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GAINS FROM COMMITMENT POLICY FOR A SMALL OPEN ECONOMY: THE CASE OF NEW ZEALAND

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Gains from commitment policy for a small open economy: The case of New Zealand *

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Abstract

The importance of the time-consistency problem depends critically on the model one is working with and its parameterizations. This paper attempts to quantify the magnitude of stabilization bias for a small open economy using an empirically estimated micro-founded dynamic stochastic general equilibrium model. The resultant model is used to investigate the degree to which precommitment policy can improve welfare. Rather than presenting a point estimate of the welfare gain measures, the paper maps out the entire distribution of the welfare gain using the Bayesian posterior distribution of the model's parameters. The welfare improvement is an increasing function of the weight the central bank place on exchange rate variability. However, there is no simple relationship between the gains from precommitment and the degree of openness of the economy.

Keywords: Time-consistency; DSGE models; Bayesian estimation; Small open economy;
JEL Classification: C15, C51, E17, E61

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1 Introduction

The time-consistency problem in the operation of monetary policy has been an active area of research following the seminal work by Kydland and Prescott (1977), and Barro and Gordon (1983). The time-consistency problem describes situations where policies that were determined to be optimal yesterday are no longer considered optimal today. If the policy maker is given the chance to re-optimize and change their plan, he would want to deviate from the initially chosen path. Kydland-Prescott and Barro-Gordon (KPBG) demonstrate that time-inconsistent policies are suboptimal, leading to inefficient high inflation and consequently lower welfare. The result is not due to conflicting objectives between the monetary authority and private sector agents, nor to the authority's inability to react to unforseen shocks. The problem lies with the implication of rational dynamic policymaking when private sector expectations place restrictions on future policy decisions.

The KPBG framework provided a new perspective for the analysis of stagflation in the late 1970s. The sustained high rate of inflation during that period may not be the consequence of irrational policy decisions, it simply reflected the inability of policymakers to commit to a monetary policy leading to excessively high and volatile inflation. This insight has shifted much of the focus from the operational side of monetary policy making to the design of institutional frameworks aimed at mitigating the time consistency problem, see Rogoff (1985). The apparent consensus from this strand of research is the importance of credibility and transparency in the operation and implementation of monetary policy. Consequently, the reforms of many central banks around the world in the early 1990s was largely motivated to mitigate the time-inconsistency problem.

New Zealand was the first country to explicitly adopt an inflation targeting framework in 1989 with the hope of bringing inflation down to a more manageable level compared with the early 1980s. Walsh (1995) finds significant similarities between the Reserve Bank of New Zealand (RBNZ) Act 1989 and an optimal dismissal rule aimed at mitigating the time-consistency problem. In the past 15 years, the RBNZ has been successful in bringing inflation to a relatively low level, averaging about 2.2%. Moreover, it has been relatively stable with a standard deviation of just 0.7%. As the New Zealand economy has now had a stable macro-economic environment for more than a decade, it is desirable to find ways of utilizing the available historical data to investigate the size of the gain from precommitment, making it an ideal case study.

A number of studies have examined the percentage welfare gains from optimal policy under discretion to optimal policy with commitment (precommitment). Dennis (2004) shows that the welfare improvement from precommitment using the New Keynesian model developed by Clarida et al. (1999) ranges between 0% to 11% depending on the policy objectives, while the forward looking model estimated by Rudebusch (2002) only generates modest gains. Ehrmann and Smets (2003) use a New Keynesian model estimated on Euro data and find the welfare gain to be between 17% and 31%. Using an alternative measure, Dennis and Soderstrom (2006) consider a range of models estimated using US data and find that the inflation equivalent measure of welfare ranges from 0.05% to 3.6%. The paper also stresses the importance of the time-consistency problem depends critically on the model being considered as well as the value of parameters used in the simulations. Lees (2006) estimates the size of the stabilization bias for New Zealand to be around 1% of permanent inflation. However, estimation of the model did not account for the behavior of dynamic rational expectations.

The papers cited above primarily focus on the closed economy case, apart from Lees (2006). It is interesting to note that most of the radical institutional reforms in the operation and implementation of monetary policy have taken place in small open economies such as Canada, New Zealand and Chile. The operation of monetary policy in a small open economy can differ in two important dimensions. First, the domestic economy is subject to various foreign disturbances as well as supply and demand shocks traditionally analyzed in closed economy models. Second, the exchange rate implies an additional transmission channel of monetary policy as well as an indirect channel for the transmission of foreign disturbances to the domestic economy. Adolfson (2001) points out that incomplete pass-through creates less conflict between inflation and output variability from lower policy induced exchange rate movements.

This paper attempts to bridge the gap in the analysis of optimal policy for a small open economy together with a micro-founded dynamic stochastic general equilibrium (DSGE) model. The model is empirically estimated by incorporating private sector rational expectations to provide a set of deep structural parameters of the New Zealand economy. The resulting model is used to investigate the degree to which precommitment policy can improve welfare. Comparison is also made with previous closed economy studies. Rather than presenting a point estimate of the welfare gain measures, one of the contributions of this paper is to map out the entire distribution of the welfare gain. The analysis can be interpreted as a step towards understanding the variation in the welfare gain measure arising from parameter uncertainty.

The analysis begins by presenting a slightly modified version of the workhorse small open economy New Keynesian model. The design of the model builds extensively on previous work done in this area, notably by Smets and Wouters (2004), Justiniano and Preston (2004), Gali and Monacelli (2005), Monacelli (2005), Lubik and Schorfheide (2005) and Lubik and Schorfheide (2006). Among these studies, key aggregate relationships are derived from microfoundations with optimizing agents and rational expectations. Models based on optimizing agents and deep parameters are more likely to be immune to the Lucas critique, making them more suitable for analyzing policy experiments. To confront the model with the data, Bayesian methods are used to combine prior judgements with information contained in the comparatively short historical data. The Bayesian approach also allows for the explicit evaluation of parameter and model uncertainty. Using the posterior distribution of the model's parameters, one can solve for optimal policy under discretion and commitment, and calculate the welfare gain from precommitment. The approach of using an empirically estimated model takes a step further in inferring the distribution of the welfare improvements that might reasonably be achieved in an actual economy as opposed to results obtained using point estimates.

The structure of the paper is organized as follows. Section (2) lays out the basic structure of the small open economy model. Section (3) briefly discusses the estimation methodology and the data used in estimating the model. Section (4) presents the estimation results from the Bayesian simulations. Section (5) presents the simulation results for a wide range of policy objectives and investigate the gains from precommitment when the economy becomes more open. Finally, section (6) reviews the main findings and makes some suggestions for further work.

2 A small open economy model

This section describes the key structural equations implied by the model proposed by Gali and Monacelli (2005) and Monacelli (2005). The model's dynamics are enriched by allowing for external habit formation and indexation of prices, as in Smets and Wouters (2004), and Christiano et al. (2005).

2.1 Households

The economy is inhabited by a representative household who seeks to maximize:

$$E_0 \sum_{t=0}^{\infty} \beta^t \{U(C_t) - V(N_t)\} \tag{1}$$

$$U(C_t, H_t) = \frac{(C_t - hC_{t-1})^{1-\sigma}}{1-\sigma} \quad \text{and} \quad V(N_t) = \frac{N_t^{1+\varphi}}{1+\varphi}$$

where β is the rate of time preference, σ is the inverse elasticity of intertemporal substitution, and φ is the inverse elasticity of labour supply. N_t denotes hours of labour, and hC_{t-1} represents external habit formation for the optimizing household, for $h \in [0,\ 1]$. C_t is a composite consumption index of foreign ($C_{F,t}$) and domestically ($C_{H,t}$) produced goods defined as:

$$C_t \equiv \left((1-\alpha)^{\frac{1}{\eta}} C_{H,t}^{\frac{\eta-1}{\eta}} + \alpha^{\frac{1}{\eta}} C_{F,t}^{\frac{\eta-1}{\eta}} \right)^{\frac{\eta}{\eta-1}} \tag{2}$$

where $\alpha \in [0,\ 1]$ is the import ratio measuring the degree of openness, and $\eta > 0$ is the elasticity of substitution between home and foreign goods. The household's maximization problem is completed given the following budget constraint at time t:

$$\int_0^1 \{P_{H,t}(i)C_{H,t}(i) + P_{F,t}(i)C_{F,t}(i)\}di + E_t\{Q_{t,t+1}D_{t+1}\} \leq D_t + W_t N_t \tag{3}$$

for $t = 1, 2, \ldots, \infty$, where $P_{H,t}(i)$ and $P_{F,t}(i)$ denote the prices of domestic and foreign good $i \in [0,\ 1]$ respectively, $Q_{t,t+1}$ is the stochastic discount rate on nominal payoffs, D_t is the nominal payoff on a portfolio held at $t-1$ and W_t is the nominal wage.

Solving the household's optimization problem yields the following set of first order conditions (FOCs):

$$(C_t - hC_{t-1})^{-\sigma}\frac{W_t}{P_t} = N_t^{\varphi} \tag{4}$$

$$\beta R_t E_t \left\{ \frac{P_t}{P_{t+1}} \left(\frac{C_{t+1} - hC_t}{C_t - hC_{t-1}} \right)^{-\sigma} \right\} = 1 \tag{5}$$

where $R_t = 1/E_t Q_{t,t+1}$ is the gross nominal return on a riskless one-period bond maturing in $t+1$ and $P_t = (1-\alpha)P_{H,t} + \alpha P_{F,t}$ is the Consumer Price Index (CPI). The intra-temporal optimality condition in equation (4) states that the marginal utility of consumption is equal to the marginal value of labour at any one point of time; equation (5) gives the Euler equation for inter-temporal consumption.

