Central Bank Learning and Stabilization With Complete and Partial Pass-Through

G.C. Lim*and Paul D. McNelis†

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Abstract

This paper examines the outcomes of alternative policy targets for monetary policy in an open economy subject to terms of trade shocks, when the central bank must learn the evolution of inflation and output growth in the design of its policy rules. We show that under conditions of intermediate exchange-rate pass through, a feedback rule for the interest rate, based on output growth as well as inflation targets, yields higher welfare effects than comparable feedback rules based only on inflation targets. Pure inflation targeting is preferable only in the polar cases of complete and zero pass through.

Key words: inflation targeting, Taylor rule, learning, exchange rate pass-through.

JEL Classification: E5, F4

*Department of Economics, University of Melbourne, Victoria, Australia. email: g.lim@unimelb.edu.au

†Department of Economics, Georgetown University, Washington, D.C. 20057. Email: McNelisP@georgetown.edu.

1 Introduction

There is now a growing literature concerned with the role of monetary policy within the class of "new open economy" macromodels [for a survey, see Lane (2002)]. Most of the papers deal with Taylor rules[1] and rely on "stickiness" either in price or wage setting to argue the case for monetary policy. In contrast, in this paper we draw attention to the problem of "learning", which is a form of "stickiness" in information. Mankiw and Reis (2002) contend that this form of stickiness displays properties which are more consistent with accepted views about monetary policy than the commonly used sticky-price model.

Learning has been introduced in this literature, but the papers have focussed on private sector learning of the policy rule of the Central Bank. For example, Bullard and Metra (2002) incorporate private sector learning of the specific Taylor rules used by the central bank in the Rotemberg-Woodford closed economy framework. They argue for Taylor rules based on *expectations* of *current* inflation and output deviations from target levels, rather than rules based on lagged values or forecasts further into the future. Orphanides and Williams (2002) also assume private sector learning, but the learning is about the "true" inflation dynamics as they reformulate their expectations.

In contrast to Bullard and Metra (2002) and Orphanides and Williams (2002), we assume, following Sargent (1999), that the learning process is on the side of the Central Bank. The monetary policy authority does not know the true laws of motion of inflation and growth dynamics generated by the private sector whose behavior can be described by a stochastic dynamic, nonlinear general equilibrium model, with forward-looking rational expectations. Instead the Central Bank has to learn about the laws of motion of inflation and growth from past data, through continuously-updated least squares regression. This information is then used to obtain an optimal interest rate feedback rule based on linear quadratic optimization, using weights in the objective function for inflation and growth which can vary with current conditions.

Such a learning framework accords more closely with real-life Central Bank policy setting behavior based on approximating models of the true economy. The monetary authority is thus "boundedly rational", in the sense of Sargent (1999), with "rational" describing the use of least squares, and "bounded" meaning model misspecification. The policy setting framework

[1] Recent technical papers on all aspects of the Taylor rule may be found on the web page, http://www.stanford.edu/~johntayl/PolRulLink.htm#Technical%20articles

may also be viewed as an adaptation of the robust optimal control modelling framework of Hansen and Sargent (2002).

The specific aim of the paper is to examine the role of interest rate policy in a small open economy subject to terms of trade shocks, with central bank learning. The price of export-goods is determined exogenously while the price of import-goods is determined according to the local currency pricing formulation of Betts and Devereux (1996, 2000). In this case, the degree of pass-through determines the degree of price stickiness in the model.

The focus on the pass-through as a measure of stickiness is also partly motivated by two seemingly contradictory results dealing with monetary policy and pass-through: Clarida, Gali and Gertler (2001) conclude that central banks should target domestic inflation for economies with *high* exchange rate pass-through, while Devereux (2001) argues for strict inflation targeting in an economy with *low* exchange rate pass-through. Of course, the results are not directly comparable since there are differences between the two models.

In this paper, the same model with "information stickiness" in the form of central bank learning behavior is simulated for different scenarios - the cases of complete and high pass-through as well as the cases of low and zero pass-through. Our results show that the effect of the degree of exchange-rate pass-through, on the price of traded goods does not matter for the design of central bank policy, if the degree of pass-through falls in the intermediate zone between complete and zero pass-through. To anticipate results, we show that under conditions of low or high exchange-rate pass through, a feedback rule for the interest rate, based on growth as well as inflation targets, yields equal or better welfare effects than comparable feedback rules based on pure price stability or low inflation targets. Only in the cases of zero or complete pass-through does pure inflation targeting dominate inflation and growth targeting in a welfare sense.

Thus, with central bank learning, a nonlinear relationship develops between the degree of pass-through and the inclusion of growth with inflation targets in the design of monetary policy. The reason we offer for this result is that in a learning environment, there are "information spillovers" between growth and inflation, which the monetary authority can exploit, in the evolution of its monetary feedback rule, when the degree of exchange-rate pass through is "intermediate".

In any learning environment, there is always the risk that the approximated laws of motion lag behind the actual laws of motion, or as Orphanides and Williams (2002) put it, learning adds an additional layer of dynamic interactions between monetary policy and economic outcomes. Since the learning that takes place in our model is done by the central bank, our results differ from Orphanides and Williams, who argued that monetary policy should respond more aggressively to inflation under the imperfect knowledge of learning than under perfect knowledge.

The next Section 2 describes the theoretical structure of the model for the private sector and the nature of the monetary authority "learning". Section 3 discusses the calibration as well as the solution method, while Section 4 analyzes the simulation results of the model for the two policy scenarios. It also discusses the accuracy and consistency of the model simulations as well as the implications for welfare. This section also contains a comparison of the central bank learning model for monetary policy with a simple optimal Taylor rule model of monetary policy. The last Section 5 concludes.

2 The Model

The framework of analysis contains two modules - a module which describes the behavior of the private sector and a module which describes the behavior of the central bank.

2.1 Private Sector Behavior

The private sector is assumed to follow the standard optimizing behavior characterized in dynamic stochastic general equilibrium models.

