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.

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

$$q_t = e_t + p_t^* - p_t = \psi_{F,t} + (1-\alpha)\,s_t \tag{15}$$

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

$$\pi_{H,t} - \delta\pi_{H,t-1} = \theta_H^{-1}\,(1-\theta_H)\,(1-\theta_H\beta)\,mc_t + \beta E_t\left(\pi_{H,t+1} - \delta\pi_{H,t}\right) \tag{16}$$

where

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

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. 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 (13)).

The optimality conditions for the retailers' pricing problem yields

$$\pi_{F,t} - \delta\pi_{F,t-1} = \theta_F^{-1}(1-\theta_F)(1-\theta_F\beta)\psi_{F,t} + \beta E_t(\pi_{F,t+1} - \delta\pi_{F,t}). \tag{17}$$

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.

The uncovered interest-rate parity condition gives

$$(i_t - E_t\pi_{t+1}) - \left(i_t^* - E_t\pi_{t+1}^*\right) = E_t\Delta q_{t+1} - \chi a_t - \phi_t \tag{18}$$

while the flow budget constraint implies

$$c_t + a_t = \beta^{-1}a_{t-1} - \tau\left(s_t + \psi_{F,t}\right) + y_t \tag{19}$$

where $a_t = \log(e_tB_t^f/(P_t\bar{Y}))$ is the log real net foreign asset position as a fraction of steady state domestic GDP.

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

$$i_t = \rho_i i_{t-1} + \psi_\pi\pi_t + \psi_y y_t + \psi_{\Delta y}\Delta y_t + \psi_e e_t + \varepsilon_{M,t} \tag{20}$$

so that the nominal interest rate is determined by past interest rates and also responds to the current CPI inflation rate, output, output growth and the change in the nominal exchange rate. 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

$$\pi_t = \pi_{H,t} + \alpha\Delta s_t. \tag{21}$$

The domestic block of the economy is therefore given by equations (13)-(21) 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 $\{\pi_t^*,\ y_t^*,\ i_t^*\}$ 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 $\{\pi_t^*,\ y_t^*,\ i_t^*\}$ is discussed in the subsequent section. In estimation, we only make use of observable series for $\{y_t,\ i_t,\ q_t,\ \pi_{H,t},\ \pi_t^*,\ y_t^*,\ i_t^*\}$ 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. However, 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 $\{\pi_t^*,\ y_t^*,\ i_t^*\}$ are determined by autoregressive processes of order one. Estimation assuming a vector autoregressive process of degree one in these three variables yielded similar results. Hence, defining $z_t^* = [y_t^*, \pi_t^*, i_t^*]'$ as the vector of foreign variables, the data generating process is assumed to take the form:

$$z_t^* = A z_{t-1}^* + \varepsilon_t^* \tag{22}$$

where A is a diagonal coefficient matrix of appropriate dimension and ε_t^* an error vector with the usual properties. This specification has the advantage of not imposing tight cross-equation restrictions implied by a structural model and therefore allows for a more flexible representation of the reduced form dynamics of these variables.

3 Data

For all three countries, Australia, Canada and New Zealand, estimation uses quarterly data on output, inflation, interest rates and the real exchange rate. GDP is per-capita in log deviations from a linear trend. The inflation series corresponds to the annualized quarterly log-difference in the consumer price index. 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. For Canada we consider an inflation measure excluding food and energy. Similar considerations to those in Australia dictate adjusting the large outlier in the first quarter of 1991 with the use – for that quarter only – of a measure that also excludes the effects of indirect taxes. 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. For Canada and New Zealand all data were obtained from Data Stream International. We constructed a model consistent real exchange rate using U.S. price data discussed below, each country's CPI and the bilateral nominal exchange rate. The real exchange rate is expressed in log-difference for the estimation.

For specifications in which the foreign block is observable we assume it to be reasonably proxied by U.S. data. The U.S. 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 2005:III for Australia, and 1988:III-2005:III 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.[7]

In summary, for each country the model is taken to the data using 7 observable series and the same number of disturbances. We demean the series before the estimation.

4 Estimation

Our objective is not only to estimate the parameters of the DSGE model specified in the previous section using Bayesian methods, but also to provide an accurate characterization of uncertainty surrounding these estimates and its impact on policy design. Therefore, we aim to characterize the posterior distribution of the model parameters $\theta \in \Theta$. Given a prior, $\pi(\theta)$, the posterior density is proportional to the product of the likelihood and the prior. As described by Schorfheide (2000), posterior draws for this density can be generated using a random walk metropolis algorithm and the state-space representation implied by the solution of the linear rational expectations model and the Kalman filter. Measures of location and scatter are obtained from the draws by computing, for instance, the median and standard deviations as well as posterior probability bands. Furthermore, given the draws it is possible to characterize the posterior distribution of any functional of interest, by computing the corresponding functional for each of the draws. This convenient feature of the estimation will later be exploited to analyze the implication of model uncertainty on optimal policy.

An optimization algorithm (Christopher Sims' csminwel) is used to obtain an initial estimate of the mode. We start the maximization algorithm from a number of random draws from the prior — before launching the MCMC chains — and check that the optimization routine always converges to the same value.[8] This is a useful diagnostic for the presence of identification problems, conditional on a given set of priors. Indeed, our experience is that this is a crucial in identifying local modes which may achieve almost identical values of the posterior with sometimes rather different configurations of coefficients. Of course, this procedure remains silent on the role of priors in achieving identification,

[7] 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.

[8] For the baseline model discussed in the paper over 30 optimization chains were launched from the prior draws, all converging to the same mode. Note, however, obtaining different modes with substantially different values of the posterior/likelihood need not reflect identification issues but rather the properties of the optimization routine in place. In this respect, we differ from Canova and Sala (2005) in that we view the convergence to multiple modes with similar fit as problematic, not the convergence to multiple modes per se.

which may be discerned by looking at univariate or 2-dimensional plots of the likelihood. We shall return to the role of priors in aiding identification later.

Having ensured a unique mode, the Hessian from the optimization routine is used as a proposal density, properly scaled to yield a target acceptance rate of 25%. For the MCMC results, five chains of 100,000 draws each were initialized by randomly selecting starting values (using an over dispersed normal density centered at the mode with a scaled-up Hessian as variance covariance matrix). For each chain, following a burn-in phase of 40,000 draws, convergence is monitored using CUMSUM plots and, for the overall chains, the potential scale reduction factors and confidence interval variants of Brooks and Gelman (1998).

The priors are described in the first three columns of Table 1, which display the type of distribution, mean and standard deviation. The same priors are used for all countries. We adopt fairly loose Gamma priors, with large tails, for the inverse Frisch elasticity of labor supply as well as the elasticity of substitution between domestic and foreign goods, considering the plethora of estimates emerging from macro and micro studies. Similarly, our prior for the intertemporal elasticity of substitution easily accommodates values of 1 or 0.5 as used in the international business cycle literature, as well as substantially larger estimates, that may result from the absence of capital and the consumption of durables in our model — see Rotemberg and Woodford (1999). Priors for the Calvo price parameters assume the presence of nominal rigidities centered at a compromise between traditionally large values obtained in macro studies and recent evidence of greater flexibility in prices in disaggregated data for the U.S. — Bils and Klenow (2004). For imported goods, it may be reasonable to assume a lower degree of stickiness. Nonetheless, estimated open economy models tend to produce fairly large deviations from the law of one price in the absence of cost push shocks in the imported goods sectors (Justiniano and Preston 2006). We follow Lubik and Schorfheide (2003) in specifying the prior for the parameters of the Taylor rule, except for output growth which is not considered in their analysis.

For the openness parameter, α, relatively tight priors are specified close to the shares of trade to GDP. Habit and indexation have been found to be crucial for fitting closed economy models which suggests considering possibly large values for the parameters governing these intrinsic mechanisms of persistence. The prior for habit is fairly flat while we a-priori push towards intrinsic persistence in inflation by choosing a beta prior centered at 0.7 for indexation. In section 8 we shall return to address the role of the priors in aiding identification of these parameters and the consequences for policy design. As for the exogenous stochastic disturbances (risk premium, technology and preference) it is assumed these are fairly persistent, reflected in a beta prior with a mean of 0.8 for the autoregressive coefficients. Regarding the AR coefficients for the foreign block, priors are centered on pre-sample individual AR regressions. Estimates obtained with an unrestricted, VAR were almost identical and do not alter any of our results. Finally, the priors for the standard deviations of the shocks are the same for foreign and domestic shocks, of the Inverse-Gamma 1 distribution, with infinite variance by fixing the degrees of freedom at 2 and choosing the scale parameter which characterizes this density in order to obtain a mean of 0.5.

5 Results

The following section details a number of properties of the estimated models. The baseline estimates are presented for each country and the model's ability to fit particular second order characteristics of the data discussed.

5.1 Estimates

Table 1 reports the estimation results for the baseline model for each country. For the most part estimates are somewhat similar across countries and fall within conventional bounds. The intertemporal elasticity of substitution is a little below unity taking values around 0.7. The inverse elasticity of labor supply, a parameter notoriously poorly identified in DSGE models, takes values a little above unity, although has fairly wide posterior probability bands. Optimal price setting in the production of home goods displays some variation across countries. At the median of our parameter estimates, firms re-optimize prices approximately every 1.5, 3 and 2 quarters respectively in Australia, Canada and New Zealand. These numbers are somewhat lower than typically found in closed economy studies based on U.S. data. Perhaps more surprising is the finding that prices in the imported goods sector are adjusted at roughly the same frequency as home goods prices, every two quarters.

The parameter describing the openness of the economy, α, takes plausible values that are consistent with the findings of Lubik and Schorfheide (2003). The elasticity of substitution between domestic and foreign goods is somewhat low, despite a prior that allows for far larger values, with median estimates between 0.6 and 0.76. These values have relevance for papers such as Obstfeld and Rogoff (2000) which proposes a model in which large values of the elasticity of substitution between domestic and foreign goods together with transaction costs help explain a number of prominent puzzles in international macroeconomics. In estimated open economy models inference on this parameter has tended to produce either small elasticities, particularly with complete markets or seemingly implausibly large values — see Rabanal and Tuesta (2005) and Adolfson, Laseen, Linde, and Villani (2005) respectively.

Regarding the role of intrinsic mechanisms of persistence, habit formation appears to play a less prominent role than in other studies, having a maximum value of 0.39 in Canada. In contrast, price indexation would seem, judging from the magnitude of the coefficients, to be more important as a source of endogenous persistence with values in the neighborhood of 0.55 for all countries. Hence all prices are adjusted each period even if firms do not have the chance to re-optimize by roughly 50 percent of the previous period's inflation in each sector of production. Since these mechanisms have been found key in taking closed economy models to the data we revisit inference on these parameters in the context of identification issues in DSGE models in section 7.

The policy parameters bear resemblances across countries as well. However, differences can be seen in the responses to the nominal exchange rate and output growth which are somewhat larger in Canada than in Australia and New Zealand. The response to the nominal exchange rate is consistent with the Lubik and Schorfheide (2003) study, which similarly finds that the Bank of Canada targeted nominal exchange rate variations in the conduct of monetary policy.