Households in the foreign economy are assumed to face exactly the same optimization problem with identical preferences, with the only difference being that the influence from the other economy is negligible.[1] One can arrive at a similar set of optimality conditions describing the dynamic behaviour of key variables in the foreign economy.

2.2 Inflation, the real exchange rate and terms of trade

Throughout this paper, the assumption of the *law of one price* (LOP) holds for the export sector, but incomplete pass-through for imports is allowed. The motivation behind this assumption is that the small open economy is a price taker with little bargaining power in the international markets. For its export bundle, prices are determined exogenously in the rest of the world. On the import side, competition in the world market is assumed to make import prices equal to marginal cost at the wholesale level, but rigidities arising from inefficient distribution networks and monopolistic retailers allow domestic import prices to deviate from the world price. Burstein et al. (2003) provide a similar argument, which is supported using United States (US) data.

First, defining the *terms of trade* (TOT) as $S_t = \frac{P_{F,t}}{P_{H,t}}$ (or in logs $s_t = p_{F,t} - p_{H,t}$). The terms of trade is thus the price of foreign goods per unit of home good.[2] Log-linearizing the CPI formula around the steady state and taking the first difference yields the following

[1]Assuming the domestic economy is small relative to the foreign economy, foreign consumption approximately comprises only foreign-produced goods such that $C_t^* = C_{F,t}^*$ and $P_t^* = P_{F,t}^*$.

[2]An increase in s_t is equivalent to an increase in competitiveness for the domestic economy because foreign prices increase and/or home prices fall.

identity linking CPI-inflation, domestic inflation ($\pi_{H,t}$) and the change in the TOT:

$$\Delta s_t = \pi_{F,t} - \pi_{H,t} \tag{6}$$

The change in the TOT is proportional to the difference between import and domestic inflation. In addition, define $\mathcal{E}_t$ as the nominal exchange rate (expressed in terms of foreign currency per unit of domestic currency).[3] Similarly, the real exchange rate and the law of one price (LOP) gap are defined as $\zeta_t \equiv \frac{\mathcal{E}_t P_t}{P_t^*}$ and $\Psi_t = \frac{P_t^*}{\mathcal{E}_t P_{F,t}}$ respectively. If the LOP holds, i.e. if $\Psi_t = 1$, then the import price index $P_{F,t}$ is simply the foreign price index divided by $\mathcal{E}_t$, or $P_{F,t} = \frac{P_t^*}{\mathcal{E}_t}$. The LOP gap is a wedge or inverse mark-up between the *world* price of world goods and the *domestic* price of these imported world goods. Substituting the definition of the CPI, s_t and $\psi_t = \ln(\Psi_t)$ into $q_t = \ln(\zeta_t)$ gives:

$$\begin{aligned} q_t &= e_t + p_t - p_t^* \\ &= -\psi_t - (1-\alpha)s_t \end{aligned} \tag{7}$$

$$\Rightarrow \psi_t = -[q_t + (1-\alpha)s_t]$$

Consequently, the LOP gap is inversely proportionate to the real exchange rate and the degree of international competitiveness for the domestic economy.

Under the assumption of complete international financial markets and perfect capital mobility, the expected nominal return from risk-free bonds, in domestic currency terms, must be the same as the expected domestic-currency return from foreign bonds, that is $E_t Q_{t,t+1} = E_t(Q_{t,t+1}^* \frac{\mathcal{E}_{t+1}}{\mathcal{E}_t})$. Using this relationship, the intertemporal optimality conditions can be equated for the domestic and foreign households' optimization problem. Assuming the same habit formation parameter across the two countries gives a similar international risk sharing condition as in Gali and Monacelli (2005) under external habit formation:

$$C_t - hC_{t-1} = \vartheta(C_t^* - hC_{t-1}^*)\zeta_t^{-\frac{1}{\sigma}} \tag{8}$$

where ϑ is some constant depending on initial asset positions. Log-linearizing equation (8)

[3] An increase in $\mathcal{E}_t$ means an appreciation of the domestic currency.

around the steady gives:

$$c_t - hc_{t-1} = (y_t^* - hy_{t-1}^*) - \frac{1-h}{\sigma} q_t \tag{9}$$

where $c_t^* = y_t^*$. The assumption of complete international financial markets and perfect capital mobility leads to a simple relationship linking the domestic economy with world output and the real exchange rate. Furthermore, these assumptions help to recover another important relationship, the *uncovered interest parity* condition:

$$E_t \left(Q_{t,t+1} \{ R_t - R_t^* \frac{\mathcal{E}_t}{\mathcal{E}_{t+1}} \} \right) = 0 \tag{10}$$

Log linearizing around the perfect foresight steady state yields the familiar UIP condition for the real exchange rate:[4]

$$E_t \Delta q_{t+1} = -\{(r_t - \pi_{t+1}) - (r_t^* - \pi_{t+1}^*)\} \tag{11}$$

that is, the expected change in q_t depends on the current real interest rate differentials.

2.3 Firms

2.3.1 Production technology

There is a continuum of identical monopolistically-competitive firms; the j^{th} firm produces a differentiated good, Y_j, using a linear production function:

$$Y_t(j) = A_t N_t(j) \tag{12}$$

where $a_t \equiv \log A_t$ follows an AR(1) process, $a_t = \rho_a a_{t-1} + \nu_t^a$, describing the firm-specific productivity index. Given the firm's technology, the real total cost of production is $TC_t = \frac{W_t}{P_{H,t}} \frac{Y_t}{A_t}$. Hence, the real marginal cost, $MC_t = \frac{W_t}{A_t P_{H,t}}$, will be common across all domestic firms. Substituting the intertemporal Euler equation (equation (4)) and the production

[4]The risk premium is assumed to be constant in the steady state.

function (equation (12)) into the marginal cost equation, after log-linearizing obtains:

$$mc_t = \frac{\sigma}{1-h}(c_t - hc_{t-1}) + \varphi y_t + \alpha s_t - (1+\varphi)a_t \tag{13}$$

Thus, it can be seen that the marginal cost is an increasing function of domestic output and s_t, and is inversely related to the level of labour productivity.

2.3.2 Price setting behaviour and incomplete pass-through

In the domestic economy, monopolistic firms are assumed to set prices in a Calvo-staggered fashion. In any period t, only $1-\theta_H$, where $\theta_H \in [0,1]$, fraction of firms are able to reset their prices optimally, while the other fraction θ_H cannot. Instead, the latter are assumed to adjust their prices, $P_t^I(j)$, by indexing it to last period's inflation as follows:

$$P_{H,t}^I(j) = P_{H,t-1}(j)\left(\frac{P_{H,t-1}}{P_{H,t-2}}\right)^{\theta_H} \tag{14}$$

The degree of past inflation indexation is assumed to be the same as the probability of resetting its prices.[5] Consider only the symmetric equilibrium case, where $P_{H,t}(j) = P_{H,t}(k)$, $\forall j,k$. Let $\bar{P}_{H,t}$ denote the price level that optimizing firms set each period. When setting the new price, in period t, an optimizing firm will seek to maximize the current value of its dividend stream subject to the sequence of demand constraints. In aggregate, the following function is maximised:

$$\max_{\bar{P}_{H,t}} \sum_{k=0}^{\infty} (\theta_H)^k E_t \left\{ Q_{t,t+k}\left(Y_{t+k}(\bar{P}_{H,t} - MC_{t+k}^n)\right)\right\} \tag{15}$$

$$\text{subject to} \quad Y_{t+k} \leq \left(\frac{\bar{P}_{H,t}}{P_{H,t+k}}\right)^{-\varepsilon}(C_{H,t+k} + C_{H,t+k}^*)$$

where MC_{t+k}^n is the nominal marginal cost and the effective stochastic discount rate is now $\theta_H^k E_t Q_{t+k-1,t+k}$ to allow for the fact that firms have a $1-\theta_H$ probability of being able to reset prices in each period. From the FOC (see Appendix (A)) for more detail, one can obtain the evolution of domestic inflation as:

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

[5]The assumption ensures that the Phillips curve is vertical in the long run and reduces the number of parameters to be estimated.

where $\lambda_H = \frac{(1-\beta\theta_H)(1-\theta_H)}{\theta_H}$. The Calvo pricing structure yields a familiar New Keynesian Phillips Curve (NKPC), that is, the domestic inflation dynamic has both a forward looking component and a backward-looking component. If all firms were able to adjust their prices at each and every period, the inflation process would be purely forward looking and disinflationary policy would be completely costless. The real marginal costs faced by the firm are also an important determinant and contributor to the dynamics of domestic inflation.

As for the importing sector, it is assumed the LOP hold at the wholesale level. However, inefficiency in distribution channels together with monopolistic retailers keep domestic import prices over and above the marginal cost (the world price). As a result, the LOP fails to hold at the retail level for domestic consumers. Following a similar Calvo-pricing argument as before, the price setting behavior for the domestic import retailers can be summarized by looking at the FOC:[6]

$$\bar{p}_{F,t} = p_{F,t-1} + \sum_{k=0}^{\infty} (\beta\theta_F)^k \{E_t \pi_{F,t+k} + (1-\beta\theta_F) E_t \psi_{t+k}\} \tag{17}$$

where $\theta_F \in [0,1]$ is the fraction of importer retailers that cannot re-optimize their prices every period. In setting the new price for imports, domestic retailers are concerned with the future path of import inflation as well as the LOP gap, ψ_t. Essentially, ψ_t is the margin over and above the wholesale import price. A non-zero LOP gap represents a wedge between the *world* and domestic import prices. This provides a mechanism for incomplete import pass-through in the short-run, implying changes in world import prices have a gradual effect on the domestic economy. Substituting equation (17) into the determination of $P_{F,t}$ arising from the Calvo-pricing structure yields:

$$\pi_{F,t} = \beta(1-\theta_F) E_t \pi_{F,t+1} + \theta_F \pi_{F,t-1} + \lambda_F \psi_t \tag{18}$$

where $\lambda_F = \frac{(1-\beta\theta_F)(1-\theta_F)}{\theta_F}$. Log-linearizing the definition of CPI and taking the first difference yields the following relationship for overall inflation:

$$\pi_t = (1-\alpha)\pi_H + \alpha\pi_F \tag{19}$$

[6] See Gali and Monacelli (2005) for more detail.