2.1.1 Consumption

The utility function for the private sector "representative agent" is given by the following function:

$$U(C_t) = \frac{C_t^{1-\gamma}}{1-\gamma} \tag{1}$$

where C is the aggregate consumption index and γ is the coefficient of relative risk aversion. Unless otherwise specified, upper case variables denote the levels of the variables while lower case letters denote logarithms of the same variables. The exception is the nominal interest rate denoted as i.

The representative agent as "household/firm" optimizes the following intertemporal welfare function, with an endogenous discount factor:

$$\begin{aligned} W_t &= \mathbf{E}\left[\sum_{i=0}^{\infty} \vartheta_{t+i} U(C_{t+i})\right] & (2)\\ \vartheta_{t+1+i} &= [1+\overline{C}_t]^{-\beta} \cdot \vartheta_{t+i} & (3)\\ \vartheta_t &= 1 & (4) \end{aligned}$$

where $\mathbf{E}_t$ is the expectations operator, conditional on information available at time t, while β approximates the elasticity of the endogenous discount factor ϑ with respect to the average consumption index, $\overline{C}$. Endogenous discounting is due to Uzawa (1968) and Mendoza (2000) states that endogenous discounting is needed for the model to produce well-behaved dynamics with deterministic stationary equilibria.[2]

The specification used in this paper is due to Schmitt-Grohé and Uribe (2001). In our model, an individual agent's discount factor does not depend on their own consumption, but rather their discount factor depends on the average level of consumption. Schmitt-Grohé and Uribe (2001) argue that this simplification reduces the equilibrium conditions by one Euler equation and one state variable, over the standard model with endogenous discounting, it greatly facilitates the computation of the equilibrium dynamics, while delivering "virtually identical" predictions of key macroeconomic variables as the standard endogenous-discounting model.[3] In equilibrium, of course, the individual consumption index and the average consumption index are identical. Hence,

$$C_t = \overline{C}_t \tag{5}$$

The consumption index is a composite index of non-tradeable goods n and tradeable goods f :

$$C_t = \left(C_t^f\right)^{\alpha_f} (C_t^n)^{1-\alpha_f} \tag{6}$$

where α_f is the proportion of traded goods. Given the aggregate consumption expenditure constraint,

$$P_t C_t = P_t^f C_t^f + P_t^n C_t^n \tag{7}$$

and the definition of the real exchange rate,

$$Z_t = \frac{P_t^f}{P_t^n} \tag{8}$$

the following expressions give the demand for traded and non-traded goods

[2] Endogenous discounting also allows the model to support equilibria in which credit frictions may remain binding.

[3] Schmitt-Grohé and Uribe (2001) argue that if the reason for introducing endogenous discounting is solely for introducing stationarity, "computational convenience" should be the decisive factor for modifying the standard Uzawa-type model. Kim and Kose (2001) reached similar conclusions.

as functions of aggregate expenditure and the real exchange rate Z:

$$C_t^f = \left(\frac{1-\alpha_f}{\alpha_f}\right)^{-1+\alpha_f} Z_t^{-1+\alpha_f} C_t \tag{9}$$

$$C_t^n = \left(\frac{1-\alpha_f}{\alpha_f}\right)^{\alpha_f} Z_t^{\alpha_f} C_t \tag{10}$$

Similarly, we can express the consumption of traded goods as a composite index of the consumption of export goods, C^x, and import goods C^m:

$$C_t^f = (C_t^x)_t^{\alpha_x} (C_t^m)^{1-\alpha_x} \tag{11}$$

where α_x is the proportion of export goods. The aggregate expenditure constraint for tradeable goods is given by the following expression:

$$P_t^f C_t^f = P_t^m C_t^m + P_t^x C_t^x \tag{12}$$

where P^x and P^m are the prices of export and import type goods respectively. Defining the terms of trade index J as:

$$J = \frac{P^x}{P^m} \tag{13}$$

yields the demand for export and import goods as functions of the aggregate consumption of traded goods as well as the terms of trade index:

$$C_t^x = \left(\frac{1-\alpha_x}{\alpha_x}\right)^{-1+\alpha_x} J_t^{-1+\alpha_x} C_t^f \tag{14}$$

$$C_t^m = \left(\frac{1-\alpha_x}{\alpha_x}\right)^{\alpha_x} J_t^{\alpha_x} C_t^f \tag{15}$$

2.1.2 Production

Production of exports and imports is by the Cobb-Douglas technology:

$$Y_t^x = A_t^x (K_{t-1}^x)^{1-\theta_x} \tag{16}$$

$$Y_t^m = A_t^m (K_{t-1}^m)^{1-\theta_m} \tag{17}$$

where A^x, A^m represents the labour factor productivity terms[4] in the production of export and import goods, and $(1-\theta_x)$, $(1-\theta_m)$ are the coefficients of

[4]Since the representative agent determines both consumption and production decisions, we have simplified the analysis by abstracting from issues about labour-leisure choice and wage determination.

the capital K^x and K^m respectively. The time subscripts $(t-1)$ indicates that they are the beginning-of-period values. The production of non-traded goods, which is usually in services, is given by the labour productivity term, A_t^n :

$$Y_t^n = A_t^n \tag{18}$$

Capital in each sector has the respective depreciation rates, δ_x and δ_m, and evolves according to the following identities:

$$\begin{aligned} K_t^x &= (1-\delta_x)K_{t-1}^x + I_t^x && (19) \\ K_t^m &= (1-\delta_m)K_{t-1}^m + I_t^m && (20) \end{aligned}$$

where I_t^x and I_t^m represents investment in each sector.