The estimates of the foreign block are remarkably similar across countries, as expected, considering U.S. data is used in all cases. Note that even though the foreign block is exogenous, in the sense that economic developments in each small country under consideration cannot feedback into the foreign block, it is not true that the foreign block is exogenous econometrically speaking. The cross-equation restrictions that result from uncovered interest parity tie the estimates of the foreign data generating process to domestic parameters. Differences in domestic parameter estimates across countries explain the small fluctuations in the coefficients governing the evolution of the foreign block. While, for simplicity, we have chosen independent autoregressions for the elements of the foreign block, estimates are largely unchanged by considering a vector autoregression.[9]

Finally, the exogenous disturbances in technology, preferences and the risk premium capture a significant amount of persistence in the data having autoregressive coefficients between 0.87 and 0.96 across all three countries. The estimated standard deviations are for the most part plausible, with the biggest differences across countries emerging for the estimated technology shock. This standard deviation is 2.4 for Australia in contrast to 1.49 and 0.38 in New Zealand and Canada respectively. As previously mentioned, we chose the same fairly uninformative priors for all standard deviations and countries to let the model reveal the sources of fluctuations in these economies.

5.2 Second order properties

To give further insight into the model estimates and their implications for fit, Table 2 presents a set of second order moments for the data and the corresponding statistics implied by the estimated

[9] In future work the foreign block will be estimated independently. This would be more in spirit with the small open economy assumption as foreign block parameter estimats should not be affected by variation in domestic series even though related by certain cross equation restrictions.

model. The (5, 95) percent probability bands for these estimates are also presented and account for the small sample in simulating the model.[10] Taking Australia first, the small open economy model matches the second order characteristics reasonably well. The standard deviation of inflation implied by the model is almost identical to the data, while those for interest rates and output are somewhat low and high respectively. Nonetheless, the data standard deviations fall comfortably within the 90 percent probability bands. The first order autocorrelations are also fit reasonably well with the exception of the change in the real exchange rate which has an estimated serial correlation close to zero. This reflects the well known and often found random walk hypothesis for the exchange rate and highlights the difficulty structural models have in matching the persistence and volatility of the real exchange rate using a tightly specified structural model — see Chari, Kehoe, and McGrattan (2002) and Justiniano and Preston (2006) for calibration and estimation based studies. We note, however, that the cyclical properties of the level real exchange rate, as implied by band-pass filtered data simulated from the model, accord rather well with similarly filtered data for all three countries.[11]

The Canadian model provides a less accurate characterization of the data than for Australian — at least judging from the fit of the model at the mode. The volatility of inflation is over predicted while output and interest rates are under predicted. Moreover, the data standard deviations for these variables fall outside the 90 percent probability bands. The real exchange rate is the best matched variable. The serial correlation properties are better matched, with the real exchange rate being an exception along with the first order correlation for output which falls on the boundary of the 90 percent probability band. Finally, for New Zealand similar remarks to Australia apply. The second order properties of output are better matched than in the case of Canada, and all second order properties bar the autocorrelation in the real exchange rate have broadly similar median estimates relative to the data. Accordingly, the $(5, 95)$ percent probability bands encompass the sample statistics for all estimates.

Overall, therefore, the same model does reasonably well for all three countries, with the exception of the serial correlation properties of the log difference in the real exchange rate, a feature shared by most structural and reduced form models.

[10] We note that these moments are computed at the mode obtained in the first step of the estimation. Repeating this exercise over the draws, to include also parameter uncertainty, would deliver in wider posterior bands. As such, we view this as a rather stringent comparison between model and data.

[11] A number of studies, such as Chari, Kehoe, and McGrattan (2002), have choesen to report this statistics, so it is included here for completeness. Note also, in our setup, deviations from interest parity captured by a risk premium shock which is close to a random walk account for most of the variations in the real exchange rate.

6 Monetary Policy Design and Uncertainty

Recent theoretical analyses have emphasized the importance of pricing to market assumptions for optimal exchange rate and monetary policy. Whether a country has producer currency pricing or local currency pricing can give rise to rather different policy recommendations, even when the sole objective of policy is to stabilize the domestic inflation rate. For instance, Devereux and Engel (2003) show in a two country model with local currency pricing that optimal monetary policy stipulates stabilization of the nominal exchange rate. Similarly, Monacelli (2003), in a model nested by the one estimated in this paper, shows that deviations from the law of one price leads to a trade-off in the stabilization of inflation and output in the absence of inefficient variations in markups. His analysis overturns the closed economy result that stabilizing the inflation rate serves to simultaneously stabilize the output gap and introduces an explicit motive to stabilize the exchange rate even when consumer prices are the solve objective of policy.

Despite these theoretical contributions there has been relatively little work on policy evaluation in empirical open economy models. In the small open economy literature, and of most relevance to the present study, Smets and Wouters (2002) consider the implications of imperfect pass through for optimal monetary policy, demonstrating that welfare maximizing policies introduce a motive to stabilize the exchange rate (see also the references therein). Lubik and Schorfheide (2003), rather than explore the question of optimal policy instead seek to identify in the small open economies considered here, as well as the United Kingdom, whether there is evidence that monetary authorities have responded to nominal exchange rate fluctuations. They find that only in the case Canada does there exist strong evidence supporting such responses, as also evidenced by our estimates.

The following sections build on these analyses by considering optimal policy in the estimated model of the previous section. Three exercises are pursued. First we look at the design of optimal monetary policies within the class of Taylor-type rule adopted in the empirical model. Initially, the policy rule coefficients are chosen to minimize a quadratic loss function assuming that estimated model parameters take their median values. Amongst other things, this elucidates whether the optimal policy requires nominal interest rates to be adjusted in response to nominal exchange rate fluctuations.

Second, and following Levin, Onatski, Williams, and Williams (2005), assuming the central bank adopts either the empirical or optimal policy rule we evaluate the welfare losses arising from having any particular parameter incorrectly specified in the model. Here "incorrectly specified" means that the parameter takes any value on the interval defined by the 90 percent posterior probability band implied by the MCMC estimation. This helps identify whether there are any components of model uncertainty that, at least when considered individually, are particularly relevant to policy design. In the present context, of specific interest is the impact of uncertainty on the open economy elements of the model in determining monetary policy.

Third, we determine the optimal policy rule that takes into account all parameter uncertainty implied by the estimated model. That is, we compute the policy rule that minimizes the expected loss, where expectations are also taken with respect to the posterior distribution of model parameters. This analysis is facilitated by pursuing a Bayesian approach to inference. It also allows taking into account the covariance terms across parameters when quantifying the dispersion around the estimated model parameters and permits addressing an old question of whether parameter uncertainty leads to more cautious policy prescriptions as suggested by the seminal analysis of Brainard (1967).

6.1 Optimal Policy Rules

The policy maker seeks to minimize the objective function

$$W_0 = E_0 \sum_{t=0}^{\infty} \beta^t L_t \tag{23}$$

where $0 < \beta < 1$ coincides with the household's discount factor and

$$L_t = {\pi_t}^2 + \lambda_y {y_t}^2 + \lambda_i {i_t}^2 \tag{24}$$

is the period loss at any date $t \geq 0$. The policy maker is therefore assumed to stabilize variation in consumer price inflation, output and the nominal interest rates, where the weights $\lambda_x,\ \lambda_i > 0$ determine the relative priority given to each of these objectives. The assumption of arbitrary weights $\lambda_x,\ \lambda_i$ and the assertion that consumer price inflation, output and nominal interest rate variation ought to be stabilized is questionable. Therefore, to gauge the robustness of our conclusions, we analyze the above loss function as the weights (λ_y, λ_i) are varied over a fine grid on the unit square. Hence, we consider over one hundred objective functions and our conclusions are largely unaffected by the precise choice of weights.[12]

To simplify further, we consider the limiting case of this objective when β goes to unity. This transforms the analysis of the loss function (24) into the analysis of the objective

$$\bar{W}_0(\theta) = var(\pi_t) + \lambda_y var(y_t) + \lambda_i var(i_t)$$

a weighted sum of variances and θ makes explicit the dependency of the variance calculation on model parameters. To focus on the effects of model uncertainty on policy design, attention is restricted to

[12] In future work the analysis will consider the model consistent measure of welfare.

optimal policies within a class of Taylor-type rules of the form

$$i_t = \rho_i i_{t-1} + \psi_\pi \pi_t + \psi_y y_t + \psi_{\Delta y} \Delta y_t + \psi_e \Delta e_t. \tag{25}$$

Thus, as in estimation, the policy maker is assumed to adjust nominal interest rates in response to contemporaneous values of inflation, output, output growth, the nominal exchange rate growth and lagged observations of the nominal interest rate.

Partition the estimated parameters for a given model as $\theta = \{\theta_p,\ \theta_s\}$ where $\theta_p = \left\{\rho_i,\ \psi_\pi,\ \psi_y,\ \psi_{\Delta y},\ \psi_e\right\}$ collects policy parameters and θ_s collects the remaining structural parameters and conformably partition the associated parameter space as $\Theta = \{\Theta_p,\ \Theta_s\}$.[13] Let $\bar{\theta}_s$ denote the estimated median value of the structural parameters. In our first policy experiment the optimal policy coefficients are chosen assuming the structural parameters are known and equal to $\bar{\theta}_s$. Thus the effects of parameter uncertainty are ignored and optimal policy is determined as

$$\theta_p^* = \arg \min_{\theta_p \in \Theta_p} \bar{W}_0 \left(\theta_p \mid \bar{\theta}_s\right)$$

where the minimization is subject to the constraint that policy is given by (25) and aggregate dynamics are as determined in section 2.[14] The final restriction placed on the policy design is that the coefficient on the lagged nominal interest rate must satisfy $0 \leq \rho_i \leq 1$. The study of super-inertial interest rate rules is left for future research.

Table 3 provides results for this optimal policy problem for two different objective functions, which differ according to the weight assigned to the stabilization of output. Consider the results for Australia when the median of our estimates, $\bar{\theta}_s$, is used and output is assigned a weight of $\lambda_y = 0.25$ in the objective function. Optimal policies are highly inertial, characterized by a unit coefficient on the lagged interest rate. Hence, the optimal policy is one that prescribes the stance of policy in terms of the evolution of the first difference of nominal interest rates, rather than the level. The optimal response to inflation is large relative to typical estimates of this parameter — compare Lubik and Schorfheide (2003) and the estimated policy reaction functions in section 5. In contrast, the response to output and the nominal exchange rate is zero to the second decimal place. The latter is particularly surprising: despite the open economy dimension of the model and the existence of deviations from the law of one price, optimal policy does not require a direct response to exchange rate fluctuations to ensure that its objectives of stable output and inflation are met. This is at odds with the theoretical literature which underscores models characterized by local currency pricing should give cause to respond to exchange rate fluctuations as an alternative

[13] Note that the MCMC posterior simulator produces joint and marginal posterior densities which validate this approach.

[14] We use the csminwel minimization algorithm developed by Chris Sims.

channel by which to stabilize domestic prices. Furthermore, it is also suggests the findings of Lubik and Schorfheide (2003) of little evidence that the Reserve Bank of Australia has responded to exchange rate fluctuations, is part of an optimal policy framework, at least in this restricted family of Taylor-type rules. Finally, the response to output growth is larger taking a value of 0.61.

The second column gives results for an objective function that places greater weight on output stabilization. Similar comments apply. Note, however, that the response to output growth is some three times as large, and perhaps surprisingly, the response to inflation is larger than in the case where $\lambda_y = 0.25$.