Taking the definition for overall inflation in (19) together with equations (16) and (18) completes the specification of inflation dynamics for the small open economy.

2.4 Equilibrium

2.4.1 Aggregate demand and output

Goods market clearing in the domestic economy requires that domestic output is equal to the sum of domestic consumption and foreign consumption of home produced goods (exports):

$$y_t = c_{H,t} + c^*_{H,t} \tag{20}$$

Acknowledging the optimal demand functions for $C_{H,t}$ and $C_{F,t}$ is given by:

$$C_{H,t} = (1-\alpha)\left(\frac{P_{H,t}}{P_t}\right)^{-\eta} C_t \quad \text{and} \quad C_{F,t} = \alpha\left(\frac{P_{F,t}}{P_t}\right)^{-\eta} C^*_t \tag{21}$$

and taking the log of the two demand functions and using the definitions of the log of TOT (s_t) and the log of the LOP gap (ψ_t) gives:

$$c_{H,t} = (1-\alpha)[\alpha\eta s_t + c_t] \tag{22}$$

$$c^*_{H,t} = \alpha[\eta(s_t + \psi_t) + c^*_t] \tag{23}$$

From equation (22), an increase in s_t (equivalent to an increase in domestic competitiveness in the world market) will see domestic agents substitute out of foreign-produced goods into home-produced goods for a given level of consumption. The magnitude of substitution will depend on η, the elasticity of substitution between foreign and domestic goods; and the degree of openness, α. Similarly, from equation (23) an increase in s_t will see foreigners substitute out of foreign goods and consume more home goods for a given level of income.

Substituting equations (22) and (23) into (20) yields the goods market clearing condition for the small open economy as:

$$y_t = (1-\alpha)c_t + \alpha c^*_t + (2-\alpha)\alpha\eta s_t + \alpha\eta\psi_t \tag{24}$$

Notice that when $\alpha = 0$, the closed economy case, it gives $y_t = c_t$.

2.5 A simple reaction function

In order to estimate the deep structural parameters, the behavior of the domestic monetary authority is specified to complete the small open economy model. The aim of the monetary authority is to stabilize both output and inflation according to a simple Taylor type rule such that:

$$r_t = \rho_r r_{t-1} + (1 - \rho_r)[\phi_1 \pi_t + \phi_2 \Delta y_t] \tag{25}$$

where ρ_r is the degree of interest rate smoothing, ϕ_1 and ϕ_2 are the relative weights on inflation and output growth respectively. The approach here follows Orphanides (2003) in including output growth rather than the traditional output gap measure in the Taylor rule to provide a historical view on the central bank's behavior over the sampling period. This precludes the need to estimate the potential output of the economy.

2.6 The linearized model

This subsection summarizes the complete log-linearized model. Log-linearizing the intertemporal Euler equation in equation (5) gives the following dynamic equation relating past, current and future consumption with the real interest rate:

$$c_t - hc_{t-1} = E_t(c_{t+1} - hc_t) - \frac{1-h}{\sigma}(r_t - E_t\pi_{t+1}) \tag{26}$$

Using the model's definition for the terms of trade, the terms of trade growth can be rewritten as:

$$\Delta s_t = \pi_{F,t} - \pi_{H,t} + \nu_t^s \tag{27}$$

where ν_t^s represents the measurement error from the model's definition. The assumption of perfect capital mobility and complete international markets gives the usual UIP condition in equation (11) plus a risk premium term (ν_t^q) as:

$$\Delta E_t q_{t+1} = -\{(r_t - E_t\pi_{t+1}) - (r_t^* - E_t\pi_{t+1}^*)\} + \nu_t^q \tag{28}$$

In addition to the UIP condition, domestic consumption is tied with foreign consumption through the international risk sharing condition in equation (9) as:

$$c_t - hc_{t-1} = y_t^* - hy_{t-1}^* - \frac{1-h}{\sigma} q_t \tag{29}$$

The dynamic behavior of domestic inflation can be summarized using a Phillips curve under the assumption of monopolistic producers together with the Calvo pricing mechanism as:

$$\pi_{H,t} = \beta(1-\theta_H)E_t\pi_{H,t+1} + \theta_H\pi_{H,t-1} + \lambda_H mc_t + \nu_t^{\pi_H} \tag{30}$$

where $mc_t = \frac{\sigma}{1-h}(c_t - hc_{t-1}) + \varphi y_t + \alpha s_t - (1+\varphi)a_t$ is the log of the marginal cost, and $\nu_t^{\pi_H}$ is the measurement error to the domestic inflation Phillips curve. The assumption of monopolistic importers give similar Phillips curve describing the behavior of import inflation:

$$\pi_{F,t} = \beta(1-\theta_F)E_t\pi_{F,t+1} + \theta_F\pi_{F,t-1} + \lambda_F\psi_t + \nu_t^{\pi_F} \tag{31}$$

where $\psi_t = -[q_t + (1-\alpha)s_t]$ is the log of LOP gap that give rise to imperfect exchange rate pass-through, and $\nu_t^{\pi_F}$ is the measurement error to the import inflation Phillips curve. From the definition of the CPI, overall inflation can be written as:

$$\pi_t = (1-\alpha)\pi_{H,t} + \alpha\pi_{F,t} \tag{32}$$

The goods market clearing condition requires that domestic output is equal to the sum of domestic consumption plus exports gives:

$$y_t = (2-\alpha)\alpha\eta s_t + (1-\alpha)c_t + \alpha\eta\psi_t + \alpha y_t^* \tag{33}$$

The behavior of the central bank is described using a Taylor type reaction function:

$$r_t = \rho_r r_{t-1} + (1-\rho_r)(\phi_1\pi_t + \phi_2\Delta y_t) + \nu_t^r \tag{34}$$

where ν_t^r is the measurement error to the policy maker's reaction function. To complete the linearized model, three exogenous AR(1) driving processes are included for a_t, y_t^* and $r_t^* - \pi_t^*$

with AR(1) coefficients ρ_a, ρ_{y^*} and ρ_{r^*} respectively.

3 Empirical analysis

This section outlines the procedure used to obtain the posterior distribution of the structural parameters underlying the model described in section (2).

3.1 The Bayesian approach

Fernandez-Villaverde and Rubio-Ramirez (2004) showed the Bayesian estimator is consistent in large samples such that the posterior distribution of the parameters collapses to its pseudotrue values. Furthermore, small sample experiments suggests the Bayesian estimator tends to outperform classical ones even when evaluated by the frequentist criteria. The use of prior, $p(\theta)$, allows researchers to include information about the possible values of parameters that is considered to be outside the formal modeling framework. On the practical aspect, adding $\ln p(\theta)$ smoothes the often uneven surface of the log likelihood function making estimation much easier. However, just like any other econometric methods, there is also weakness associated with the Bayesian method. When the likelihood around a particular parameter is relatively flat, the choice of prior becomes very important in determining the estimated parameter values. The work here takes an agnostic approach where the specified prior distributions are relatively diffuse.

In the Bayesian context, all inference about the parameter θ is contained in the posterior distribution. For a particular model i, the posterior density of the model parameter θ can be written as:

$$p(\theta|Y^T, i) = \frac{L(Y^T|\theta, i)p(\theta|i)}{\int L(Y^T|\theta, i)p(\theta|i)d\theta} \tag{35}$$

where $p(\theta|i)$ is the prior density and $L(Y^T|\theta, i)$ is the likelihood conditional on the observed data Y^T. The centre of the Bayesian philosophy is to find a model i that maximizes the marginal density of the data.

The likelihood function can be computed via the state-space representation of the model together with the measurement equation linking the observed data to the state vector. The solution of the linearized economic model described in section (2.6) has the following (approximate) state-space representation:

$$X_{t+1} = \Gamma_1 X_t + \Gamma_2 w_{t+1} \quad (36)$$

$$Y_t = \Lambda X_t + \mu_t \quad (37)$$

where X_t is the state vector, Y_t is the vector observed variables, Γ_1 and Γ_2 are the solution matrices of the rational expectation model, and Λ is the matrix defining the relationship between the state vector and the observed variables. Assuming the state innovations and measurement errors are normally distributed with mean zero and variance-covariance matrices Ξ and Υ respectively, the likelihood function of the model is given by:

$$\ln L(Y^T|\Gamma_1, \Gamma_2, \Lambda, \Xi, \Upsilon) = -\frac{TN}{2}\ln 2\pi - \sum_{t-1}^{T}\left[\frac{1}{2}\ln|\Omega_{t|t-1}| + \frac{1}{2}\mu_t'\Omega_{t|t-1}^{-1}\mu_t\right] \quad (38)$$

Recognizing that $\int L(Y^T|\theta, i)p(\theta|i)d\theta$ is constant for a particular model i, it is only neccessary to be able to evaluate the posterior density up to a proportionate constant using the following relationship:

$$p(\theta|Y^T) \propto L(Y^T|\theta)p(\theta) \quad (39)$$

The posterior density can be seen as a way of summarizing information contained in the likelihood weighted by the prior density $p(\theta)$. The prior can be used to bear information that is not contained in the sample, Y^T. The random walk Metropolis Hastings algorithm described in Lubik and Schorfheide (2006) was used to simulate the Markov chain Monte Carlo (MCMC) draws to construct the posterior distribution of the model's parameters.