2.1.3 Budget Constraint

The budget constraint faced by the household/firm representative agent is:

$$P_t C_t = \Pi_t + S_t \left[L_t^* - L_{t-1}^*(1+i_{t-1}^*) \right] - \left[B_t - B_{t-1}(1+i_{t-1}) \right] \tag{21}$$

where S is the exchange rate (defined as domestic currency per foreign), L_t^* is foreign debt in foreign currency, and B_t is domestic debt in domestic currency. Profits Π is defined by the following expression:

$$\begin{aligned} \Pi_t &= P_t^x \left[A_t^x \left(K_{t-1}^x \right)^{1-\theta_x} - \frac{\phi_x}{2K_{t-1}^x} \left(I_t^x \right)^2 - I_t^x \right] \\ &\quad + P_t^m \left[A_t^m (K_{t-1}^m)^{1-\theta_m} - \frac{\phi_m}{2K_{t-1}^m} \left(I_t^m \right)^2 - I_t^m \right] + P_t^n A_t^n && (22) \end{aligned}$$

The aggregate resource constraint shows that the firm faces quadratic adjustment costs when they accumulate capital, with these costs given by the terms $\frac{\phi_x}{2K_{t-1}^x} \left(I_t^x \right)^2$ and $\frac{\phi_m}{2K_{t-1}^m} \left(I_t^m \right)^2$.

The household/firm may lend to the domestic government and accumulate bonds B which pay the nominal interest rate i. They can also borrow internationally and accumulate international debt L^* at the fixed rate i^*, but this would also include a cost of currency exchange.[5]

The change in bond holdings and foreign debt holdings evolves as follows:

$$\begin{aligned} P_t^n G_t &= B_{t+1} - B_t(1+i_t) && (23) \\ (P_t^x X_t - P_t^m M_t) &= -S_t \left(L_{t+1}^* - L_t^*[1+i_t^*] \right) && (24) \end{aligned}$$

[5]The time-varying risk premium is assumed to be zero.

2.1.4 Euler Equations

The household/firm optimizes the expected value of the utility of consumption (2) subject to the budget constraint defined in (21) and (22) and the constraints in (19) and (20).

$$
\begin{aligned}
Max \quad : \quad & Ł = \mathbf{E}_t \sum_{i=0}^{\infty} \vartheta_{t+i} \{ U(C_{t+i}) \\
& -\Lambda_{t+i} [C_{t+i} - \frac{P^x_{t+i}}{P_{t+i}} \left(A^x_{t+i} (K^x_{t-1+i})^{1-\theta_x} - \frac{\phi_x}{2K^x_{t-1+i}} \left(I^x_{t+i} \right)^2 - I^x_{t+i} \right) \\
& - \frac{P^m_{t+i}}{P_{t+i}} \left(A^m_{t+i} (K^m_{t-1+i})^{1-\theta_m} - \frac{\phi_m}{2K^m_{t-1+i}} \left(I^m_{t+i} \right)^2 - I^m_{t+i} \right) - \frac{P^n_{t+i}}{P_{t+i}} A^n_{t+i} \\
& - \frac{S_{t+i}}{P_{t+i}} \left(L^*_{t+i} - L^*_{t-1+i} (1 + i^*_{t-1+i}) \right) + \frac{1}{P_{t+i}} \left(B_{t+i} - B_{t-1+i} (1 + i_{t-1+i}) \right)] \\
& - Q^x_{t+i} \left[K^x_{t+i} - I^x_{t+i} - (1 - \delta_x) K^x_{t-1+i} \right] \\
& - Q^m_{t+i} \left[K^m_{t+i} - I^m_{t+i} - (1 - \delta_m) K^m_{t-1+i} \right] \}
\end{aligned}
$$

The variable Λ is the familiar Lagrangean multiplier representing the marginal utility of wealth. The terms Q^x and Q^m, known as Tobin's Q, represent the Lagrange multipliers for the evolution of capital in each sector - they are the "shadow prices" for new capital. Maximizing the Lagrangean with respect to $C_t, L^*_t, B_t, K^x_t, K^m_t, I^x_t, I^m_t$ yields the following first order conditions:

$$
\begin{aligned}
U'(C_t) - \Lambda_t &= 0 \\
\vartheta_t \Lambda_t \frac{S_t}{P_t} - \mathbf{E}_t \left[\vartheta_{t+1} \Lambda_{t+1} \frac{S_{t+1}}{P_{t+1}} (1 + i^*_t) \right] &= 0 \\
-\vartheta_t \Lambda_t \frac{1}{P_t} + \mathbf{E}_t \vartheta_{t+1} \Lambda_{t+1} \frac{1}{P_{t+1}} (1 + i_t) &= 0 \\
\left[\begin{array}{c} -\vartheta_t Q^x_t \\ +\mathbf{E}_t \vartheta_{t+1} Q^x_{t+1} (1 - \delta_x) \end{array} \right] + \mathbf{E}_t \vartheta_{t+1} \Lambda_{t+1} \frac{P^x_{t+1}}{P_{t+1}} \left[\begin{array}{c} A^x_{t+1} (1 - \theta_x) (K^x_t)^{-\theta_x} \\ + \frac{\phi_x \left(I^x_{t+1} \right)^2}{2 (K^x_t)^2} \end{array} \right] &= 0 \\
\left[\begin{array}{c} -\vartheta_t Q^m_t \\ +\mathbf{E}_t \vartheta_{t+1} Q^m_{t+1} (1 - \delta_m) \end{array} \right] + \mathbf{E}_t \vartheta_{t+1} \Lambda_{t+1} \frac{P^m_{t+1}}{P_{t+1}} \left[\begin{array}{c} A^m_{t+1} (1 - \theta_m) (K^m_t)^{-\theta_m} \\ + \frac{\phi_m \left(I^m_{t+1} \right)^2}{2 (K^m_t)^2} \end{array} \right] &= 0
\end{aligned}
$$

$$
\begin{aligned}
-\vartheta_t \Lambda_t \frac{P_t^x}{P_t}\left(\frac{\phi_x I_t^x}{K_{t-1}^x}+1\right)+\vartheta_t Q_t^x &= 0 \\
-\vartheta_t \Lambda_t \frac{P_t^m}{P_t}\left(\frac{\phi_m I_t^m}{K_{t-1}^m}+1\right)+\vartheta_t Q_t^m &= 0
\end{aligned}
$$