Turning to the results for Canada and New Zealand, the broad theme of the results for Australia carry over. In the case of Canada, however, the response to inflation in the optimal policy rule is far less aggressive. Indeed, under the objective with $\lambda_y = 0.25$ response parameters obtained are in line with the estimated policy function. For New Zealand the optimal policy at the median estimates stipulate a strong response to inflation and output growth, little response to the level of output and the nominal exchange rate and unit coefficient on the lagged interest rate. These conclusions are valid regardless of the weight placed on output stabilization. As an example, Figure 1 pots the optimal exchange rate coefficient as the weights (λ_y, λ_i) are varied on the unit square. The coefficients are tiny for all loss functions in the case of Australia and bounded by 0.02 and 0.04 in the case of Canada and New Zealand.[15]

Further insight into the stabilizing properties of the optimal policy rules can be gained by looking at the standard deviations for inflation implied by the optimal policies. In Australia the standard deviation of inflation is 0.1 implying that the optimal policy approximates inflation targeting, consistent with remarks made above. In the case of Canada and New Zealand the standard deviations are somewhat larger when $\lambda_y = 0.25$ though remain small relative to the historical variation observed in the data. To shed light on why strict inflation targeting might be optimal two points are worth making. First, in the closed economy version of this model (essentially determined by setting $\alpha = 0$ so that foreign goods are a negligible part of the domestic consumption bundle), inflation targeting is in fact optimal if the central bank is concerned only with stabilizing output and inflation variation. Because of the absence of a cost push shock in the Phillips curve complete stabilization of inflation and output gap is possible.

Second, as shown by Monacelli (2003), introducing local currency pricing as done in the present paper, analogously to a cost-push shock, induces a trade-off in the stabilization objectives between inflation and the output gap. Variations in the law of one price gap shifts the achievable trade-off

[15] Note that the coefficient magnitudes themselves are not sufficient to infer the relevance of the exchange rate — one also must consider the magnitude of exchange rate variations. Although not reported, we confirm that removing a response to the exchange rate from the policy rule implies almost identical stabilization policy.

between inflation and output over time and importantly prohibits the complete stabilization of both these variables. What is perhaps interesting about the results of Table 3 is the finding that despite the presence of this trade-off, optimal policy stabilizes inflation to a large degree — most notably for the case of Australia — even when output and inflation stabilization are given equal weight in the loss function.

As mentioned, for Canada and New Zealand, inflation is largely stabilized when the weight on output is 0.25, but increasing λ_y leads to larger inflation volatility. The reduction in output variance across weights is most significant for Canada, while in New Zealand, wide variations in the response coefficient to output growth only bring about a small decline in output volatility. While strict inflation targeting is not prescribed here as was the case for Australia across weights, standard deviations for inflation of 0.47 and 1.08 for New Zealand and Canada when λ_y equals one are certainly consistent with the notion of flexible inflation targeting — see Svensson (1997, 1999).

Overall, we interpret these results from this open economy model as suggesting that trade-offs caused by deviations from the law of one price might not be as important for describing optimal policy as suggested by the theoretical literature. Further evidence on this conjecture is adduced in section 7. Later we will also revisit whether the absence of an optimal response to the exchange rate is fundamentally related to the inability to predict changes in this variable which is largely driven by a risk premium shock — a manifestation of the exchange rate disconnect puzzle discussed by Obstfeld and Rogoff (2000) among others. Nonetheless, we acknowledge that given the somewhat arbitrary choice of weights in the policy maker's loss function, computing the fully optimal policy for the model consistent measure of welfare would be desirable in future work.

These findings differ from Smets and Wouters (2002) which presents evidence in an empirical small open economy model with local currency pricing that optimal policy does respond to exchange rate fluctuations. While the precise details of the underlying models differ, they do have the same basic elements. The biggest source of discrepancy in the two studies lies in the estimation methodology. Smets and Wouters estimate a small subset of model parameters by matching impulse response functions. Our conjecture is that confronting the model with data on a greater number of dimensions as done in the likelihood-based estimation procedure of this paper engenders considerably different second order moments which in turn delivers different optimal policy prescriptions. At the very least, this presents a significant challenge for policy evaluation in small open economy models.

6.2 Individual Parameter Uncertainty and Welfare

The previous section considered optimal policy design assuming the policy maker knows model parameters with certainty. We now turn to an exercise that seeks to evaluate the robustness of these policy prescriptions to specific sources of uncertainty regarding individual parameters. Rather than use the posterior distribution to capture the uncertainty inherent in any given model parameter, we follow Levin, Onatski, Williams, and Williams (2005) and ask what are the welfare implications of getting a particular parameter wrong. We assume that the policy maker adopts either the estimated policy rule or the optimal policy rule obtained in section 6.1 and evaluates the magnitude of the welfare change induced by variations of a given parameter over some interval — which in this case we take to be the posterior uncertainty bands from the estimation. Hence the thought experiment is one that assumes the policy maker knows with certainty the values of the remaining parameters. However, the approach has the advantage of clearly identifying which parameters are the parameters for which precise inference is crucial in order to avoid possibly large losses when designing monetary policy. Importantly, this exercise sheds light on whether parameters specific to the open economy dimension of the model are particularly relevant in this regard.

Figure 2 plots the loss function as a given parameter is varied for the Australian data, with $\lambda = 0.25$. All remaining parameters are held at their median estimated value. Two measures of loss are plotted. The first is the one that obtains under the empirical policy rule as determined in section 5. The second is the optimal policy rule obtained in the previous section. The more horizontal these lines, the smaller are the losses associated with deviations from the estimated value of the parameter, which is shown by a vertical line. Finally note that the ordinate axis is determined by the 99 percent probability band for the parameter implied by model MCMC estimation. While this gives a plausible bound on the degree of parameter uncertainty in the context of the model, it likely understates parameter variation that may obtain in reality due to model misspecification.

Results are presented for a subset of the domestic structural parameters: the intertemporal elasticity of substitution, the elasticity of labor supply, the degree of habit formation and the degree of indexation of prices and the open economy parameters: the elasticity of substitution between home and foreign goods, the degree of openness and the Calvo price parameter in imported goods. The remaining results are available on request. It is immediate that parameter variation can have large effect on welfare under both the empirical and optimal policy rules. While the intertemporal elasticity of substitution gives rise to welfare variations of the order of 30 percent, errors in the estimation of the elasticity of labor supply and degree of habit formation give rise to more substantial losses. In the case of the former, losses are some 3 to 4 times larger if the elasticity takes less than a third its estimated value. Note, however, that the nature of the loss is asymmetric — overestimating this elasticity does not result in large variations in losses. The intuition is that as the labor supply elasticity increases (so the inverse declines) a given variance of the technology shock translates into more volatile marginal costs and therefore greater variability in inflation. Similarly, the degree of habit formation has considerable implications for welfare as it increases over the estimated 90 percent probability band. Noteworthy, though not shown, is that as habit approaches values nearing unity, the losses are considerably higher under the estimated and optimal policy rules. Notice that, the degree of indexation matters little for the estimated welfare loss. As discussed later, this is consistent with the findings in section 8 that the degree of indexation is not well identified by the data.

The Calvo parameter governing the frequency of price setting in home goods is revealed to matter greatly for welfare. Under both the estimated policy rules and the optimal policy rule higher values of this parameter engender significant welfare loss, some 3 to 4 times that obtained under the estimated value. Again, it is noteworthy that these losses arise even for moderate values for this parameter. The intuition for the relative importance of having a precise estimate of the Calvo price parameter is straightforward. The greater is the magnitude of this parameter the less frequently do firms have the opportunity to reset their prices. This contributes to greater price dispersion and more persistent inflation through strategic complementarity — hence confounding the central bank's stabilization objectives. Interestingly, the three open economy parameters seem not to have too great an impact on welfare. Indeed, the Calvo parameter governing price setting in the imported goods sector appears to have no effect on the estimated loss, supporting further our claim that at least in the context of this estimated model, the degree of deviation from the law of one price does not play a prominent role in optimal policy design. Meanwhile only for smaller values of the degree of openness and the elasticity of substitution between goods does welfare appear to deteriorate.

Similar broad conclusions apply from repeating the analysis for Canada and New Zealand and for this reason we report results only for the former in Figure 3. Once again, of particular importance are the Calvo parameter governing the frequency of price setting in the home goods sector, the intertemporal elasticity of substitution, the elasticity of labor supply and the degree of habit formation. In large part the relevance of these parameters arises from their role in parameterizing the persistence of output and inflation. Note once again that the policy losses are largely invariant to the frequency of price adjustment in the import sector. What is perhaps most surprising is that welfare exhibits relatively little sensitivity to the parameters relating to the open economy dimensions of the model.

One might conjecture that these findings on the open economy parameters reflect the difficulty faced by this class of small open economy DSGE model in capturing the international transmission mechanism of foreign disturbances — see Justiniano and Preston (2006) for a detailed discussion. And therefore that a direct implication of foreign shocks mattering little for the evolution of domestic variables is that the parameters regulating the interaction of the domestic and foreign block play a muted role in determining the properties of domestic inflation, output and interest rates and hence matter little for the design of policy.

To address this criticism, section 7 estimates a version of the model in which foreign disturbances explain a significant fraction of the variance of domestic series. We preview the results of that section by noticing that while the elasticity of substitution between domestic and foreign goods and the degree of openness appear to become more prominent sources of variation in losses, it remains true that the degree of loss is significantly smaller than those that would result from having, say, the incorrect Calvo pricing parameter on domestic goods. Furthermore, the Calvo pricing parameter in imported goods still remains largely irrelevant even in this set-up, providing indirect evidence that local currency pricing may not be too important for the characterization of macroeconomic data in these small open economies.

6.3 Optimal Policy under Parameter Uncertainty

As a final policy exercise, we determine the optimal policy that takes into account the effects of uncertainty regarding θ_s on the choice of optimal policy coefficients. The optimal policy problem is:

$$\hat{\theta}_p^* = \arg \min_{\theta_p \in \Theta_p} \int_{\Theta_s} \bar{W}_0 \left(\theta_p \mid \bar{\theta}_s\right) p(\theta_s | \, Y_t) d\theta_s$$

where minimization is subject to the same constraints as before and where $p(\theta_s | \, Y_t)$ is the estimated posterior distribution of the structural parameters. Thus in determining the optimal policy coefficients the policy maker integrates out the uncertainty surrounding structural parameters by making use of the posterior distribution for these parameters obtained from model estimation.[16] In contrast to section 5.1 this problem accounts for the covariance across all estimated model parameters.

The results of this exercise based on 5,000 draws are reported in columns three and four of Table 3, for $\lambda_y = 0.25$ and $\lambda_y = 1$ respectively. In the case of Australia, the second column of the panel reveals that once parameter uncertainty is taken account of there is some evidence for attenuated policy responses. While optimal policy remains inertial, the inflation response coefficient falls by 0.60 to 4.65 and the output growth response coefficient falls 0.03 to 0.58 when λ_y is 0.25. Similar insights emerge from assigning equal weights to all terms in the loss function. Hence Brainard's seminal insight appears to hold true in this estimated small open economy model. Note, nonetheless, that optimal policy at the median coefficients and the fully optimal policy taking into account all parameter uncertainty give roughly the same loss. Indeed, the variances of inflation, output and

[16] It is important to note that this second approach to policy design, which entails discarding the draws of the policy parameters and retaining those of the non-policy block to represent $p(\theta_s | \, Y_t)$, is consistent with our estimation of the DSGE models. This is because Bayesian MCMC methods yield draws that correspond to the marginal densities of the model parameters. What we would have not been able to do, given our approach to inference, is to make any statements that required the conditional densities, say $p(\theta_s | \, Y_t, \theta_p)$, since we do not have samples from these ordinates in the estimation.

interest rates are identical to those obtained under the optimal policy at the median value of the estimated coefficients. This provides some initial indication that the effects of coefficient uncertainty may be rather small for policy design.