3.2 Data and priors

Data from 1991Q1 to 2004Q4 for New Zealand was used to estimate the small open economy New Keynesian model. Quarterly observations on domestic output per capita (y_t), interest rates (r_t), overall inflation(π_t), import inflation ($\pi_{F,t}$), real exchange rate (q_t), the competitive price index or equivalently terms of trade (s_t), foreign output (y_t^*) and foreign real interest rate ($\bar{r}_t^* = r_t^* - \pi_t^*$) are taken from Statistics New Zealand and the Reserve Bank of New Zealand. All variables are re-scaled to have a mean of zero and could be interpreted as an approximate percentage deviation from the mean.[7] See Appendix B for a more detailed description of the data transformations.

The choice of priors for the estimation are guided by several considerations. At the basic level, the priors reflect the modeler's beliefs and confidence about the likely location of the structural parameters. Information on the structural characteristics of the New Zealand economy, such as the degree of openness, being a commodity producer and its institutional settings, were all taken into account. In the case of New Zealand, micro-level studies are relatively scarce. Priors from similar studies using New Zealand data, for example Justiniano and Preston (2004), and Lubik and Schorfheide (2006), were also considered. The Reserve Bank of NZ's main macro model FPS is taken as a good approximation of the Bank's view of the New Zealand economy, and key parameters contained in FPS and its implied dynamic properties were used to inform the choice of priors. Finally, the choice of prior distributions reflects restrictions on the parameters such as non-negativity or interval restrictions. Beta distributions were chosen for parameters that are constrained on the unit-interval. Gamma and normal distributions were selected for parameters in $\Re^+$, while the inverse gamma distribution was used for the variance of the shocks.

The priors on the model's parameters are assumed to be independent of each other, which allows for easier construction of the joint prior density used in the MCMC algorithm. Furthermore, the parameter space is truncated to avoid indeterminacy or non-uniqueness in the model's solution. The marginal prior distributions for the model's parameters are summarized in Table (1).

3.3 Estimation and convergence diagnostics

Given the data and prior specifications in section 3.2, two parallel 1,500,000 draws of the Markov chain were generated.[8] The Markov chains are generated conditional on the degree of openness (α) and the time preference (β) parameters, which are fixed at 0.4 and 0.99 respectively.[9]

Various convergence diagnostic statistics were computed after 40% burn-in. The aim is to

[7] Apart from the interest rate and inflation data which are already in percentage terms.

[8] Each chain is generated at different starting values. It takes approximately 120 CPU hours to generate each independent chain using the APAC linux cluster machine.

[9] $\alpha = 0.4$ coincides with the proportion of imported goods in the CPI over the sample period.

assess whether the sequence of Markov chain draws has converged to its target distribution to ensure the reliability of the estimates generated from the Metropolis Hastings algorithm. The first column of Table (2) shows the mean of the posterior distribution. The NSE refers to the Numeric Standard Error as an approximation to the true posterior standard error and the p-value is the test between the means generated from the two independent chains as in Geweke (1999). There is no indication that the two means are significantly different from each other. The fourth column shows the univariate "shrink factor" using the ratio of between and within variances as in Brooks and Gelman (1998). A shrink factor close to 1 is evidence for convergence to a stationary distribution. The autocorrelations statistics are shown in column 5 to 8. The multivariate "shrink factor" was computed to be 1.0117. All MCMC diagnostic tests suggest that the Markov chains have converged to its stationary distribution after 1.5 million iterations.

4 Parameter estimates

Based on the two independent Markov Chains,[10] the posterior mean, median and 95 percent probability intervals are computed for each of the parameters, with results reported in Table (3). The prior and estimated posterior marginal densities are plotted in Figure 1. The plots indicate there is a significant amount of information contained in the data to update the prior beliefs about the model's parameters. The posterior marginal densities are much more concentrated compared to the prior densities with the exception of ϕ (the inverse elasticity of labour supply). Furthermore, the last column (no prior) of Table (3) reports the mean of the Markov chain draws with no priors placed on the model's parameters. The mean of the parameters[11] does not change significantly compare to the model estimated with the priors. However, there are a few exceptions: the inverse elasticity of intertemporal substitution (σ) is 0.15 compare to 0.39, the prior $\sigma = 1$ was slightly too high; the the inverse elasticity of labour supply (ϕ) turns out to be a lot higher, the weak identification in ϕ seems to be present in both cases; the Taylor rule coefficients ϕ_1 and ϕ_2 are 1.74 and 0.68 compare with 1.44 and 0.41 respectively, though the reaction function coefficients will not significantly affect the simulation results presented here.

[10]The reported statistics are computed after eliminating the first 40% of the Markov Chain (burn-in).

[11]These should collapse to the classical estimates.

The results indicate there is a relatively high degree of external habit persistence with $h^m = 0.92$ (the superscript m denotes the median of the posterior distribution) compared with other studies for the US and the euro area, eg: Smets and Wouters (2004) and Lubik and Schorfheide (2005). The degree of habit formation limits the elasticity of consumption with respect to real interest rate changes, while the impact from consumption on domestic inflation is much stronger. The median of the inverse elasticity of intertemporal substitution, σ, is estimated to be 0.39. Smaller values of σ imply households are less willing to accept deviations from a uniform pattern of consumption over time. This low value seems to be consistent with the relatively high degree of habit persistence discussed earlier. The posterior median for the elasticity of substitution between home and foreign goods, η, is around 0.85. The relatively low value for η is in line with the prior that New Zealand is a commodity-producer and its consumption basket relies heavily on foreign produced goods. The estimated inverse elasticity of substitution for labour, φ, turns out to be much greater than 1. This means a 1 percent increase in the real wage will result in only a small change in labour supply.

On the producer side, the median estimate of the probability of not changing price in a given quarter, or equivalently the proportion of firms that do not re-optimize their prices in a given quarter, is around 75 percent for domestic firms and slightly lower for import retailers at 72 percent. These Calvo coefficients imply the average duration of price contracts is around four quarters for domestic firms and three and half quarters for import retailers.[12] The aggregate degree of nominal price rigidity is much lower than that reported for the Euro area, but comparable with estimates for the US.

The simple reaction function used in the model provides a fairly good description of monetary policy over the stable inflation period in New Zealand. The posterior median for the degree of interest rate smoothing is estimated to be 0.724 with 1.445 and 0.413 being the weight on inflation and output respectively. The results obtained here are consistent with empirical estimates of Taylor rule coefficients in Plantier and Scrimgeour (2002).

[12] Duration $= \frac{1}{1-\theta_i}$.

5 Gains from commitment policy

This section investigates the welfare gain (or stabilization bias) to monetary policy under commitment using the small open economy model described in section (2) and parameters estimated in section (4). It is well recognized in the literature that commitment policy will produce a universally superior inflation outcome compared with discretionary policy due to the problem of time-inconsistency advocated by KPBG. The analysis here essentially quantifies the welfare improvement moving from discretionary to commitment policy (precommitment) for a small open economy.

For a small class of models, the second order approximation of the representative household's discounted life-time utility can be used as a measure of the model's theoretically consistent social welfare, see Erceg et al. (2000) and Woodford (2002) for example. However, this approach is only feasible for a small subset of models or as a special case by restricting the model's parameters.[13] As an alternative, it is widely accepted in the monetary policy literature that central banks should be concerned with inflation and some measure of real activity. In the case of New Zealand, this is much more explicitly set out in the Policy Target Agreement (PTA) between the Bank and the Minister of Finance.

> *"In pursuing its price stability objective, the Bank shall implement monetary policy in a sustainable, consistent, and transparent manner and shall seek to avoid unnecessary instability in output, interest rates and the exchange rate."*[14]

The social objective function is set up to be consistent with the PTA agreement, one that penalizes squared deviations in inflation from target, squared deviation in output from potential, squared deviation in the exchange rate and an interest rate smoothing term as in Rudebusch and Svensson (1998). The society's social welfare is approximated using the following loss function:

$$L(t,\infty) = E_t \sum_{j=0}^{\infty} \delta^j \left[\pi_{a,t+j}^2 + \lambda y_{t+j}^2 + \varsigma q_{t+j}^2 + \nu \Delta r_{t+j}^2 \right] \tag{40}$$

where $\pi_{a,t}$ is annualized inflation, y_t is output, q_t is the real exchange rate and Δr_t is the

[13] Gali and Monacelli (2005) derived the social welfare function using the second order approximation of the household's utility by setting $\sigma = \eta = \varphi = 1$.

[14] Extract from Section 4(c) of the PTA aggrement, 1999, available on the RBNZ website: `http://www.rbnz.govt.nz/monpol/pta/`.

change in the nominal interest rate; and λ, ς and ν are the weights relative to inflation. All variables are written as deviations from its steady state.

Under optimal commitment policy, the central bank optimizes once at $t = 0$ by minimizing the loss function given in equation (40) subject to the dynamic constraints of the economy, and permanently commits to the optimal plan. In this case, the dynamic equilibria of the economy will be augmented to reflect the commitment made earlier by the central bank.[15] Optimal discretionary policy is one where the central bank optimizes equation (40) on a period by period basis. The problem occurs once agents form expectation about the future, there is no longer any incentive for the central bank to follow through with earlier policy announcements, the classic time-inconsistency problem. The dynamic behavior of the economy under discretion constitutes Markov-perfect Stackelberg-Nash equilibria in which policymakers optimizing today is the Stackelberg leader, and private agents and future policymakers are Stackelberg followers. The algorithms described in Dennis (2006) was used to solve for the commitment and discretionary dynamic equilibria and the society's loss is calculated for each case.