These equations can then be re-expressed as:

$$\Lambda_t = U'(C_t) \tag{25}$$

$$\vartheta_t U'(C_t) = \mathbf{E}_t \vartheta_{t+1} U'(C_{t+1})(1+i_t-\pi_{t+1}) \tag{26}$$

$$\mathbf{E}_t(s_{t+1}-s_t) = i_t - i_t^* \tag{27}$$

$$\left[\begin{array}{c} \vartheta_t Q_t^x \\ -\mathbf{E}_t \vartheta_{t+1} Q_{t+1}^x (1-\delta_x) \end{array}\right] = \mathbf{E}_t \vartheta_{t+1} \Lambda_{t+1} \frac{P_{t+1}^x}{P_{t+1}} \left[\begin{array}{c} A_{t+1}^x (1-\theta_x)(K_t^x)^{-\theta_x} \\ +\frac{\phi_x \left(I_{t+1}^x\right)^2}{2(K_t^x)^2} \end{array}\right] \tag{28}$$

$$\left[\begin{array}{c} \vartheta_t Q_t^m \\ -\mathbf{E}_t \vartheta_{t+1} Q_{t+1}^m (1-\delta_m) \end{array}\right] = \mathbf{E}_t \vartheta_{t+1} \Lambda_{t+1} \frac{P_{t+1}^m}{P_{t+1}} \left[\begin{array}{c} A_{t+1}^m (1-\theta_m)(K_t^m)^{-\theta_m} \\ +\frac{\phi_m \left(I_{t+1}^m\right)^2}{2(K_t^m)^2} \end{array}\right] \tag{29}$$

$$I_t^x = \frac{1}{\phi_x}\left(\frac{P_t}{P_t^x}\frac{Q_t^x}{\Lambda_t}-1\right) K_{t-1}^x \tag{30}$$

$$I_t^m = \frac{1}{\phi_m}\left(\frac{P_t}{P_t^m}\frac{Q_t^m}{\Lambda_t}-1\right) K_{t-1}^m \tag{31}$$

where $\Delta p_{t+1} = \log(P_{t+1}/P_t)$ is the per period inflation, s is the logarithm of the nominal exchange rate S and $(\mathbf{E}_t s_{t+1} - s_t)$ is the expected rate of exchange rate depreciation.

Equation (26) is the typical Euler equation for consumption. Using the utility function in (1) yields the consumption function:

$$C_t = \mathbf{E}_t\left[(1+i_t-\pi_{t+1})\vartheta_{t+1} C_{t+1}^{-\gamma}\right]^{-\frac{1}{\gamma}}$$

which shows how current consumption depends on expectations of future values. Equation (27) describes the interest arbitrage condition and the forwarding-looking behavior of the exchange rate.

The above equations (28) and (29) also show that the solutions for Q_t^x and Q_t^m, which determine investment and the evolution of capital in each sector, come from forward-looking stochastic Euler equations. The shadow price or replacement value of capital in each sector is equal to the discounted value of next period's marginal productivity, the adjustment costs due to the new capital stock, and the expected replacement value net of depreciation.

Thus the model has four "forward-looking" stochastic Euler equations, which determine C_t, s_t, Q_t^x, Q_t^m These variables, together with (25), in turn determine current investment I_t^x and I_t^m as describe by the conditions in (30) and (31).

2.1.5 Relative prices, exchange rate pass-through and stickiness

There are 7 prices (absolute and relative) to be determined (P^x, P^m, J, Z, P_t^f, P_t^n, P). The price of export goods is determined exogenously for a small open economy (P^{x*}) and its price in domestic currency is $P^x = SP^{x*}$. The price of import goods is also determined exogenously for a small open economy P^{m*}, but, we assume that price changes are incompletely passed-through (see Campa and Goldberg (2002) for a study on exchange rate pass-through and import prices). Using the definition: $P^m = SP^{m*}$ and assuming partial adjustment, we obtain:

$$p_t^m = \omega(s_t + p_t^{m*}) + (1-\omega)p_{t-1}^m \tag{32}$$

where $\omega = 1$ indicates complete pass-through of foreign price changes.

Thus, given P^x and P^m, we have $J = P^x/P^m$, and:

$$P_t^f = \left[(\alpha_x)^{-\alpha_x}(1-\alpha_x)^{-1+\alpha_x}\right](P_t^x)^{\alpha_x}(P_t^m)^{1-\alpha_x} \tag{33}$$

Finally, we obtain the aggregate consumption price deflator as:

$$P_t = \left[(\alpha_f)^{-\alpha_f}(1-\alpha_f)^{-1+\alpha_f}\right]\left(P_t^f\right)^{\alpha_f}(P_t^n)^{1-\alpha_f} \tag{34}$$

2.1.6 Macroeconomic Conditions And Market Clearing

The national accounting equation is:

$$\begin{aligned} & P_t^x\left(Y_t^x - \frac{\phi_x}{2K_t^x}(I_t^x)^2\right) + P_t^m\left(Y_t^m - \frac{\phi_m}{2K_t^m}(I_t^m)^2\right) + P_t^n Y_t^n \\ = \; & P_t^x\left(C_t^x + X_t + I_t^x\right) + P_t^m\left(C_t^m - M_t + I_t^m\right) + P_t^n\left(C_t^n + G_t\right) \\ = \; & P_t C_t + (P_t^x I_t^x + P_t^m I_t^m) + (P_t^x X_t - P_t^m M_t) + P_t^n G_t \end{aligned} \tag{35}$$

Real gross domestic product is given as:

$$y = \frac{1}{P_t}\left[P_t^x\left(Y_t^x - \frac{\phi_x}{2K_t^x}(I_t^x)^2\right) + P_t^m\left(Y_t^m - \frac{\phi_m}{2K_t^m}(I_t^m)^2\right) + P_t^n Y_t^n\right] \tag{36}$$

2.2 Monetary Authority

The Central Bank adopts practices consistent with optimal control models, specifically, the linear quadratic regulator problem. . It chooses an optimal interest rate reaction function, given its loss function equation, and its perception of the evolution of the state variables, inflation and growth. The change in the interest rate is the solution of the optimal linear quadratic regulator problem,with control variable Δi solved as a feedback response to the lagged state variables.