For Canada, there are differing implications of uncertainty on policy design depending on the weight placed on output in the objective function. In the case of a low weight, so that $\lambda_y = 0.25$, attenuation obtains in the inflation and output growth response coefficients, while those on the level of output and the nominal exchange rate rise slightly. In contrast, when $\lambda_y = 1$ this inference is reversed: the optimal policy responds more strongly to inflation, output and output growth. Again, worth noting is that the variances of each variable appearing in the objective function change little when parameter uncertainty is accounted for. Hence, depending on the precise policy objectives and the estimated correlations between model parameters, uncertainty can lead to slightly attenuated or more aggressive policy responses but overall seems to matter little for the characterization of optimal policy.

New Zealand presents a final pattern of results. In the presence of parameter uncertainty the response to inflation is attenuated, while the response to output growth is somewhat more aggressive, across both weight combinations. Taking all results together indicates that model uncertainty fails to have clear implications for the design of simple optimal monetary rules. Depending on the country at hand, more or less aggressive policy might obtain, though differences are usually small both in terms of policy coefficients and resulting welfare losses. This is not surprising. As Chow (1975) notes, in a multivariate setting the conclusions of Brainard (1967) for attenuation in policy need not obtain, depending on the covariance properties of the uncertain model parameters. Similarly, the robust control literature on optimal policy design, which is equivalent to Bayesian inference for a particular prior, demonstrates that model uncertainty can lead to more aggressive policy settings — see Giannoni (2002). [Compare to Onatski and Williams (2003) and Rudebusch (2001)]. It follows that resolution of the implications of uncertainty for policy design is largely an empirical matter. What is clear from the present analysis is that parameter uncertainty matters little for the optimal policy coefficients and the resulting second order properties of the macroeconomic variables in the objective of policy makers.

7 Unobserved Foreign Block

This section turns to the first of two robustness exercises. Rather than modeling the foreign block as been driven by autoregressive processes in observed U.S. inflation, output and nominal interest rates, we instead treat this component of the model as unobserved following the analysis of Lubik and Schorfheide (2003) and Justiniano and Preston (2004). Two possible criticisms motivate this alternative specification. First, while for Canada the use of U.S. data as proxy for the foreign block may be plausible, it seems less appropriate in the case of Australia and New Zealand where construction of trade-weighted indices of the relevant foreign variables (including, for instance, Japan) seems more appropriate. Furthermore, it permits the model to be agnostic about the precise nature of the foreign disturbances and allows evaluating the sensitivity of results to the choice of observables used in estimation. Second, and related to this last point, the estimated model of section 2 is prone to some of the difficulties detailed in Justiniano and Preston (2006). In particular, variance decompositions reveal a limited role for foreign sourced disturbances in the evolution of domestic variables. It is plausible that it is this feature of the model which engenders a negligible role for stabilizing exchange rate fluctuations in the design of optimal policy rules.

Table 5 presents the estimates when the foreign block is treated as unobserved. We continue to assume that foreign output, inflation and interest rate shocks follow first order autoregressive processes and we drop the domestic preference shock and the risk premium shock to ensure identification of the exogenous disturbances. The prior used in estimation coincides with that employed in section 4 with the following exception: the prior on the foreign block autoregressive coefficients in the case of Canada were tightened around the corresponding estimates of the observable model to ensure convergence to a unique mode in the estimation.[17]

For all three countries, coefficient estimates exhibit similar patterns of variation across observed and unobserved foreign block models. Assuming a latent foreign block produces higher estimates of the intertemporal elasticity of substitution and conversely lower values for the inverse elasticity of labor supply. The Calvo price setting parameters typically take lower values, as do the degree of habit formation and the degree of price indexation. The measure of openness is identified to be slightly higher in all models while the elasticity of substitution between domestic and foreign goods is similar to the earlier estimates. As discussed in detail in Justiniano and Preston (2004) these parameter shifts largely take place to exploit the flexibility permitted by having an unobserved foreign block. Because the model is no longer constrained to fit the US time series it is free to exploit the variation inherent in these shocks to fit the domestic observable series. Not surprisingly, these foreign disturbances are found to explain a much greater fraction of the variation in domestic observables than in the model with an observable foreign block. The variance decompositions are presented in Table 6 without further comment.

Given these estimates, we revisit two of three policy exercises conducted earlier. First, the optimal policy within the same class of nominal interest rate rules is re-computed taking as given that the median estimates of non-policy model parameters are known with certainty. Second, we

[17] This is not altogether surprising given that there are five shocks, and the exogenous foreign block affords considerable flexibility in fitting the data.

consider the same parameter perturbations reported in Section 5.2. These two exercises are of particular interest in discerning both whether policy remains unresponsive to nominal exchange rate fluctuations despite having a model in which foreign disturbances are more important and also whether misspecification in key parameters governing the international transmission of disturbances might give rise to greater losses in the context of such a model.

The optimal policy results are reported in Table 7. Casual inspection immediately reveals that optimal policy coefficients on nominal exchange rates to be zero across both countries and policy objective functions in all but one case. The sole exception is for Australia when the weight given to output stabilization is equal to unity. However, in this case the inflation response coefficient is equal to 99.17 and therefore represents a dominant source of variation in nominal interest rates. More importantly, it is clear from the variances of inflation, output and nominal interest rates under the optimal policy that there is little difference between the policies obtained when $\lambda_y = 0.25$ and $\lambda_y = 1$. We therefore conclude that the finding that optimal policies within this class of Taylor rule do not respond to exchange rate variations is a robust one. Even when the economy has significant variation driven by foreign sourced disturbances, it appears that local currency pricing and the associated departure from the law of one price does not induce much incentive to respond to nominal exchange rate fluctuations in order to bring about the stated policy objectives.

Finally, Figure 5 gives the analogous plots to Figure 3 for the case of the observed foreign block in the case of Canada only. The results for Australia and New Zealand are omitted as they are qualitatively and quantitatively similar to earlier results. Two key insights emerge from reconsidering the welfare losses from specific variations in individual parameters given that the central bank makes use of either the optimal or empirical policy rule. The first is that the elasticity of substitution between the domestic and foreign block and the degree of openness now gives rise to slightly larger welfare losses. However, these losses are small relative to those incurred from having poor estimates of the Calvo price parameter for domestic goods and the elasticity labor supply. The corresponding losses for Australia and New Zealand are smaller still.

The second observation regards the plot for the Calvo pricing parameter on imported goods. The welfare obtained under either the optimal or empirical policy rule is almost invariant to the degree of price stickiness in this sector across all three countries. This suggests once more that from a policy perspective the degree of deviations from the law of one price lead to very small variations in loss and, furthermore, that the model approximates one with producer currency pricing, in which case there is no independent reason to stabilize the nominal exchange rate. Note, however, that while it might be tempting to conclude this implies that local currency pricing is of little import to the fit of this model our results are qualified by an important caveat. In line with much of the recent empirical literature on open economy DSGE models we have abstracted from terms of trade data, which, if included as an observable variable in estimation, imposes additional cross-equation restrictions that require large deviations from the law of one price and which may therefore play a prominent role in policy design. Indeed, absent local currency pricing, this model predicts the terms of trade and real exchange rate to be proportional in a log linear approximation — a prediction clearly rejected by the data. Hence the choice of observables has non-trivial consequences for inference.

8 Mechanisms of Persistence and Priors

One surprising feature of the estimation results from section 4 is the low degree of endogenous sources of persistence in all three all countries. In fact, compared to many closed economy studies for a variety of countries, the structural estimates suggest domestic home goods prices are adjusted relatively frequently and habit formation and price indexation take values that are significantly smaller that those associated, say, with similar models applied to U.S. data. Indeed, our choice of priors for these coefficients was motivated by the large degree of habit and indexation usually reported usually in DSGE models estimated with U.S. or Euro Area data. See for instance Christiano, Eichenbaum, and Evans (2005), Smets and Wouters (2003) and Jullard, Karam, Laxton, and Pesenti (2005).

This section explores an alternative prior which is more agnostic about these sources of endogenous persistence and permits evaluating the relative importance of indexation and habit formation in describing dynamics. As such, this provides and open economy analogue to the study by Rabanal and Rubio-Ramirez (2002) which also analyzes the role of wage rigidity for the fit of a closed economy model.[18]

To this end, we consider a prior with a uniform distribution on the (0,1) interval for coefficients h and δ. In specifying an alternative prior we also modify prior beliefs concerning the intertemporal elasticities of substitution and labor supply, considering the important role of these coefficients for policy design, as evidenced in section 6. Table 8 reports the resulting estimates. Comparison with Table 1 provides several interesting insights. Under the alternative prior, the Calvo pricing parameters typically rise, while the degree of price indexation falls dramatically (taking a value close to zero in the case of Australia) as does the standard deviation of the technology shock. Moreover, the inverse Frisch elasticity of labor supply falls somewhat. Note also that the degree of habit formation remains roughly unchanged highlight that the data is quite informative about this feature the data across countries.

[18] In an earlier version of this paper we had explored this issue throught posterior model odds. Here instead we analyze the sensitivity of these comparisons to the choice of priors and frame the disccussion in the context of identification issues in DSGE models

What is the intuition for the observed parameter changes? As the degree of indexation declines inflation tends to be less persistent. To compensate, the Calvo pricing parameters both rise, leading to decreases in the frequency of price changes in the domestic and imported goods sectors. This in turn, combined with strategic complementarity in price setting, leads to greater persistence in inflation. At the same time, a higher Frisch elasticity can also be shown to increase persistence. For a given standard deviation of technology shocks this would raise the variance of marginal costs and therefore inflation. Hence, a lower technology standard deviation obtains.

Given that this more agnostic prior regarding the endogenous sources of persistence suggests price indexation matters little for the characterization of the data an important question is whether this matters for our conclusions on policy design. Table 9 reports the optimal policy coefficients assuming that policy makers know the median coefficients estimates with certainty. Across countries, the inflation response coefficients decline relative to the result for the baseline prior, while the response coefficients on output growth tend to rise somewhat. Furthermore, optimal policies induce a higher standard deviation under the alternative prior than do policies under the benchmark prior. This suggests that the decline in indexation engenders a less favorable inflation-output trade-off.

Most importantly, optimal policies continue to stipulate a negligible response to nominal exchange changes. Only for Canada are the policy coefficients non-zero at the second decimal point, providing some support for the evidence adduced by Lubik and Schorfheide (2003) that the Bank of Canada has actively responded to the nominal in exchange rate over the past two decades and that such responses are part of an optimal policy framework. However, scrutiny of second order properties implied by policy when nominal exchange rate variations are removed (not reported) reveals them to be virtually identical to those reported in Table 9.

To summarize, these results suggest that considering alternative priors characterized by a more agnostic stance on the sources of endogenous persistence arising through price indexation and habit formation give quite similar conclusions as our benchmark analysis. While suggesting that indexation is not too important in characterizing aggregate dynamics in the estimated models, optimal policies have the same broad qualitative properties. Most importantly, they once more reveal that optimal policy rules within the class of generalized Taylor rules considered in this paper do not respond to nominal exchange rate variations. This despite the presence of local currency pricing. That this conclusion differs markedly from the theoretical literature on monetary policy design in an open economy setting.