To gain further quantitative insights into the welfare differential between discretionary policy and commitment, Dennis and Soderstrom (2006) used the permanent deviation of inflation from target that is equivalent to moving from discretion to commitment as a measure of society's welfare gain. The *inflation equivalent* measure for a particular set of model parameters, Θ, is given by:

$$\hat{\pi}(\Theta) = \sqrt{L_d(\Theta) - L_c(\Theta)} \tag{41}$$

where $L_c(\Theta)$ and $L_d(\Theta)$ are the values of the optimized social loss function for a particular set of model parameters Θ under commitment and discretion respectively. Other studies also report the percentage gain measure defined as $100\left(1 - \frac{L_c(\Theta)}{L_d(\Theta)}\right)$. The two different welfare measures are not necessarily monotonically related to each other. In some cases the two measures may even give quite conflicting results. The problem is more pronounced when both L_c and L_d are very small, and L_d approaches zero at a faster rate. The ratio in the percentage gain measure can grow very large. The inflation equivalent measure does not depend on the absolute value of the loss function, only the relative values, making

[15]The solution of the model will include a set of dynamic lagrange multipliers.

comparisons under different simulation scenarios much more meaningful. The discussion here will concentrate on the inflation equivalent measure which is also intuitively more appealing.

5.1 Baseline welfare simulation

First present the simulation results of 20,000 random draws from the stationary Markov chains distribution for six different combinations of policy preferences $[\lambda\ \nu\ \varsigma]$. This can also be thought of as a boot strapping exercise to simulate the actual distribution of the welfare gains using the MCMC draws. The PTA gives guidance on the choice of target variables, but not their relative weights in the loss function. Therefore the six different combinations of policy preferences presented here are by no means exhaustive, instead, these are chosen to provide a reasonable comparison with previous studies. The density plots of the inflation equivalent welfare measure ($\hat{\pi}$) is shown in Figure (2). Across all policy parameters, the mean of $\hat{\pi}$ is slightly higher than the mode of the distribution. This indicates the resultant welfare gains may not be symmetric about the peak of its distribution. There is greater uncertainty for higher values of welfare gain. Table (4) presents the simulation results in more detail. The value of the optimized loss is markedly higher once q_t^2 is included into the loss function, i.e: $\varsigma > 0$, this is mainly due to the relatively high estimated standard deviation for the real exchange rate shock.

If the central bank were to commit to an optimal policy rule, the welfare gain using the inflation equivalent measure varies between 2.07-4.52% depending on the central bank's preferences. The point estimates of $\hat{\pi}$ is slightly higher than those reported in Dennis and Soderstrom (2006) using various estimated models of the US economy, and Lees (2006) for New Zealand. However, the results are comparable once the probability intervals of the simulations are taken into account. All reported results indicate gains from precommitment are significantly above zero across a range of policy preferences. The largest gain is where the central bank only cares about inflation and smoothing interesting rate changes; whereas the smallest gain coincides with relatively large weight on output fluctuations. This is because commitment policy will always result in lower volatility in inflation and interest rate changes, but more volatility for output. This tradeoff between inflation and output volatility is consistent with many closed economy studies.

Figure (3) gives a 3-dimensional view of the simulation results as the weights on output

(λ) and exchange rate (ς) are varied while fixing the weight on the interest rate smoothing term (ν) to be 0.5.[16] The welfare gain is a monotonic increasing function with respect to the weight placed on the exchange rate for any given weight on output. $\hat{\pi}$ is maximized when the central bank places no weight on output and the highest weight on the exchange rate. Essentially the behavior of the exchange rate in the model is driven by changes in inflation and the interest rate through the UIP equation. For a given magnitude of the risk premium shock, commitment policy will always produce lower volatility for inflation and interest rate changes, this automatically translates into lower volatility for the exchange rate, hence greater gains from precommitment policy. The result is robust across all specifications of the policy weights for output and interest rate smoothing. If the central bank were to care about exchange rate fluctuations, as it is explicitly specified in the Reserve Bank of New Zealand's PTA, there is a much larger welfare gain from adopting optimal commitment rules.

5.2 The degree of openness

Next, the analysis focus on the welfare gains from precommitment as the economy becomes more open and integrated with the rest of the world. The control parameter α corresponds to the weight of foreign goods in the domestic consumption basket. The results of two policy preference scenarios are presented. First is the case where the central bank places no weight on exchange rate volatility and $\lambda = \nu = 0.5$, the second scenario corresponds to $\lambda = \nu = \varsigma = 0.5$.

For the first scenario, the mean (solid line) welfare gain across different degree of the openness are shown in Figure (4) along with its probability intervals (dotted line). The corresponding numerical statistics are summarized in Table (5). The mean of the distributions ranges from 2.07% to 2.36%. The estimated standard deviations are fairly constant across the different values of α at around 10% of the mean of the distributions. An "U" shaped function is observed for the welfare gain measure as α increases. The smallest welfare gain occurs when $\alpha = 0.4$ and the gain increases as the economy becomes either more open or closer.

To gain further insights into this phenomenon, the discussion here focus on the reduction

[16] The simulation results are generated using the mean of the posterior distribution of the model's structural parameters.

in the unconditional variances for each of the target variables π_t, y_t and Δr_t moving from discretion to commitment policy. The reduction in the unconditional variance of inflation increases as α gets larger. As the economy becomes more open, a larger proportion of the CPI is made up of foreign goods. A more credible policy stance is likely to reduce the volatility of inflation much more compare with a less credible one. On the other hand, the unconditional variance for output under discretion is smaller compared with commitment policy except in the case where the economy is sufficiently isolated ($\alpha < 0.15$). Furthermore, the welfare loss in terms of higher output volatility moving from precommitment increases with the degree of openness.

It can also be observed that the reduction in the unconditional variance for interest rate changes decrease as the degree of openness increases. As the economy becomes more open, the effect of the exchange rate channel becomes much stronger. This requires smaller interest rate movements to maintain inflation from its target, hence the reduction in the volatility of Δr_t from precommitment policy is smaller. The observed "U" shaped inflation equivalent welfare measure as the degree of openness increases comes down to the three way tradeoff between inflation, output and changes in the interest rate.

For the second scenario, output, exchange rate and interest rate changes enter the loss function with equal weights ($\lambda = \nu = \varsigma = 0.5$). The mean (solid line) of the inflation equivalent measures are shown in Figure (5) along with its probability intervals (dotted line), and the numerical values are summarized in Table (6). The variability of the inflation equivalent welfare measure is fairly constant across the different values of α. As discussed earlier in section (5.1), the welfare gain is larger once q_t^2 is included in the loss function. The social planner will find it more desirable to move to a optimal commitment plan if it is also concerned about exchange rate volatility. In this scenario, as the economy becomes more open, the welfare gains from precommitment decrease. This observation is mainly driven by the fact that the reduction in the unconditional variance of inflation decreases as α gets bigger, opposite to the first scenario where no exchange rate volatility is attached to the loss function. As the economy becomes more open, a greater proportion of the variation in the domestic economy can be attributed to foreign disturbances. In which case, optimal commitment policy is not able to deliver as much welfare gain compared with the close economy case.

The two different policy preference scenarios produce relatively different results in terms of welfare gains to optimal commitment policy when the economy becomes more open. In the first case, where the exchange rate is not included in the loss function, a higher degree of openness can deliver a higher magnitude of welfare gain from precommitment. The higher welfare gain can be explained by the significant reduction in inflation volatility relative to increased volatility in output. On the other hand, where the exchange rate is included in the loss function, a higher degree of openness reduces the welfare gain of commitment policy. The reduction comes as the gain from the lower unconditional variance of inflation decreases as the economy becomes more open.

6 Concluding remarks

This paper used Bayesian methods to combine prior information with the historical data, to develop a small open economy model of the New Zealand economy. The Bayesian approach provides a tool to understand and learn about the sources of uncertainty imbedded in quantitative macroeconomic modelling. The model was then set up to investigate the welfare gains from optimal commitment versus optimal discretion policy for a small open economy.

Dennis and Soderstrom (2006) had emphasized, the time-inconsistency problem is ultimately an empirical issue. This critically depends on the model one is working with as well as its parameters. This paper use a workhorse small open economy New Keynesian model and focus much of the discussion on welfare analysis arising from parameter uncertainty. This can also be thought of as a boot strapping exercise to simulate the actual distribution of the welfare gains using the MCMC draws. The simulation results reveal the welfare gains for a small open economy like New Zealand from committing to an optimal monetary rule is strictly positive. The result is robust across a range of policy preferences and model parameters. However, the exact magnitude of welfare gains differ significantly across different policy preferences and parameters. The welfare gain can be seen as an increasing function with respect to the weight placed on exchange rate variability. For a given magnitude of the risk premium shock, commitment policy will always produce lower volatility for inflation and interest rate changes. This automatically translates into lower volatility for the exchange rate through the UIP condition, hence greater gains from precommitment. This observation is independent of other policy preference parameters. However, there is no simple relationship between the gains from precommitment and the degree of openness of the economy. When exchange rate volatility is excluded from the loss function, an "U" shaped function is observed for the welfare gain as the economy becomes more open. On other hand, when exchange rate volatility is included, the gains from precommitment is an decreasing function of the degree of openness.

One of contributions in this paper was the use of Bayesian estimation technique to help isolate the source of uncertainty coming from the model's parameters. Using the posterior distribution of the parameters, the entire distribution for the estimated welfare gains are calculated rather than relying on the point estimates that is often reported in the literature. Furthermore, the behavior and policy decisions for a small open economy can differ hugely from its closed economy counterpart. The welfare gains presented in this paper can be thought of as the upper bound from precommitment, whereas in practice one would expect institutional constraints placed on the operation of monetary policy will limit the central bank's ability to fully commit to an optimal rule. However, in the case of New Zealand, there is still room for greater welfare improvements from more transparent and credible policy stance.