We assume, perhaps more realistically, that the monetary authority does not know the exact nature of the private sector model, instead it "learns" and updates the state-space model equation, which underpins its calculation of the optimal interest rate policy period by period. In other words, at each period time t, the Central Bank updates its information about the evolution of inflation and growth, and re-estimates the state-space system to obtain new estimates The central bank then uses this information to determine the optimal interest rate.

For this paper, two different policy scenarios are considered - a pure inflation targeting policy stance and an inflation-growth policy stance. The weights for inflation and output growth in the loss function depend on the conditions at time t.

- Pure Inflation targeting

In the pure inflation target case, the monetary authority estimates or "learns" the evolution of inflation as a function of its own lag as well as of changes in the interest rate.

$$\Lambda_1 = \lambda_{1t}(\pi_t - \pi^*)^2 \tag{37}$$

$$\pi_t = \sum_{j=0}^{k} \Gamma_{1t,j}\pi_{t-j-1} + \Gamma_{2t}\Delta i_t + e_t \tag{38}$$

$$i_{t+1} = i_t + \sum_{j=0}^{k} h(\widehat{\Gamma}_{1t,j}, \widehat{\Gamma}_{2t}, \lambda_{1t})\pi_{t-j-1} \tag{39}$$

where $\pi_t = \log(P_t/P_{t-4})$, an annualized rate of inflation, π^* is the target for inflation, and k is the number of lags for forecasting the evolution of the state variable. The feedback function h is obtained by solving the linear quadratic regulator problem, as discussed in Sargent (1999).

The weight on the loss function, $\lambda_t = \{\lambda_{1t}\}$ are chosen to reflect the Central Bank's concerns about inflation and is shown in Table I.

Table I: Policy Weights	
Inflation Only Target	
$\pi \leq \pi^*$	$\lambda_1 = 0.0$
$\pi > \pi^*$	$\lambda_1 = 1.0$

In this pure anti-inflation scenario, if inflation is less than the target level π^*, the central bank does not optimize; in other words, the interest rate remains at its level: $i_{t+1} = i_t$. This is the "no intervention" case. However, if inflation is above the target rate, the monetary authority implements its optimal interest policy according to equation (39).

- Inflation and Growth Targeting

In the inflation/growth scenario, the central bank learns the evolution of inflation and growth as functions of their own lags and of changes in the interest rate.

$$\Lambda_2 = \lambda_{1t}(\pi_t - \pi^*)^2 + \lambda_{2t}(\eta_t - \eta^*)^2 \tag{40}$$

$$x_t = \sum_{j=0}^{k} \Gamma_{1t,j}\pi_{t-j-1} + \sum_{j=0}^{k} \Gamma_{2t,}\eta_{t-j-1} + \Gamma_{3t}\Delta i_t + e_t \tag{41}$$

$$i_{t+1} = i_t + \sum_{j=0}^{k} h(\widehat{\Gamma}_{1t,j}, \widehat{\Gamma}_{2t,j}, \widehat{\Gamma}_{3t}, \lambda_{1t}, \lambda_{2t})x_{t-j-1} \tag{42}$$

where $n_t = \log(y_t/y_{t-4})$, the annualized rate of growth of output, and η^* represents the target for output growth. In this case, we have a bivariate forecasting model for the evolution of the state variables, π_t and η_t, with an equal number of lags; that is, the coefficient matrix $\Gamma_{1t,j}$, for k lags contains two $(k \times 1)$ recursively updated matrix coefficients, representing the effects of lagged inflation and growth on current inflation and growth.

The weights reflecting the Central Bank's preference for inflation and growth in this policy scenario are summarized in Table II.

Table II: Policy Weights		
Inflation and Growth Targets		
	Growth	
Inflation	$\eta_t < \eta^*$	$\eta_t \geq \eta^*$
$\pi \leq \pi^*$	$\lambda_1 = 0.1$ $\lambda_2 = 0.9$	$\lambda_1 = 0.0$ $\lambda_2 = 0.0$
$\pi > \pi^*$	$\lambda_1 = 0.5$ $\lambda_2 = 0.5$	$\lambda_1 = 0.9$ $\lambda_2 = 0.1$

In this second policy scenario, if inflation is below the target level π^* and output growth above the target η^*, the Central Bank does not change the policy interest rate. When inflation is below target, but growth is below target, the monetary authority puts greater weight on growth than on inflation. The contrast, when inflation is above target and growth is above target, the central bank puts strong weight on the inflation target. Finally, if inflation is above its target and growth is below its target, the weights are set equally at 0.5.

Thus, corresponding to each scenario, the Central Bank optimizes a loss function Λ and actively formulates its optimal interest-rate feedback rule. It also acts at time t as if its estimated model for the evolution of inflation and output growth is true "forever", and that its relative weights for inflation, or growth in the loss function are permanently fixed.

However, as Sargent (1999) points out in a similar model, the monetary authority's own procedure for re-estimation "falsifies" this pretense as it updates the coefficients $\{\Gamma_{1t}, \Gamma_{2t}, \Gamma_{3t}\}$, and solves the linear quadratic regulator problem for a new optimal response "rule" of the interest rate to the evolution of the state variables at every point of time t.

3 Calibration and Solution Algorithm

In this section we discuss the calibration of parameters, initial conditions, and stochastic processes for the exogenous variables of the model. We then summarize the parameterized expectations algorithm (PEA) used for solving the model.

3.1 Parameters and Initial Conditions

The parameter settings for the model appear in Table III.

Table III: Calibrated Parameters

Consumption	$\gamma = 1.5$, $\beta = 0.009$
	$\alpha_x = 0.5$, $\alpha_f = 0.5$
Production	$\theta_m = 0.7$, $\theta_x = 0.3$
	$\delta_x = \delta_m = 0.025$, $\phi_x = \phi_m = 0.03$

Many of the parameter selections follow Mendoza (1995, 2001). The constant relative risk aversion γ is set at 1.5 (to allow for high interest sensitivity).

The shares of non-traded goods in overall consumption is set at 0.5, while the shares of exports and imports in traded goods consumption is 50 percent each. Production in the export goods sector is more capital intensive than in the import goods sector.