9 Conclusions

This paper analyzes optimal policy design in an estimated small open economy for Australia, Canada and New Zealand. Motivated by the theoretical literature on local currency pricing a central question is whether, in a class of generalized Taylor rules, optimal policy responds on nominal exchange rate variations. The role of various sources of model uncertainty are also evaluated.

Assuming the policy maker knows the parameters of the structural model with certainty, the analysis finds that optimal policy is highly inertial, having a unit coefficient on past interest rates, and responds strongly to inflation and output growth. However, optimal policy dictates a negligible response to nominal exchange rate changes. This finding, and the fact that stabilization policy approximates inflation targeting, particularly in the case of Australia, stands in contrast to the theoretical literature on optimal policy with local currency pricing and the empirical findings of Smets and Wouters (2002) which suggest exchange rate stabilization is an important part of policy aimed at stabilizing domestic consumer prices. Moreover, the existence of local currency pricing introduces a trade-off in the stabilization of output and inflation. Our results suggest this trade-off is small for Australia, though somewhat more prominent for Canada and New Zealand. An implication may be that local currency pricing is not too important to the characterization of these macroeconomic data.

The effects of model uncertainty for optimal policy is assessed in two distinct exercises. First, we consider the performance in terms of welfare losses of both the estimated policy rule and the optimal policy rule derived assuming parameters are known with certainty to specific parameter perturbations. This reveals the Calvo pricing parameter in domestic goods production, the elasticity of labor supply and the degree of habit formation to be particularly important — if these parameters take values that are in the neighborhood of the median estimates from estimation significant losses can arise. Perhaps surprisingly, variations in the open economy parameters — i.e. the degree of openness, the elasticity of substitution between domestic and foreign goods and the Calvo parameter on imported goods — engender small losses in comparison.

Second, using the posterior distribution of estimated parameters, we determine the policies that minimize the expected welfare loss assuming that the estimated parameters are not known with uncertainty. The policies display the same broad characteristics as the policies that result assuming the structural parameters are known with certainty. However, depending on the country, accounting for uncertainty may lead to more or less aggressive policy responses to the variables appearing in the policy rule.

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Table 1: Prior Densities and Posterior Estimates

Coefficients		Prior Density 1/	Prior Mean	Prior Std	Posterior AUSTRALIA 2/ Median	Std	[5,95] Prob		Posterior CANADA 2/ Median	Std	[5,95] Prob		Posterior NEW ZEALAND 2/ Median	Std	[5,95] Prob	
Intertemporal ES	σ	G	1.2	0.4	0.624	0.201	[0.37	1.01]	0.716	0.244	[0.42	1.23]	0.597	0.195	[0.35	0.98]
Inverse Frisch	φ	G	1.5	0.75	1.783	0.804	[0.81	3.44]	0.956	0.553	[0.36	2.09]	1.545	0.72	[0.66	3]
Calvo domestic prices	θ_H	B	0.5	0.1	0.352	0.063	[0.26	0.46]	0.736	0.114	[0.54	0.89]	0.502	0.079	[0.38	0.64]
Calvo import prices	θ_F	B	0.5	0.1	0.438	0.084	[0.31	0.59]	0.602	0.072	[0.48	0.72]	0.533	0.101	[0.38	0.71]
Openess	α	B	0.25	0.05	0.182	0.038	[0.13	0.25]	0.199	0.045	[0.13	0.28]	0.14	0.031	[0.1	0.2]
Elasticity H-F goods	η	G	1.5	0.75	0.665	0.136	[0.53	0.96]	0.79	0.184	[0.6	1.15]	0.775	0.171	[0.59	1.12]
Habit	h	B	0.5	0.25	0.195	0.064	[0.1	0.31]	0.454	0.115	[0.28	0.66]	0.093	0.058	[0.02	0.21]
Indexation	δ	B	0.7	0.1	0.557	0.116	[0.37	0.75]	0.553	0.116	[0.37	0.75]	0.616	0.113	[0.42	0.8]
Taylor rule, smoothing	ψ_i	B	0.5	0.25	0.716	0.054	[0.61	0.79]	0.803	0.061	[0.69	0.88]	0.76	0.055	[0.66	0.82]
Taylor rule, inflation	ψ_π	G	1.5	0.3	2.131	0.185	[1.86	2.47]	2.009	0.249	[1.6	2.42]	2.213	0.22	[1.89	2.61]
Taylor rule, output	ψ_y	G	0.25	0.13	0.04	0.023	[0.02	0.09]	0.077	0.048	[0.03	0.18]	0.039	0.021	[0.02	0.08]
Taylor rule, exchange rate	ψ_e	G	0.25	0.13	0.119	0.028	[0.08	0.17]	0.276	0.115	[0.15	0.53]	0.115	0.031	[0.07	0.17]
Taylor rule, output growth	$\psi_{\Delta y}$	G	0.25	0.13	0.282	0.123	[0.11	0.52]	0.653	0.198	[0.35	1]	0.402	0.123	[0.22	0.63]

Table 1: Prior Densities and Posterior Estimates

Coefficients		Prior Density 1/	Prior Mean	Prior Std	Posterior AUSTRALIA 2/ Median	Std	[5,95] Prob		Posterior CANADA 2/ Median	Std	[5,95] Prob		Posterior NEW ZEALAND 2/ Median	Std	[5,95] Prob	
Technology	ρ_a	B	0.8	0.1	0.934	0.033	[0.87	0.97]	0.811	0.156	[0.46	0.93]	0.875	0.058	[0.76	0.95]
Preferences	ρ_g	B	0.8	0.1	0.955	0.017	[0.92	0.98]	0.94	0.028	[0.88	0.97]	0.949	0.019	[0.92	0.98]
Risk premium	ρ_{rp}	B	0.8	0.1	0.966	0.016	[0.94	0.99]	0.949	0.025	[0.9	0.98]	0.967	0.015	[0.94	0.99]
Foreign Inflation	ρ_{π^*}	N	0.64	0.15	0.45	0.076	[0.32	0.57]	0.46	0.072	[0.34	0.58]	0.503	0.081	[0.37	0.64]
Foreign Output	ρ_{y^*}	N	0.85	0.1	0.938	0.027	[0.89	0.98]	0.894	0.028	[0.85	0.94]	0.928	0.029	[0.88	0.97]
Foreign Interest Rates	ρ_{i^*}	N	0.91	0.05	0.935	0.017	[0.9	0.96]	0.929	0.017	[0.9	0.96]	0.93	0.019	[0.9	0.96]
sd foreign inflation	sd_{π^*}	I	0.5	inf	0.32	0.024	[0.28	0.36]	0.331	0.026	[0.29	0.38]	0.307	0.026	[0.27	0.36]
sd foreign output	sd_{y^*}	I	0.5	inf	0.501	0.039	[0.45	0.57]	0.55	0.042	[0.49	0.63]	0.499	0.042	[0.44	0.58]
sd foreign interest rates	sd_{i^*}	I	0.5	inf	0.141	0.011	[0.13	0.16]	0.146	0.012	[0.13	0.17]	0.132	0.012	[0.12	0.15]
sd technology	sd_a	I	0.5	inf	2.479	0.73	[1.56	3.89]	0.325	0.17	[0.2	0.73]	1.654	0.585	[0.92	2.81]
sd taylor rule	sd_{mp}	I	0.5	inf	0.346	0.049	[0.28	0.44]	0.271	0.042	[0.22	0.35]	0.269	0.052	[0.22	0.37]
sd preferences	sd_g	I	0.5	inf	0.254	0.066	[0.18	0.38]	0.179	0.036	[0.13	0.25]	0.3	0.074	[0.21	0.45]
sd risk premium	sd_{rp}	I	0.5	inf	0.43	0.086	[0.31	0.59]	0.245	0.049	[0.18	0.34]	0.313	0.068	[0.22	0.45]
Marginal Likelihood					-1013.7214				-848.8191				-791.1038			

Notes:

1/ Distributions, N Normal, B Beta, G Gamma, I Inverse-Gamma 1. Calibrated β=0.99 and χ=0.01.

2/ Corresponds to median and posterior percentiles from 5 MCMC chains of 100,000 draws each, in which 40,000 draws were used as an initial burn-in phase. Convergence diagnostics were asssesed using trace plots and the potential scale reduction factors for the variance and 95% posterior intervals.

Table 2: Data and DSGE model implied standard deviations and first order autocorrelations

AUSTRALIA

	Data Standard Deviation	Model Standard Deviation	[5%,95%]
Inflation	3.03	2.77	[2.32 , 3.33]
Real Exchange Rate (first differenc	5.627	5.961	[5.26 , 6.738]
Interest Rate	4.48	2.84	[1.83 , 4.71]
Output	2.06	1.85	[1.25 , 2.83]

	Data Autocorrelations	Model Autocorrelations	[5%,95%]
Inflation	0.67	0.46	[0.27 , 0.64]
Real Exchange Rate (BP 2-32)	0.84	0.68	[0.55 , 0.79]
Real Exchange Rate (first differenc	0.2007	0.00	[-0.17 0.16]
Interest Rate	0.97	0.91	[0.79 , 0.99]
Output	0.94	0.91	[0.79 , 0.96]

CANADA

	Data Standard Deviation	Model Standard Deviation	[5%,95%]
Inflation	1.798	2.348	[1.86 , 2.92]
Real Exchange Rate (first differenc	2.46	2.771	[2.41 , 3.125]
Interest Rate	3.092	2.365	[1.57 , 3.611]
Output	3.637	2.335	[1.6 , 3.295]

	Data Autocorrelations	Model Autocorrelations	[5%,95%]
Inflation	0.745	0.735	[0.62 0.82]
Real Exchange Rate (BP 2-32)	0.731	0.726	[0.64 0.80]
Real Exchange Rate (first differenc	0.223	0.034	[-0.13 0.21]
Interest Rate	0.95	0.899	[0.80 0.96]
Output	0.968	0.913	[0.84 0.96]

NEW ZEALAND

	Data Standard Deviation	Model Standard Deviation	[5%,95%]
Inflation	2.266	2.672	[2.22 , 3.229]
Real Exchange Rate (first differenc	4.378	4.805	[4.15 , 5.465]
Interest Rate	2.952	2.458	[1.54 , 4.119]
Output	2.818	2.526	[1.7 , 3.745]

	Data Autocorrelations	Model Autocorrelations	[5%,95%]
Inflation	0.432	0.505	[0.32 0.659]
Real Exchange Rate (BP 2-32)	0.764	0.689	[0.53 0.792]
Real Exchange Rate (first differenc	0.45	-0.007	[-0.22 0.18]
Interest Rate	0.921	0.913	[0.79 0.96]
Output	0.882	0.857	[0.72 0.93]

Model standard deviations and first order autocorrelations are computed by generating 1000 replications of length equal to the sample size for each country, at the mode of the parameter estimates, and averaging the resulting moments. For the real exchange rate, moments for the first differences and filtered series are presented. In the latter case, the data and model simulated series are band-pass filtered with cut-off frequencies 2 and 32 (quarters).