The analysis in this paper was restricted to a relatively simple specification of the model with only two sources of nominal rigidities, and a linear production function in labour. In future research, it would be interesting to expand the model to incorporate other factors of interest and investigate the welfare gain from precommitment, including: (i) capital accumulation and investment rigidities; (ii) labour market rigidities; and (iii) explicit optimizing behavior of the central bank.

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A Deriving the Domestic NKPC

The aggregate domestic price level will evolve according to:

$$P_{H,t} = \left\{ (1-\theta_H)\bar{P}_{H,t}^{1-\varrho} + \theta_H \left[P_{H,t-1} \left(\frac{P_{H,t-1}}{P_{H,t-2}} \right)^{\theta_H} \right]^{1-\varrho} \right\}^{\frac{1}{1-\varrho}} \tag{42}$$

When setting a new price, $\bar{P}_{H,t}$, in period t, an optimizing firm will seek to maximize the current value of its dividend stream subject to the sequence of demand constraints. In aggregate the following function is maximised:

$$\max_{\bar{P}_{H,t}} \sum_{k=0}^{\infty} (\theta_H)^k E_t \left\{ Q_{t,t+k} \left(Y_{t+k}(\bar{P}_{H,t} - MC_{t+k}^n) \right) \right\} \tag{43}$$

$$\text{subject to} \quad Y_{t+k} \leq \left(\frac{\bar{P}_{H,t}}{P_{H,t+k}} \right)^{-\varepsilon} (C_{H,t+k} + C_{H,t+k}^*)$$

where MC_{t+k}^n is the nominal marginal cost and the effective stochastic discount rate is now $\theta_H^k E_t Q_{t+k-1,t+k}$ to allow for the fact that firms have a $1-\theta_H$ probability of being able to reset prices in each period. The corresponding first order condition can be written as:[17]

$$\sum_{k=0}^{\infty} \theta_H^k E_t \left\{ Q_{t,t+k} Y_{t+k} (\bar{P}_{H,t} - \frac{\varepsilon}{1-\varepsilon} MC_{t+k}^n) \right\} = 0 \tag{44}$$

where $\frac{\varepsilon}{1-\varepsilon}$ is the real marginal cost if prices were fully flexible. Substituting out $Q_{t,t+k} = \beta^k \left(\frac{C_{t+k}}{C_t} \right)^{-\sigma} \left(\frac{P_t}{P_{t+k}} \right)$ from the consumption Euler equation in (5) yields:

$$\sum_{k=0}^{\infty} (\beta\theta_H)^k P_t^{-1} C_t^{-\sigma} E_t \left\{ P_{t+k}^{-1} C_{t+k}^{-\sigma} Y_{t+k} (\bar{P}_{H,t} - \frac{\varepsilon}{1-\varepsilon} MC_{t+k}^n) \right\} = 0 \tag{45}$$

[17] See the appendix in Gali and Monacelli (2005).

Since $P_t^{-1}C_t^{-\sigma}$ is known at date t, it can be taken out of the expectation summation, after rearranging yields:

$$\sum_{k=0}^{\infty}(\beta\theta_H)^k E_t\left\{P_{t+k}^{-1}C_{t+k}^{-\sigma}Y_{t+k}(\bar{P}_{H,t}-\frac{\varepsilon}{1-\varepsilon}MC_{t+k}^n)\right\}=0 \tag{46a}$$

$$\sum_{k=0}^{\infty}(\beta\theta_H)^k E_t\left\{C_{t+k}^{-\sigma}Y_{t+k}\frac{P_{H,t-1}}{P_{t+k}}\left(\frac{\bar{P}_{H,t}}{P_{H,t-1}}-\frac{\varepsilon}{\varepsilon-1}MC_{t+k}\frac{P_{H,t+k}}{P_{H,t-1}}\right)\right\}=0 \tag{46b}$$

where $MC_{t+k}=\frac{MC_{t+k}^n}{P_{H,t+k}}$ is the real marginal cost. Log-linearizing equation (46b) around the steady state to obtain the decision rule for $\bar{p}_{H,t}$ gives:

$$\bar{p}_{H,t}=p_{H,t-1}+\sum_{k=0}^{\infty}(\beta\theta_H)^k\{E_t\pi_{H,t+k}+(1-\beta\theta_H)E_t mc_{t+k}\} \tag{47}$$

that is, firms set their prices according to the future discounted sum of inflation and deviations of real marginal cost from its steady state. Log-linearizing the domestic aggregate price level in equation (42) yields:

$$\pi_{H,t}=(1-\theta_H)(\bar{p}_{H,t}-p_{H,t-1})+\theta_H^2\pi_{H,t-1} \tag{48}$$

Equation (47) can be rewritten as:

$$\begin{aligned}
\bar{p}_{H,t} &= p_{H,t-1}+\pi_{H,t}+(1-\beta\theta_H)mc_t \\
&\quad +(\beta\theta_H)\sum_{k=0}^{\infty}(\beta\theta_H)^k\{E_t\pi_{H,t+k+1}+(1-\beta\theta_H)E_t mc_{t+k+1}\} \\
&= p_{H,t-1}+\pi_{H,t}+(1-\beta\theta_H)mc_t+\beta\theta_H(\bar{p}_{H,t+1}-p_{H,t}) \\
\bar{p}_{H,t}-p_{H,t-1} &= \beta\theta_H E_t\pi_{H,t+1}+\pi_{H,t}+(1-\beta\theta_H)mc_t
\end{aligned} \tag{49}$$

The first line involves splitting up the summation into two terms, one at date t and the other from $t+1$ to ∞; the second line rewrites the last term using equation (47); lastly, (49) is rearranged to obtain the familiar NKPC equation. Substituting equation (49) back into (48), and then rearranging to obtain the evolution of domestic inflation as equation (16) in the text:

$$\pi_{H,t}=\beta(1-\theta_H)E_t\pi_{H,t+1}+\theta_H\pi_{H,t-1}+\lambda_H mc_t \tag{50}$$

where $\lambda_H=\frac{(1-\beta\theta_H)(1-\theta_H)}{\theta_H}$.

B Data description

- Domestic output (y_t) is (linear-) detrended, seasonally adjusted log real GDP per capita for New Zealand
- Overall inflation (π_t) is the annualized quarterly growth rate in the consumer price index (CPI) for New Zealand
- Import inflation ($\pi_{F,t}$) is the annualized quarterly growth rate in the import deflator for New Zealand
- Nominal interest rate (r_t) is the 90-day Bank Bill rate for New Zealand

- Competitive price index (s_t) is calculated by taking the log ratio of the foreign (80 percent US and 20 percent Australia) CPI and the domestic GDP deflator excluding imports
- Real exchange rate (q_t) is the log of weighted real exchange rate between the US (80 percent) and Australia (20 percent)
- Foreign output (y_t^*) is the weighted average of US (80 percent) and Australia (20 percent) detrended log real GDP per capita.
- Foreign real interest rate ($\bar{r}_t^*$) is the weighted average of US (80 percent) and Australia (20 percent) short term real interest rates.

Table 1: Prior distributions

Parameter	Domain	Density	Mean	Variance	95% Interval
h	[0, 1]	Beta	0.70	0.20	[0.321, 0.965]
σ	$\Re^+$	Normal	1.00	0.25	[0.589, 1.411]
η	$\Re^+$	Gamma	1.00	0.30	[0.563, 1.539]
φ	$\Re^+$	Gamma	1.00	0.30	[0.563, 1.539]
θ_H	[0, 1]	Beta	0.50	0.25	[0.097, 0.903]
θ_F	[0, 1]	Beta	0.50	0.25	[0.097, 0.903]
δ	[0, 1]	Beta	0.50	0.20	[0.178, 0.828]
ϕ_1	$\Re^+$	Gamma	1.50	0.25	[1.113, 1.933]
ϕ_2	$\Re^+$	Gamma	0.25	0.10	[0.111, 0.434]
ρ_a	[0, 1]	Beta	0.50	0.20	[0.178, 0.828]
ρ_{r^*}	[0, 1]	Beta	0.50	0.20	[0.178, 0.828]
ρ_{y^*}	[0, 1]	Beta	0.50	0.20	[0.178, 0.828]
$\sigma_i \ \forall i = 1, \ldots, 8$	$\Re^+$	Gamma	2	∞	[0, ∞]

Table 2: MCMC diagnostics tests based on two 1.5 million chains

	Post Mean	NSE[1]	P-Value[2]	B-G[3]	Auto(1)[4]	Auto(5)	Auto(10)	Auto(50)
h	0.924	0.001	0.491	1.001	0.946	0.842	0.767	0.458
σ	0.390	0.005	0.676	1.000	0.987	0.939	0.884	0.586
η	0.850	0.010	0.747	1.000	0.997	0.987	0.975	0.892
φ	1.828	0.086	0.531	1.009	1.000	0.999	0.998	0.990
θ_H	0.753	0.003	0.483	1.007	0.982	0.930	0.889	0.772
θ_F	0.724	0.001	0.670	1.000	0.963	0.843	0.735	0.429
ϕ_1	1.445	0.005	0.618	1.001	0.995	0.974	0.950	0.791
ϕ_2	0.413	0.004	0.766	1.000	0.994	0.970	0.941	0.758
ρ_r	0.724	0.002	0.775	1.000	0.989	0.948	0.903	0.668
ρ_{r^*}	0.832	0.002	0.986	1.000	0.992	0.961	0.924	0.687
ρ_a	0.978	0.000	0.950	1.000	0.923	0.725	0.584	0.224
ρ_{y^*}	0.785	0.004	0.933	1.000	0.998	0.990	0.980	0.906
σ_a	0.801	0.014	0.407	1.003	0.970	0.887	0.821	0.578
σ_s	9.164	0.042	0.812	1.000	0.998	0.991	0.981	0.912
σ_q	6.068	0.067	0.944	1.000	0.998	0.991	0.982	0.917
σ_{π_H}	1.566	0.003	0.534	1.000	0.955	0.800	0.648	0.171
σ_{π_F}	3.394	0.018	0.896	1.000	0.991	0.958	0.919	0.661
σ_r	0.771	0.002	0.773	1.000	0.991	0.955	0.912	0.645
σ_{y^*}	0.695	0.002	0.649	1.000	0.987	0.939	0.881	0.546
σ_{r^*}	0.538	0.001	0.854	1.000	0.981	0.912	0.833	0.441

1. NSE is the Numeric Standard Error as defined in Geweke (1999) .
2. The P-Value refers to test of two means generated from two independent chains, the test statistics is computed with $L = 0.08$, see Geweke (1999).
3. Univariate "shrink factor" for monitoring the between and within chain variance, see Brooks and Gelman (1998).
4. Autocorrelation functions at lag 1, 5, 10 and 50 respectively.
5. The acceptance rate for both of the Markov chains was around 22%.