The initial values of the nominal exchange rate, the price of non-tradeables and the price of importable and exportable goods are normalized at unity while the initial values for the stock of capital and financial assets (domestic and foreign debt) are selected so that they are compatible with the implied steady state value of consumption, $\overline{C} = 2.02$, which is given by the interest rate and the endogenous discount factor. The values of $\overline{C}^x$, $\overline{C}^m$, and $\overline{C}^n$ were calculated on the basis of the preference parameters in the sub-utility functions and the initial values of B and L^* deduced.

Similarly, the initial shadow price of capital for each sector is set at its steady state value. The production function coefficients A^m and A^x, along with the initial values of capital for each sector, are chosen to ensure that the marginal product of capital in each sector is equal to the real interest plus depreciation, while the level of production meets demand in each sector. Since the focus of the study is on the effects of terms of trade shocks, the domestic productivity coefficients were fixed for all the simulations.

Finally, the foreign interest rate i^* is also fixed at the annual rate of 0.04. In the simulations, the effect of initialization is mitigated by discarding the first 100 simulated values.

3.2 Terms of Trade and Currency Risk

The only shocks explored in this paper comes from the terms of trade. Specifically:

$$\begin{aligned} p_t^{x*} &= p_{t-1}^{x*} + \varepsilon_t^{x*}; \quad \varepsilon_t^{x*} \sim N(0, 0.01) \\ p_t^{m*} &= p_{t-1}^{m*} + \varepsilon_t^{m*}, \quad \varepsilon_t^{m*} \sim N(0, 0.01) \end{aligned}$$

where lower case denotes the logs of the respective prices. The evolution of the prices mimic actual data generating processes, namely that the variable is a unit-root autoregressive process, with a normally distributed innovation with standard deviation set at 0.01. The errors are assumed to be independent at this stage.

The simulations are also conducted assuming that the domestic price of export goods fully reflect the exogenously determined prices:

$$p_t^w = s_t + p_t^{x*} \tag{43}$$

however, the domestic price of import goods are partially passed on:

$$p_t^m = \omega(s_t + p_t^{m*}) + (1 - \omega)p_{t-1}^m \tag{44}$$

where ω is the coefficient of exchange rate pass-through. We consider the cases of low ($\omega = 0.3$) and high ($\omega = 0.9$) pass-through as well as the polar cases of zero ($\omega = 0.0$) and complete pass-through ($\omega = 1.0$).

Thus, this is a simulation study about the design of monetary policy for an economy subjected to relative price shocks. The log of the terms of trade (j) and the aggregate consumption price deflator (p) becomes respectively:

$$
\begin{aligned}
j &= s_t + p_t^{x*} - \omega(s_t + p_t^{m*}) - (1-\omega)p_{t-1}^m \\
p_t &= \alpha_f . \begin{bmatrix} \alpha_x(s_t + p_t^{x*}) + (1-\alpha_x)\left[\omega(s_t + p_t^{m*}) + (1-\omega)p_{t-1}^m\right] \\ -\alpha_x \ln(\alpha_x) + (\alpha_x - 1)\ln(1-\alpha_x) \end{bmatrix} \\
&\quad + (1-\alpha_f)p_t^n - \alpha_f \ln(\alpha_f) + (\alpha_f - 1)\ln(1-\alpha_f)
\end{aligned}
$$

3.3 Solution Algorithm and Constraints

Following Marcet (1988, 1993), Den Haan and Marcet (1990, 1994), and Duffy and McNelis (2001), the approach of this study is to parameterize the forward-looking expectations in this model, with non-linear functional forms ψ^S, ψ^C,ψ^{Q^x}, and ψ^{Q^f} :

$$
\begin{aligned}
\vartheta_t U'(C_t) &= \psi^C(\mathbf{x}_{t-1}; \Omega_C) \\
&= \mathbf{E}_t \vartheta_{t+1} U'(C_{t+1})(1 + i_t - \pi_{t+1})
\end{aligned} \tag{45}
$$

$$
\begin{aligned}
s_t &= \psi^S(\mathbf{x}_{t-1}; \Omega_S) \\
&= (i_t - i_t^*) - \mathbf{E}_t(s_{t+1})
\end{aligned} \tag{46}
$$

$$
\begin{aligned}
\vartheta_t Q_t^x &= \psi^{Q^x}(\mathbf{x}_{t-1}; \Omega_{Q^x}) \\
&= \mathbf{E}_t \vartheta_{t+1} \begin{bmatrix} \Lambda_{t+1} \frac{P_{t+1}^x}{P_{t+1}} \left(A_{t+1}^x (1-\theta_x)(K_t^x)^{-\theta_x} + \frac{\phi_x \left(I_{t+1}^x\right)^2}{2(K_t^x)^2} \right) \\ + Q_{t+1}^x(1-\delta_x) \end{bmatrix}
\end{aligned} \tag{47}
$$

$$
\begin{aligned}
\vartheta_t Q_t^m &= \psi^{Q^m}(\mathbf{x}_{t-1}; \Omega_{Q^m}) \\
&= \mathbf{E}_t \vartheta_{t+1} \begin{bmatrix} \Lambda_{t+1} \frac{P_{t+1}^m}{P_{t+1}} \left[A_{t+1}^m (1-\theta_m)(K_t^m)^{-\theta_m} + \frac{\phi_m \left(I_{t+1}^m\right)^2}{2(K_t^m)^2} \right] \\ + Q_{t+1}^m(1-\delta_m) \end{bmatrix}
\end{aligned} \tag{48}
$$

The symbol $\mathbf{x}_{t-1}$ represents a vector of observable instrumental variables known at time $t-$ the variables are: consumption of import C^m and export goods C^x, the marginal utility of consumption λ, the real interest rate r, the real exchange rate, Z, and the shadow prices of replacement capital for the two sectors, Q^m and Q^x, all expressed in deviations from the initial steady state:

$$\mathbf{x}_{t-1} = \{C^m - \overline{C^m}, C^x - \overline{C^x}, \lambda - \overline{\lambda}, r - \overline{r}, Z - \overline{Z}, Q^m - \overline{Q^m}, Q^x - \overline{Q^x}\} \quad (49)$$

The symbols $\Omega_\lambda, \Omega_S, \Omega_{Q^x}$, and Ω_{Q^m} represent the parameters for the expectation function, while $\psi^C, \psi^S, \psi^{Q^x}$ and ψ^{Q^f} are the expectation approximation functions.