Table 3: Optimal Policy and Uncertainty

	MEDIAN OF DRAWS		OVER DRAWS	
	Weights (Inflation,Interest Rates,Output)		Weights (Inflation,Interest Rates,Output)	
Coefficients	**1,1,1**	**1,1,0.25**	**1,1,1**	**1,1,0.25**
	Panel A: Australia			
Interest Rate	1.00	1.00	1.00	1.00
Inflation	5.25	5.60	4.65	5.02
Output	0.00	0.00	0.00	0.00
Nominal Exchange F	0.00	0.00	0.00	0.00
Output Growth	0.61	1.93	0.58	1.84
Variance				
Inflation	0.01	0.06	0.02	0.07
Interest rates	0.44	0.46	0.44	0.45
Output	6.71	6.59	6.71	6.58
	Panel B: Canada			
Loss	2.39	6.51	2.38	6.49
Interest Rate	1.00	1.00	1.00	1.00
Inflation	1.50	0.87	1.27	1.09
Output	0.03	0.10	0.05	0.13
Nominal Exchange F	0.02	0.00	0.03	0.00
Output Growth	1.32	2.05	1.23	2.28
Variance				
Inflation	0.29	1.08	0.35	0.94
Interest rates	0.40	0.72	0.41	0.68
Output	6.78	4.72	6.49	4.87
	Panel C: New Zealand			
Loss	3.02	10.33	3.02	10.33
Interest Rate	1.00	1.00	1.00	1.00
Inflation	3.21	3.73	2.87	3.65
Output	0.00	0.11	0.00	0.10
Nominal Exchange F	0.03	0.00	0.02	0.00
Output Growth	0.75	2.59	0.77	2.71
Variance				
Inflation	0.09	0.47	0.11	0.52
Interest rates	0.38	0.41	0.38	0.41
Output	10.18	9.45	10.10	9.40

1/ Optimal coefficients are obtained by minimizing the weighted sum of variances for inflation, nominal interest rates and output, with weights either [1,1,0.25] or [1,1,1] respectively. All parameters other than those in the Taylor-type rule are fixed at the median of the MCMC estimates

2/ In optimizing over the draws, we use a subset of 5000 draws, taken at equally spaced intervals, from the draws obtained with the MCMC simulator. For each candidate set of policy parameters we compute the loss over all draws and average the resulting loss.

Table 5: Prior Densities and Posterior Estimates with Unobservable Foreign Block

			Prior		Posterior AUSTRALIA 2/			Posterior CANADA 2/			Posterior NEW ZEALAND 2/		
Coefficients		**Prior Density** 1/	**Mean**	**Std**	**Median**	**Std**	**[5,95] Prob**	**Median**	**Std**	**[5,95] Prob**	**Median**	**Std**	**[5,95] Prob**
Intertemporal ES	σ	G	1.2	0.4	0.954	0.225	[0.659 , 1.404]	1.135	0.205	[0.84 , 1.515]	0.834	0.155	[0.596 , 1.097]
Inverse Frisch	φ	G	1.5	0.75	1.269	0.593	[0.535 , 2.438]	1.796	0.813	[0.731 , 3.399]	1.186	0.554	[0.506 , 2.295]
Calvo domestic prices	θ_H	B	0.5	0.1	0.274	0.065	[0.178 , 0.392]	0.642	0.079	[0.497 , 0.756]	0.414	0.074	[0.299 , 0.542]
Calvo import prices	θ_F	B	0.5	0.1	0.439	0.105	[0.26 , 0.599]	0.608	0.121	[0.42 , 0.815]	0.403	0.099	[0.264 , 0.589]
Openess	α	B	0.25	0.05	0.243	0.045	[0.176 , 0.323]	0.279	0.051	[0.201 , 0.369]	0.2	0.033	[0.15 , 0.259]
Elasticity H-F goods	η	G	1.5	0.75	0.578	0.098	[0.493 , 0.833]	0.879	0.157	[0.662 , 1.169]	0.787	0.139	[0.619 , 1.078]
Habit	h	B	0.5	0.25	0.126	0.053	[0.041 , 0.214]	0.202	0.087	[0.075 , 0.357]	0.045	0.035	[0.009 , 0.12]
Indexation	δ	B	0.7	0.1	0.509	0.116	[0.329 , 0.71]	0.516	0.114	[0.34 , 0.716]	0.593	0.114	[0.4 , 0.775]
Taylor rule, smoothing	ψ_i	B	0.5	0.25	0.68	0.056	[0.58 , 0.76]	0.697	0.05	[0.606 , 0.77]	0.727	0.045	[0.641 , 0.788]
Taylor rule, inflation	ψ_π	G	1.5	0.3	1.919	0.176	[1.668 , 2.245]	1.848	0.2	[1.539 , 2.193]	1.953	0.206	[1.669 , 2.329]
Taylor rule, output	ψ_y	G	0.25	0.13	0.046	0.024	[0.017 , 0.095]	0.03	0.016	[0.012 , 0.061]	0.035	0.018	[0.014 , 0.071]
Taylor rule, exchange rate	ψ_e	G	0.25	0.13	0.104	0.024	[0.068 , 0.147]	0.182	0.05	[0.11 , 0.271]	0.096	0.027	[0.056 , 0.144]
Taylor rule, output growth	$\psi_{\Delta y}$	G	0.25	0.13	0.216	0.101	[0.083 , 0.413]	0.396	0.146	[0.19 , 0.675]	0.313	0.1	[0.162 , 0.496]
Technology	ρ_a	B	0.8	0.1	0.94	0.036	[0.868 , 0.982]	0.957	0.03	[0.891 , 0.987]	0.887	0.051	[0.787 , 0.954]
Foreign Inflation	$\rho_{\pi*}$	N	0.64	0.15	0.618	0.147	[0.368 , 0.853]	0.448	0.02	[0.415 , 0.481]	0.622	0.138	[0.375 , 0.833]
Foreign Output	ρ_{y*}	N	0.85	0.1	0.926	0.024	[0.885 , 0.964]	0.925	0.017	[0.895 , 0.951]	0.907	0.021	[0.869 , 0.938]
Foreign Interest Rates	ρ_{i*}	N	0.91	0.05	0.923	0.022	[0.884 , 0.956]	0.943	0.016	[0.914 , 0.967]	0.91	0.028	[0.86 , 0.953]
sd foreign inflation	$sd_{\pi*}$	I	0.5	150	0.302	0.159	[0.156 , 0.658]	0.324	0.198	[0.164 , 0.801]	0.311	0.231	[0.158 , 0.83]
sd foreign output	sd_{y*}	I	0.5	150	4.31	1.49	[2.777 , 7.753]	3.538	0.892	[2.319 , 5.246]	8.593	2.214	[5.801 , 13.06]
sd foreign interest rates	sd_{i*}	I	0.5	150	0.559	0.122	[0.365 , 0.765]	0.293	0.046	[0.227 , 0.379]	0.453	0.097	[0.31 , 0.624]
sd technology	sd_a	I	0.5	150	3.143	1.106	[1.92 , 5.57]	0.596	0.244	[0.313 , 1.114]	2.183	0.747	[1.271 , 3.577]
sd taylor rule	sd_{mp}	I	0.5	150	0.347	0.05	[0.283 , 0.447]	0.287	0.036	[0.24 , 0.357]	0.269	0.038	[0.219 , 0.341]

Notes:

1/ Distributions, N Normal, B Beta, G Gamma, I Inverse-Gamma 1. Calibrated β=0.99 and χ=0.01.

2/ Corresponds to median and posterior percentiles from 5 MCMC chains of 100,000 draws each, in which 40,000 draws were used as an initial burn-in phase. Convergence diagnostics were asssesed using trace plots and the potential scale reduction factors for the variance and 95% posterior intervals.

Table 6: Variance Decompostions model with unobservable foreign block

AUSTRALIA

	Foreign Inflation	Foreign Output	Foreign Interest Rate	Technology	Monetary Policy
Inflation	0.00	0.23	0.27	0.16	0.34
Real Exchange Rate	0.01	0.52	0.43	0.04	0.00
Interest Rate	0.01	0.13	0.79	0.07	0.01
Output	0.00	0.16	0.03	0.81	0.00

CANADA

	Foreign Inflation	Foreign Output	Foreign Interest Rate	Technology	Monetary Policy
Inflation	0.00	0.25	0.31	0.25	0.19
Real Exchange Rate	0.00	0.54	0.36	0.07	0.03
Interest Rate	0.00	0.11	0.70	0.15	0.04
Output	0.00	0.04	0.00	0.95	0.00

NEW ZEALAND

	Foreign Inflation	Foreign Output	Foreign Interest Rate	Technology	Monetary Policy
Inflation	0.00	0.20	0.17	0.37	0.26
Real Exchange Rate	0.00	0.66	0.28	0.05	0.00
Interest Rate	0.00	0.21	0.52	0.25	0.02
Output	0.00	0.16	0.00	0.84	0.01

1/ Variance decomposition for the model with 3 foreign and 2 domestic shocks, at the mode of the estimated parameters

Table 7: Optimal Policy Unobservable Foreign Block

	Weights on Inflation, Interest Rates and Output 1/	
	Weights 1,1,0.25	Weights 1,1,1
	Optimal Coefficients	Optimal Coefficients
Coefficients	At Median	At Median
	Panel A: Australia	
Loss	1.366	4.900
Policy Rule coefficients		
Interest Rate	1.000	0.930
Inflation	3.798	99.173
Output	0.000	0.099
Nominal Exchange Rate	0.000	0.133
Output Growth	0.097	13.413
Variances		
Inflation	0.010	0.009
Interest rates	0.179	0.220
Output	4.707	4.671
	Panel B: Canada	
Loss	3.648	13.685
Policy Rule coefficients		
Interest Rate	1.000	1.000
Inflation	1.827	1.653
Output	0.000	0.026
Nominal Exchange Rate	0.000	0.000
Output Growth	0.594	1.663
Variances		
Inflation	0.062	0.359
Interest rates	0.150	0.206
Output	13.745	13.120
	Panel C: New Zealand	
Loss	2.169	7.916
Policy Rule coefficients		
Interest Rate	1.000	1.000
Inflation	2.260	2.024
Output	0.000	0.058
Nominal Exchange Rate	0.000	0.000
Output Growth	0.311	1.035
Variances		
Inflation	0.038	0.279
Interest rates	0.153	0.185
Output	7.910	7.452

1/ Optimal coefficients are obtained by minimizing the weighted sum of variances for inflation, nominal interest rates and output, with weights either [1,1,0.25] or [1,1,1] respectively. All parameters other than those in the Taylor-type rule are fixed at the median of the median of the MCMC estimates