Table 3: Posterior estimates using two independent 1.5 million Markov chain draws

	Prior mean	5%	95%	Post mean	Post Std	5%	95%	No prior
h	0.50	0.13	0.87	0.92	0.02	0.88	0.96	0.98
σ	1.00	0.37	1.92	0.39	0.12	0.19	0.68	0.15
η	1.00	0.38	1.92	0.85	0.15	0.58	1.16	0.81
φ	1.00	0.38	1.92	1.83	0.56	0.83	3.14	3.39
θ_H	0.50	0.06	0.94	0.75	0.02	0.71	0.80	0.79
θ_F	0.50	0.06	0.94	0.72	0.02	0.69	0.76	0.73
ϕ_1	1.50	1.05	2.03	1.44	0.10	1.27	1.67	1.74
ϕ_2	0.25	0.09	0.48	0.41	0.07	0.28	0.58	0.68
ρ_r	0.50	0.13	0.87	0.72	0.03	0.65	0.79	0.76
ρ_{r^*}	0.50	0.13	0.87	0.83	0.03	0.76	0.89	0.86
ρ_a	0.50	0.13	0.87	0.98	0.01	0.95	0.99	0.99
ρ_{y^*}	0.50	0.13	0.87	0.78	0.05	0.67	0.87	0.81
σ_a	0.53	0.32	0.88	0.80	0.20	0.49	1.27	0.65
σ_s	0.53	0.32	0.88	9.16	0.86	7.63	11.08	9.18
σ_q	0.53	0.32	0.88	6.07	0.83	4.68	8.10	6.39
σ_{π_H}	0.51	0.40	0.65	1.57	0.17	1.27	1.94	1.55
σ_{π_F}	1.04	0.70	1.55	3.39	0.40	2.70	4.30	3.31
σ_r	1.04	0.70	1.55	0.77	0.08	0.64	0.94	0.84
σ_{y^*}	2.38	1.04	5.32	0.69	0.07	0.58	0.84	0.70
σ_{r^*}	1.04	0.70	1.54	0.54	0.05	0.44	0.66	0.51

1. The parameters α and β were fixed at 0.4 and 0.99 respectively.

2. Prior statistics are computed using 100,000 prior draws.

3. Posterior statistics are computed after 40% burn in.

Table 4: Baseline welfare gains from commitment policy

λ	ν	ς	Loss		Inflation eq. $\hat{\pi}$	
y_t^2	$(\Delta r_t)^2$	q_t^2	Commit.	Discretion	Mean[1]	Std
1.0	1.0	1.0	173.1	193.6	4.52 [3.84, 5.37]	0.39
1.0	1.0	0	27.9	35.2	2.69 [2.21, 3.29]	0.28
0.5	0.5	0.5	105.6	116.4	3.28 [2.81, 3.88]	0.27
0.5	0.5	0	19.9	24.2	2.07 [1.71, 2.53]	0.21
1.0	1.0	0.5	114.6	128.2	3.67 [3.13, 4.36]	0.31
0	1.0	0	16.2	22.8	2.56 [2.11, 3.13]	0.26

1. The 2.5% and 97.5% probability intervals are indicated in the square brackets beside the mean.

Table 5: Unconditional variance and Welfare gain for $\lambda = \nu = 0.5$ and $\varsigma = 0$

Open.	$\sigma^2_{d,i} - \sigma^2_{c,i}$				Loss		Inflation eq. $\hat{\pi}$	
(α)	π	y	q	Δr	Com.	Dis.	Mean	Std
0.10	4.17	1.14	-112	3.99	24.8	30.4	2.36 [1.93, 2.84]	0.24
0.15	4.11	0.40	-103	4.75	22.1	27.3	2.27 [1.85, 2.75]	0.23
0.20	4.18	-0.47	-94	5.27	20.4	25.3	2.20 [1.80, 2.67]	0.22
0.25	4.34	-1.40	-86	5.52	19.4	24.0	2.15 [1.75, 2.61]	0.22
0.30	4.57	-2.35	-78	5.49	19.0	23.5	2.11 [1.73, 2.57]	0.22
0.35	4.85	-3.28	-71	5.18	19.2	23.6	2.08 [1.71, 2.54]	0.21
0.40	5.15	-4.17	-64	4.60	19.9	24.2	2.07 [1.71, 2.53]	0.21
0.45	5.49	-5.03	-58	3.79	20.9	25.3	2.07 [1.72, 2.54]	0.21
0.50	5.85	-5.84	-53	2.78	22.5	26.8	2.08 [1.73, 2.55]	0.21
0.55	6.26	-6.64	-49	1.64	24.1	28.6	2.12 [1.76, 2.60]	0.21
0.60	6.72	-7.42	-45	0.45	26.2	30.9	2.16 [1.79, 2.65]	0.22
0.65	7.24	-8.22	-42	-0.70	28.5	33.5	2.22 [1.83, 2.73]	0.23
0.70	7.86	-9.04	-40	-1.64	31.1	36.4	2.28 [1.88, 2.83]	0.24

1. The 2.5% and 97.5% probability intervals are indicated in the square brackets beside the mean.
2. All other reported point estimates corresponds to the mean of the distribution.

Table 6: Unconditional variance and Welfare gain for $\lambda = \nu = \varsigma = 0.5$

Open.	$\sigma^2_{d,i} - \sigma^2_{c,i}$				Loss		Inflation eq. $\hat{\pi}$	
(α)	π	y	q	Δr	Com.	Dis.	Mean	Std
0.10	25.42	4.77	-37.06	8.01	155.3	168.6	3.64 [3.03, 4.31]	0.32
0.15	24.20	4.25	-35.17	9.28	145.3	158.1	3.57 [2.99, 4.22]	0.31
0.20	23.07	3.67	-33.35	10.53	136.0	148.5	3.50 [2.96, 4.14]	0.30
0.25	22.01	3.05	-31.60	11.72	127.3	139.3	3.44 [2.93, 4.07]	0.29
0.30	21.02	2.38	-29.93	12.82	119.4	130.9	3.39 [2.89, 4.00]	0.28
0.35	20.10	1.69	-28.35	13.78	112.1	123.3	3.33 [2.85, 3.94]	0.27
0.40	19.26	0.97	-26.87	14.55	105.5	116.4	3.28 [2.81, 3.88]	0.27
0.45	18.50	0.24	-25.48	15.08	99.76	110.3	3.24 [2.78, 3.83]	0.27
0.50	17.83	-0.50	-24.20	15.35	94.74	105.0	3.19 [2.74, 3.78]	0.26
0.55	17.27	-1.25	-23.05	15.34	90.54	100.5	3.16 [2.71, 3.74]	0.26
0.60	16.84	-2.01	-22.03	15.04	87.20	97.07	3.13 [2.69, 3.70]	0.26
0.65	16.55	-2.78	-21.15	14.50	84.79	94.55	3.11 [2.67, 3.69]	0.26
0.70	16.43	-3.56	-20.42	13.80	83.32	93.05	3.11 [2.66, 3.69]	0.26

1. The 2.5% and 97.5% probability intervals are indicated in the square brackets beside the mean.
2. All other reported point estimates corresponds to the mean of the distribution.