Judd (1996) classifies this approach as a "projection" or a "weighted residual" method for solving functional equations, and notes that the approach was originally developed by Williams and Wright (1982, 1984, 1991). The functional forms for ψ^S, ψ^C, ψ^{Q^x}, and ψ^{Q^f} are usually second-order polynomial expansions [see, for example, Den Haan and Marcet (1994)]. However, Duffy and McNelis (2001) have shown that neural networks can produce results with greater accuracy for the same number of parameters, or equal accuracy with fewer parameters, than the second-order polynomial approximation.

The model was simulated for repeated parameter values for $\{\Omega_C$, Ω_S, Ω_{Q^x}, $\Omega_{Q^m}\}$ and convergence obtained when the expectational errors were minimized. In the algorithm, the following non-negativity constraints for consumption and the stocks of capital were imposed:

$$C_t^x > 0, \quad K_t^x > 0, \quad K_t^m > 0 \quad (50)$$

The latter was achieved by assuming irreversible investment for capital in each sector, that is for $i = X, M$:

$$I_t^i = \begin{cases} \frac{1}{\phi_i}\left(\frac{P_t}{P_t^x}\frac{Q_t^i}{\Lambda_t} - 1\right) K_{t-1}^i & \text{if } \frac{P_t}{P_t^x}\frac{Q_t^i}{\Lambda_t} > 1 \\ 0 & otherwise \end{cases} \quad (51)$$

The usual no-Ponzi game applies to the evolution of real government debt and foreign assets, namely:

$$\lim_{t\to\infty} B_t \exp^{-it} = 0, \qquad \lim_{t\to\infty} L_t^* \exp^{-(i^* + \Delta s_{t+1})t} = 0 \quad (52)$$

We keep the foreign asset or foreign debt to GDP ratio bounded, and thus fulfill the transversality condition, by imposing the following constraints on the parameterized expectations algorithm:[6]

[6] In the PEA algorithm, the error function will be penalized if the foreign debt/gdp ratio is violated. Thus, the coefficients for the optimal decision rules will yield debt/gdp ratios which are well belows levels at which the constaint becomes binding.

$$\left(\frac{|S_t L_t^*| / P_t}{y_t}\right) < \widetilde{L}, \qquad \left(\frac{|B_t| / P_t}{y_t}\right) < \widetilde{B} \tag{53}$$

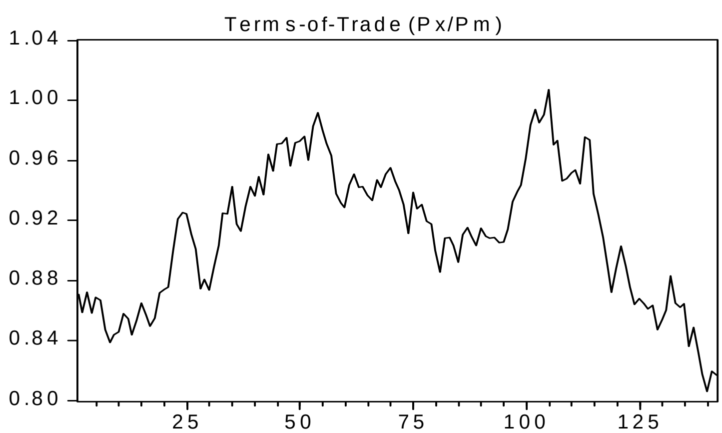
where $\widetilde{L}$, and $\widetilde{B}$ are the critical foreign and domestic debt ratios. In the simulation, the fiscal authority will exact lump sum taxes from non-traded goods sector in order to run a surplus and "buy back" domestic debt if it grows above a critical foreign or domestic debt/GDP ratio.

4 Simulation Analysis

4.1 Base-Line Results

The aim of the simulations is to compare the outcome for inflation, growth and welfare for the two policy scenarios - inflation targeting (π) and inflation-growth targeting (π and η) under the four scenarios - the zero to low pass-through ($\omega = 0.0$ and $\omega = 0.3$) and high to complete pass-through ($\omega = 0.9$, and $\omega = 1.0$). To ensure that the results are robust, we conducted 1000 simulations (each containing a time-series of 150 realizations of terms of trade shocks).

Figure 1 shows the simulated paths for one time series realization of the exogenous terms of trade index. This particular realization of the terms of trade shocks describes the case when there are improvements (upward trend) and deteriorations (downward trend), but where there are no export booms (almost all values are below one).



Evolution of the Terms of Trade

The simulated values for the key variables (inflation, growth, real exchange rate, current account) are well-behaved and Figure 2 presents the evolution of consumption for the 4 pass-through cases and for the two policy scenarios. As shown, in general, despite the large swings in the terms of trade index, consumption does not deviate appreciably and for long periods from its steady-state value. Also in general, the introduction of multiple targets for the monetary authority produces more volatility in the adjustment of consumption (reflecting to a certain extent that there is no interest-rate smoothing in the simulation analysis). But, it is interesting to note that the path of consumption is more stable with inflation targeting when $\omega = 0$ but more stable with inflation and growth targeting when $\omega = 1$.

To ascertain which policy regime yields the higher welfare value, we examined the distribution of the welfare outcomes of the different policy regimes for 1000 different realizations of the terms of trade shocks. Before presenting these results, we evaluated the accuracy of the simulation results as well as the rationality of the learning mechanism.