Table 8: Prior Densities and Posterior Estimates under Alternative Prior

Coefficients		Prior Density 1/	Prior Mean	Prior Std	Posterior AUSTRALIA 2/ Median	Std	[5,95] Prob	Posterior CANADA 2/ Median	Std	[5,95] Prob	Posterior NEW ZEALAND 2/ Median	Std	[5,95] Prob
Intertemporal ES	σ	N	1	0.1	0.941	0.10	[0.78 , 1.11]	0.944	0.10	[0.78 , 1.12]	0.932	0.103	[0.76 , 1.1]
Inverse Frisch	φ	G	1.2	0.1	1.183	0.10	[1.03 , 1.35]	1.158	0.10	[1.01 , 1.33]	1.176	0.099	[1.03 , 1.35]
Calvo domestic prices	θ_H	B	0.5	0.1	0.469	0.07	[0.37 , 0.59]	0.848	0.05	[0.74 , 0.91]	0.63	0.096	[0.45 , 0.78]
Calvo import prices	θ_F	B	0.5	0.1	0.528	0.09	[0.39 , 0.67]	0.631	0.06	[0.53 , 0.74]	0.583	0.103	[0.4 , 0.74]
Openess	α	B	0.25	0.05	0.175	0.04	[0.12 , 0.24]	0.183	0.04	[0.12 , 0.26]	0.14	0.034	[0.09 , 0.2]
Elasticity H-F goods	η	G	1.5	0.75	0.606	0.09	[0.51 , 0.81]	0.729	0.11	[0.58 , 0.94]	0.723	0.147	[0.57 , 1.03]
Habit	h	U	0.495	0.285	0.161	0.06	[0.07 , 0.27]	0.485	0.11	[0.30 , 0.67]	0.088	0.061	[0.01 , 0.21]
Indexation	δ	U	0.495	0.285	0.068	0.08	[0.01 , 0.24]	0.151	0.11	[0.02 , 0.37]	0.17	0.153	[0.03 , 0.52]
Taylor rule, smoothing	ψ_i	B	0.5	0.25	0.751	0.04	[0.68 , 0.81]	0.809	0.04	[0.74 , 0.86]	0.792	0.034	[0.73 , 0.84]
Taylor rule, inflation	ψ_π	G	1.5	0.3	2.154	0.19	[1.88 , 2.51]	1.950	0.23	[1.60 , 2.36]	2.186	0.234	[1.86 , 2.62]
Taylor rule, output	ψ_y	G	0.25	0.13	0.046	0.03	[0.02 , 0.10]	0.075	0.04	[0.03 , 0.15]	0.047	0.025	[0.02 , 0.1]
Taylor rule, exchange rate	ψ_e	G	0.25	0.13	0.127	0.03	[0.08 , 0.18]	0.284	0.08	[0.18 , 0.43]	0.118	0.034	[0.07 , 0.18]
Taylor rule, output growth	$\psi_{\Delta y}$	G	0.25	0.13	0.335	0.15	[0.14 , 0.63]	0.648	0.20	[0.36 , 0.99]	0.433	0.129	[0.24 , 0.67]

Table 8: Prior Densities and Posterior Estimates under Alternative Prior

Coefficients		Prior Density 1/	Prior Mean	Prior Std	Posterior AUSTRALIA 2/ Median	Std	[5,95] Prob	Posterior CANADA 2/ Median	Std	[5,95] Prob	Posterior NEW ZEALAND 2/ Median	Std	[5,95] Prob
Technology	ρ_a	B	0.8	0.1	0.940	0.03	[0.87 , 0.98]	0.747	0.10	[0.57 , 0.90]	0.879	0.075	[0.71 , 0.95]
Preferences	ρ_g	B	0.8	0.1	0.949	0.02	[0.92 , 0.97]	0.920	0.03	[0.87 , 0.96]	0.943	0.021	[0.9 , 0.97]
Risk premium	ρ_{rp}	B	0.8	0.1	0.965	0.02	[0.93 , 0.99]	0.933	0.02	[0.89 , 0.97]	0.961	0.017	[0.93 , 0.98]
Foreign Inflation	$\rho_{\pi*}$	N	0.64	0.15	0.437	0.07	[0.32 , 0.56]	0.448	0.06	[0.34 , 0.55]	0.495	0.079	[0.36 , 0.62]
Foreign Output	ρ_{y*}	N	0.85	0.1	0.930	0.03	[0.88 , 0.97]	0.889	0.03	[0.84 , 0.93]	0.923	0.029	[0.87 , 0.97]
Foreign Interest Rates	ρ_{i*}	N	0.91	0.05	0.953	0.02	[0.92 , 0.99]	0.968	0.02	[0.93 , 0.99]	0.956	0.021	[0.92 , 0.99]
sd foreign inflation	$sd_{\pi*}$	I	0.5	150	0.321	0.03	[0.28 , 0.36]	0.327	0.03	[0.29 , 0.37]	0.309	0.027	[0.27 , 0.36]
sd foreign output	sd_{y*}	I	0.5	150	0.500	0.04	[0.44 , 0.57]	0.555	0.04	[0.49 , 0.63]	0.498	0.042	[0.44 , 0.58]
sd foreign interest rates	sd_{i*}	I	0.5	150	0.139	0.01	[0.12 , 0.16]	0.143	0.01	[0.13 , 0.16]	0.129	0.011	[0.11 , 0.15]
sd technology	sd_a	I	0.5	150	1.134	0.35	[0.66 , 1.83]	0.187	0.04	[0.14 , 0.28]	0.779	0.449	[0.41 , 1.93]
sd taylor rule	sd_{mp}	I	0.5	150	0.319	0.04	[0.27 , 0.40]	0.264	0.03	[0.22 , 0.33]	0.246	0.032	[0.2 , 0.31]
sd preferences	sd_g	I	0.5	150	0.203	0.03	[0.16 , 0.26]	0.165	0.03	[0.13 , 0.22]	0.242	0.041	[0.19 , 0.32]
sd risk premium	sd_{rp}	I	0.5	150	0.387	0.09	[0.27 , 0.55]	0.261	0.05	[0.19 , 0.35]	0.314	0.069	[0.22 , 0.45]

Notes:

1/ Distributions, N Normal, B Beta, G Gamma, I Inverse-Gamma 1. Calibrated β=0.99 and χ=0.01.

2/ Corresponds to median and posterior percentiles from 5 MCMC chains of 100,000 draws each, in which 40,000 draws were used as an initial burn-in phase. Convergence diagnostics were asssesed using trace plots and the potential scale reduction factors for the variance and 95% posterior intervals.

Table 9: Optimal Policy (Alternative Prior)

Coefficients	Weights on Inflation, Interest Rates and Output 1/ Weights 1,1,0.25 Optimal Coefficients At Median	 Weights 1,1,1 Optimal Coefficients At Median
	Panel A: Australia	
Loss	2.029	6.664
Policy Rule coefficients		
Interest Rate	1.000	1.000
Inflation	3.320	3.523
Output	0.000	0.011
Nominal Exchange Rate	0.000	0.010
Output Growth	0.762	2.779
Variances		
Inflation	0.035	0.212
Interest rates	0.409	0.413
Output	6.343	6.039
	Panel B: Canada	
Loss	1.249	1.979
Policy Rule coefficients		
Interest Rate	1.000	1.000
Inflation	0.569	0.424
Output	0.077	0.153
Nominal Exchange Rate	0.056	0.023
Output Growth	1.336	3.408
Variances		
Inflation	0.407	0.762
Interest rates	0.377	0.653
Output	1.861	0.564
	Panel C: New Zealand	
Loss	2.754	7.886
Policy Rule coefficients		
Interest Rate	1.000	1.000
Inflation	1.710	1.055
Output	0.003	0.058
Nominal Exchange Rate	0.038	0.000
Output Growth	1.234	2.304
Variances		
Inflation	0.313	1.382
Interest rates	0.385	0.563
Output	8.223	5.941

1/ Optimal coefficients are obtained by minimizing the weighted sum of variances for inflation, nominal interest rates and output, with weights either [1,1,0.25] or [1,1,1] respectively. All parameters other than those in the Taylor-type rule are fixed at the median of the median of the MCMC estimates

Fig 1: Optimal Weight on Exchange Rate as Weights Vary

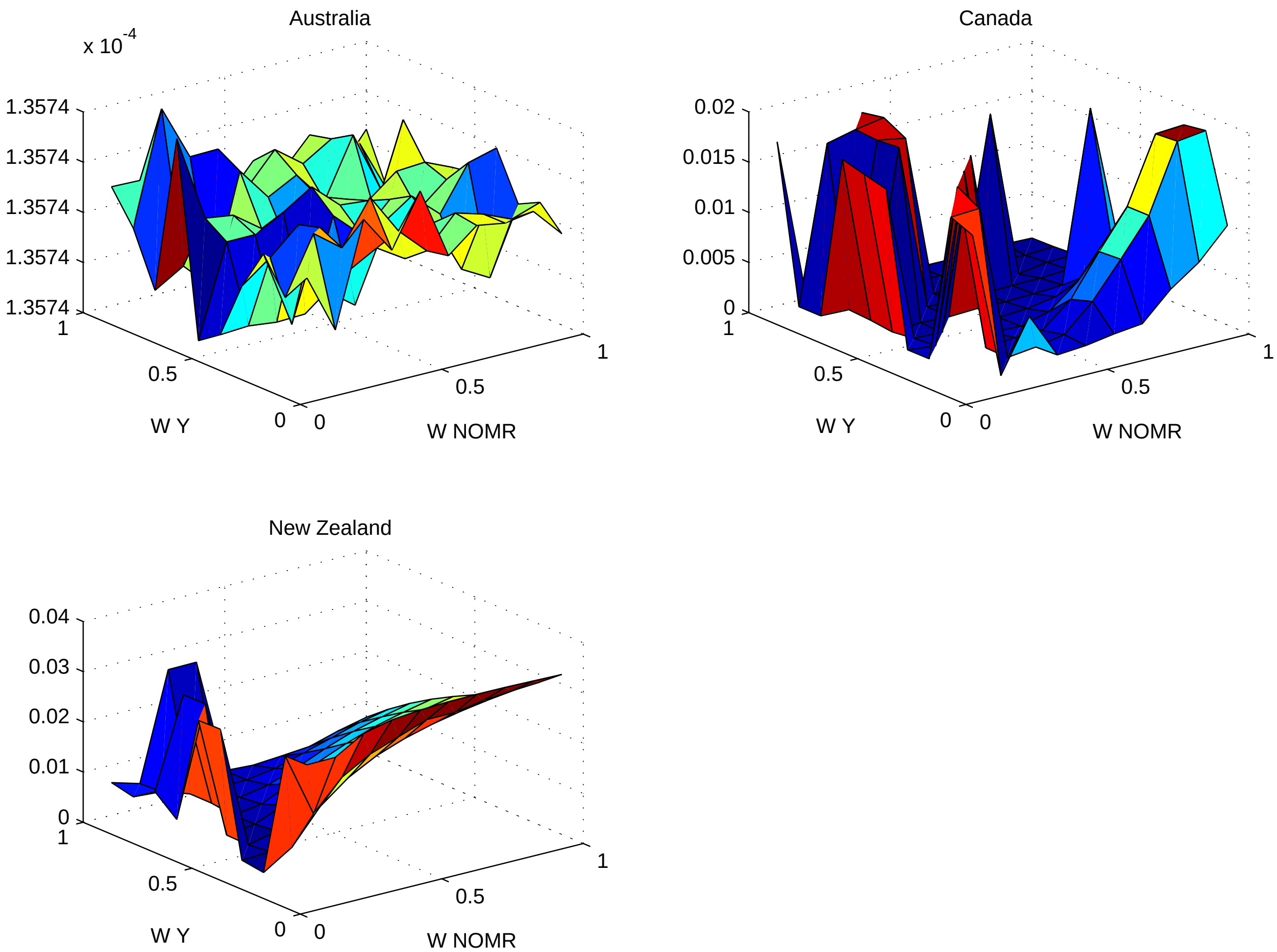

Figure 2: Australia, Loss for Individual Coefficients
Optimal (solid), Empirical (dashed)