Figure 1: Posterior and prior marginal density plot

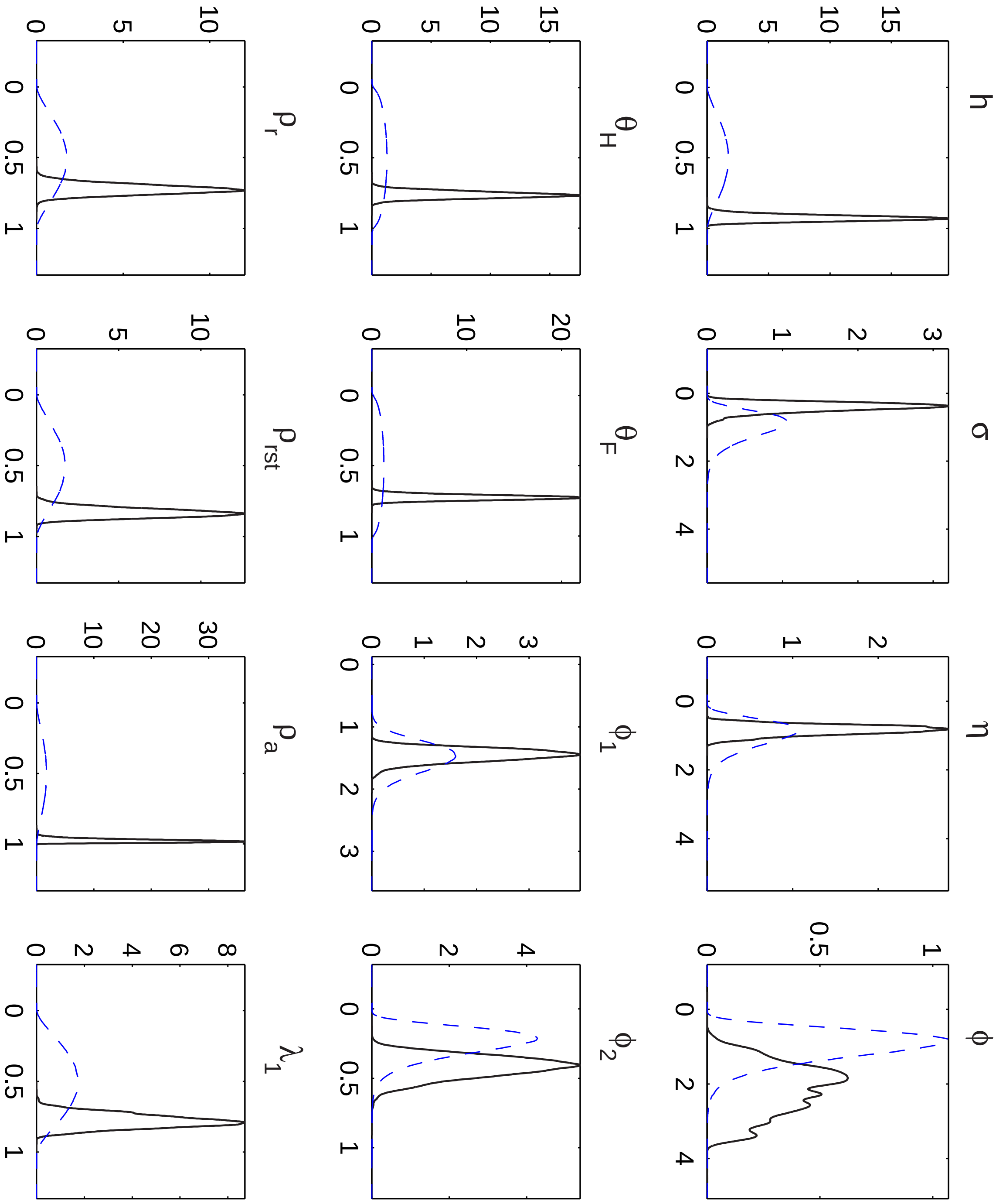

Figure 2: Inflation equivalent ($\hat{\pi}$) for various policy preferences

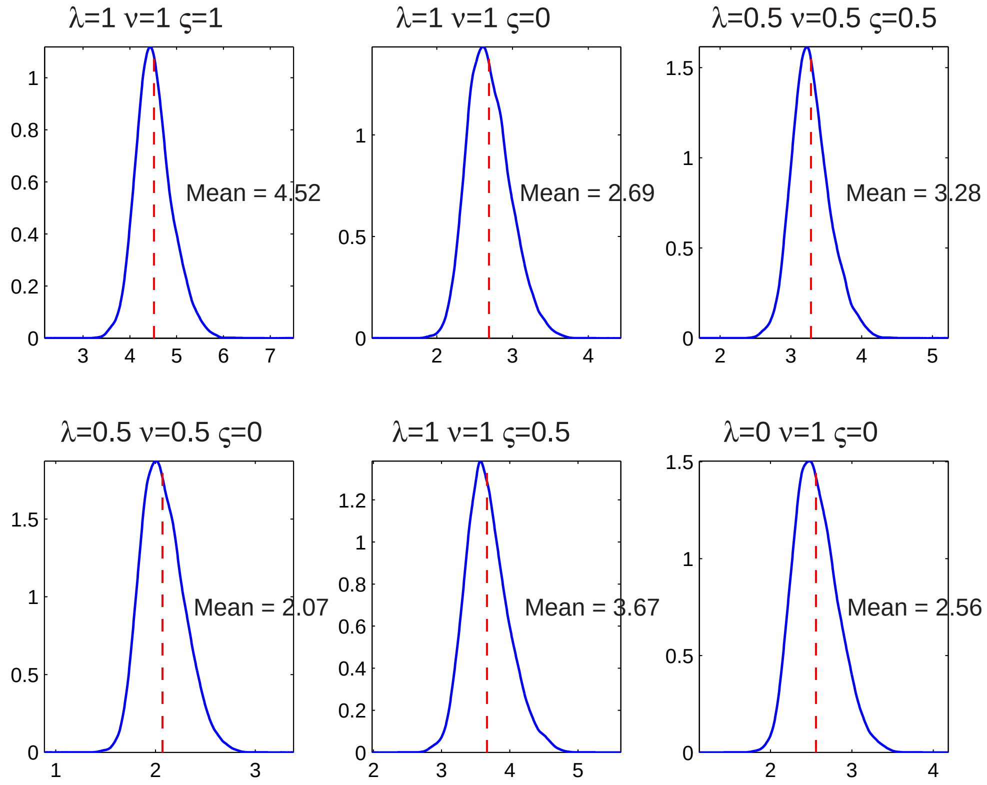

Figure 3: Inflation equivalent ($\hat{\pi}$) for λ and ς

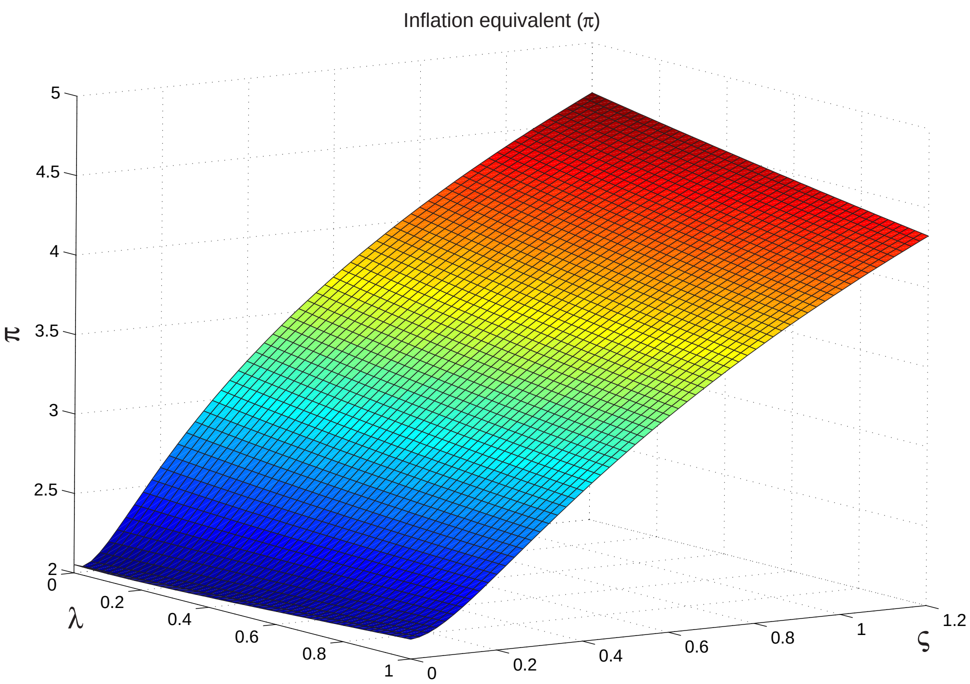

Figure 4: Inflation equivalent ($\hat{\pi}$) for various degree of openness (α) with $\lambda = \nu = 0.5$ and $\varsigma = 0$

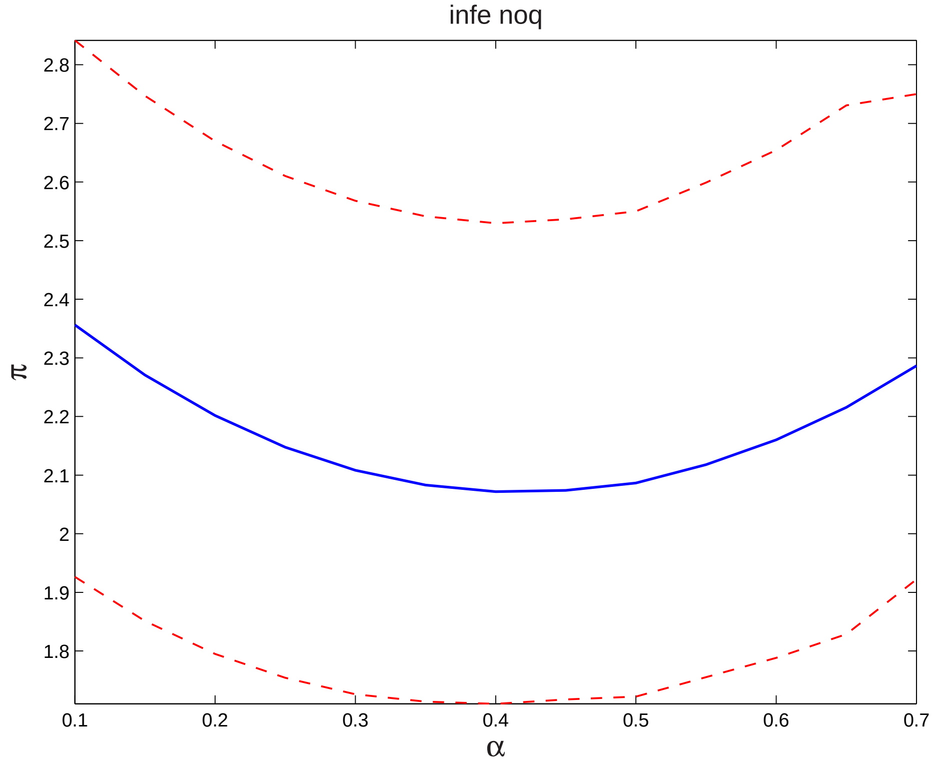

Figure 5: Inflation equivalent ($\hat{\pi}$) for various degree of openness (α) with $\lambda = \nu = 0.5$ and $\varsigma = 0.5$