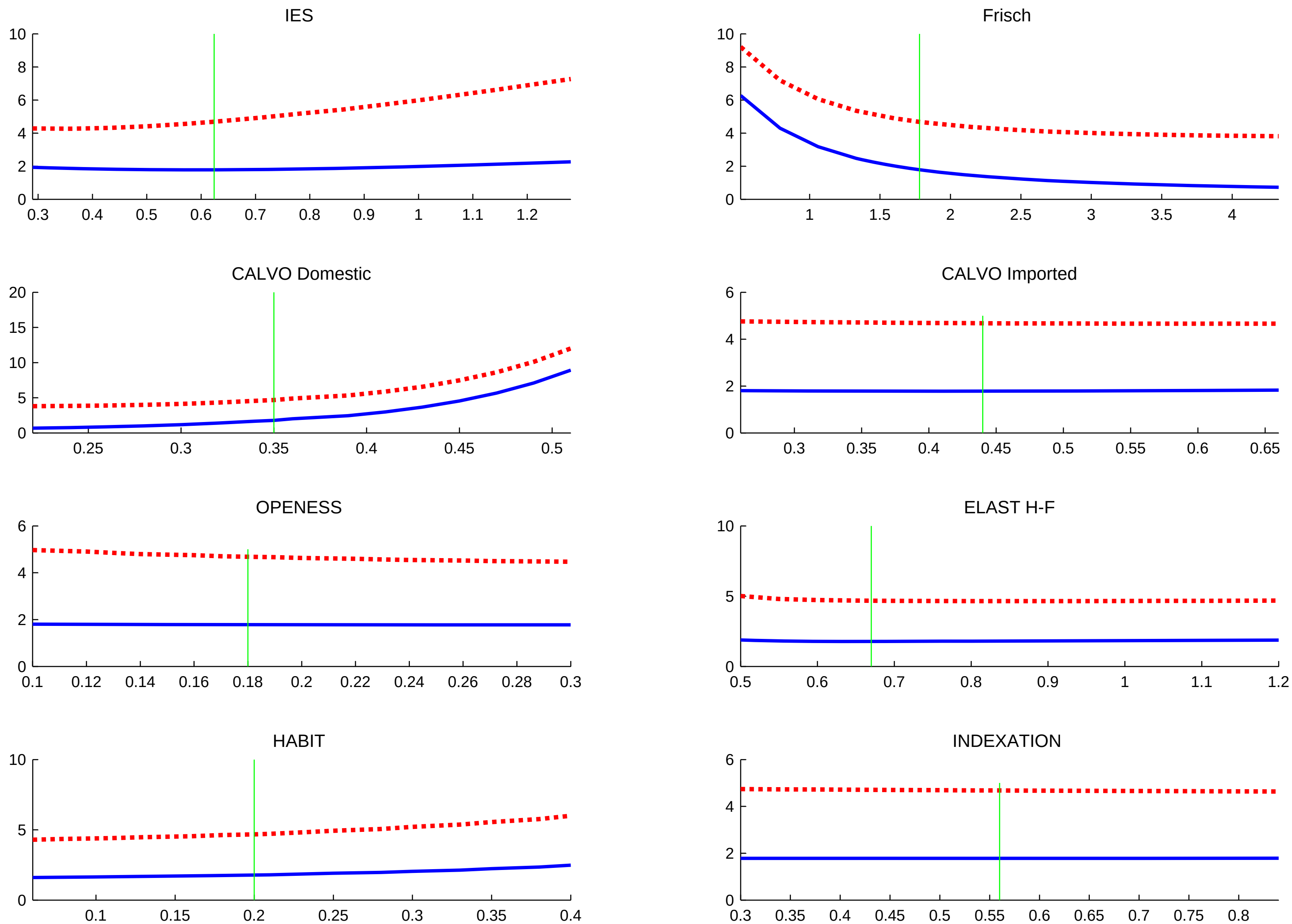

Figure 3: Canada, Loss for Individual Coefficients
Optimal (solid), Empirical (dashed)

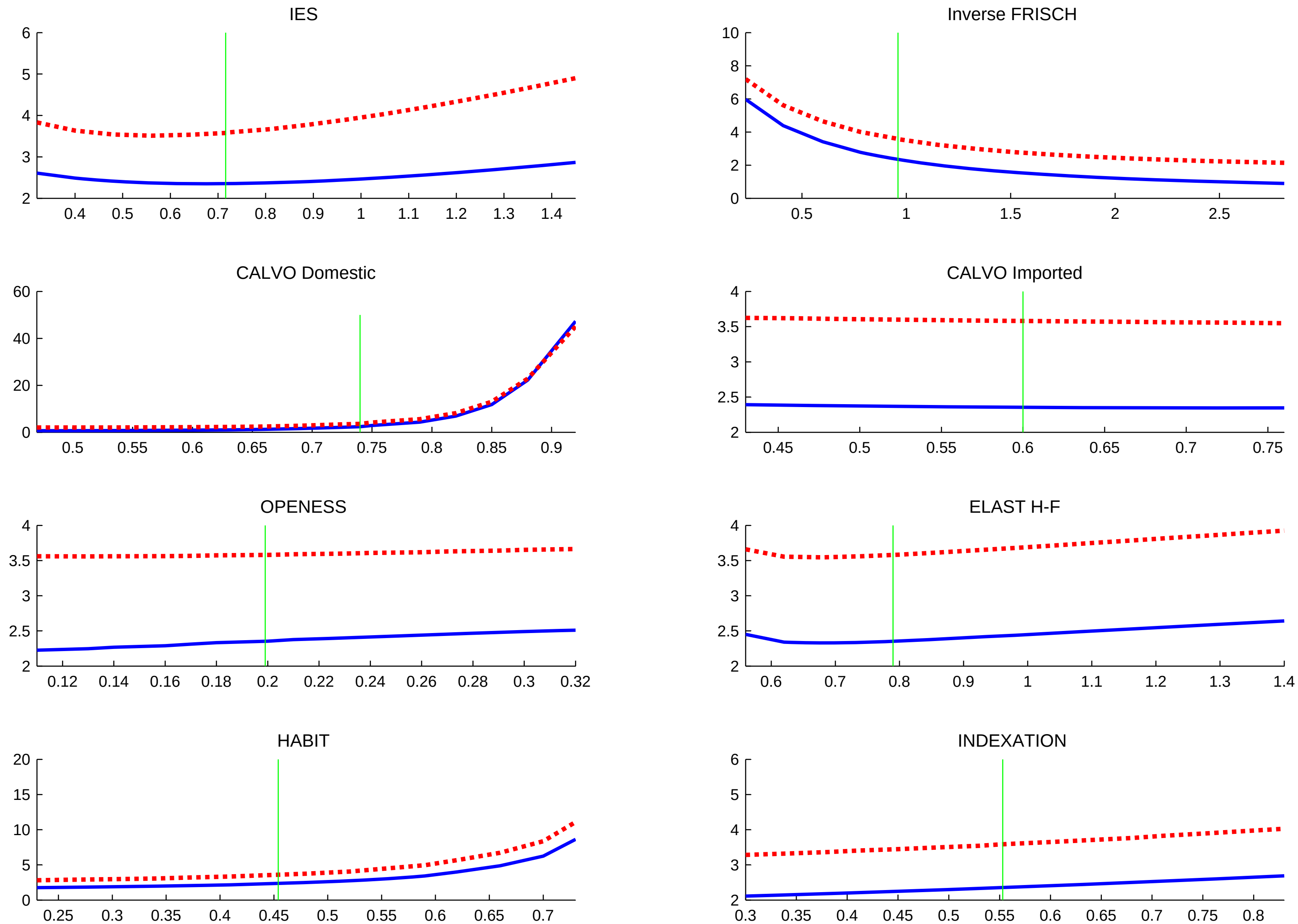

Figure 4: Australia Unobservable, Loss for Individual Coefficients
Optimal (solid), Empirical (dashed)

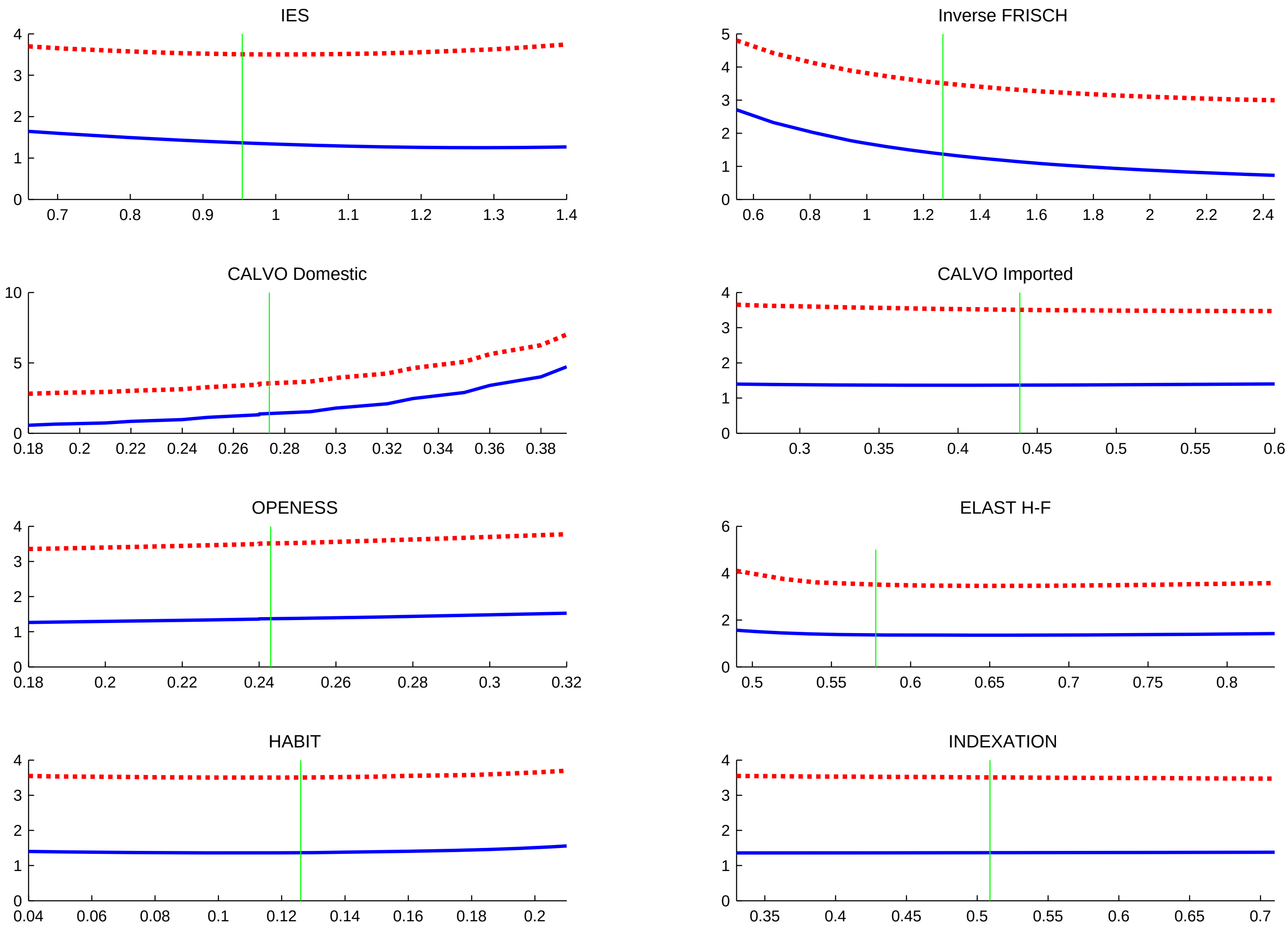

Figure 5: Canada Unobservable, Loss for Individual Coefficients
Optimal (solid), Empirical (dashed)