4.2 Den Haan-Marcet Accuracy Test

The accuracy of the simulations is checked by the Den Haan-Marcet statistic, originally developed for the parameterized expectations solution algorithm but applicable to other procedures as well. This test makes use of the Euler equation for consumption, under the assumption that with accurate expectations, the path of consumption would be optimal, so that expectational term in the Euler equation may be replaced by the actual term and a random error term, ν_t :

$$\vartheta_{t+1}\Lambda_{t+1}\frac{1}{P_{t+1}}(1+i_t) - \vartheta_t\Lambda_t\frac{1}{P_t} = \nu_t$$

To test whether v_t is significantly different from zero, Den Haan and Marcet propose a transformation of ν_t which has a chi-squared distribution under the hypothesis of accuracy. If the value of this statistic belongs to the upper or lower critical region of the chi-squared distribution, Den Haan and Marcet suggest that this is evidence "against the accuracy of the solution". [Den Haan and Marcet (1994): p. 5].

Table IV presents the percentage of realizations (out of 1000) in which the Den Haan-Marcet statistics fell in the upper or lower critical regions of the chi-squared distribution, for each policy regime, under alternative exchange-rate pass coefficients.

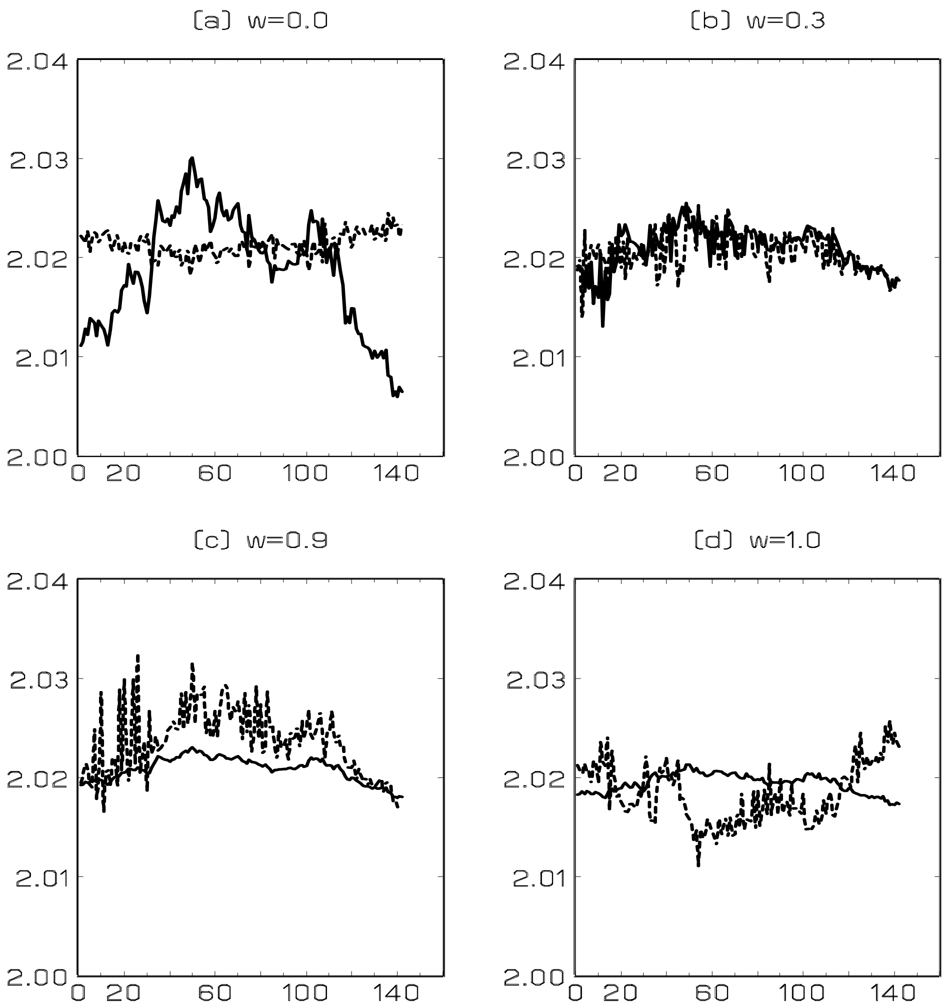


Figure 1: Evolution of Consumption under different exchange rate pass-throughs and policy regimes: inflation targetting (solid line) inflation-growth targetting (dashed line)

Table IV: Distribution of Den-Haan Marcet Statistic Percentage in Upper/Lower Critical Region				
	Pass Through Effect			
Policy Regime	$\omega = 0.0$	$\omega = 0.3$	$\omega = 0.9$	$\omega = 1.0$
Inflation Targeting	0.8/0.0	0.2/0.1	0.0/0.2	5.2/0.0
Inflation/Growth Targeting	3.7/0.0	0.7/0.0	2.0/0.0	1.9/0.0

4.3 Learning and Quasi-Rationality

In our model, the central bank learns the underlying process for inflation in the pure inflation-target regime and the underlying processes for inflation and growth in the inflation-growth target regime. The learning takes place by updating recursively the least-squares estimates of a vector autoregressive model.

Marcet and Nicolini (1997) raise the issue of reasonable rationality requirements in their discussion of recurrent hyperinflations and learning behavior. In our model, a similar issue arises. Given that the only shocks in the model are recurring terms of trade shocks, with no abrupt, unexpected structural changes taking place, the learning behavior of the central bank should not depart, for too long, from the rational expectations paths. The central bank, after a certain period of time, should develop forecasts which converge to the true inflation and growth paths of the economy, unless we wish to make some special assumption about monetary authority behavior.

Marcet and Nicolini discuss the concepts of "asymptotic rationality", "epsilon-delta rationality" and "internal consistency", as criteria for "boundedly rational" solutions. They draw attention to the work of Bray and Savin (1996). These authors examine whether the learning model rejects serially uncorrelated prediction errors between the learning model and the rational expectations solution, with the use of the Durbin-Watson statistic. Marcet and Nicolini point out that the Bray-Savin method carries the flavor of "epsilon-delta" rationality in the sense that it requires that the learning schemes be consistent "even along the transition" [Marcet and Nicolini (1997): p.16, footnote 22].

Following Bray and Savin, we use the Durbin-Watson statistic to examine whether the learning behavior is "boundedly rational". Table V gives the Durbin-Watson statistics for the inflation forecast errors of the central bank, under both policy regimes, and under alternative pass-through coefficients. In the majority of cases, we see that the learning behavior does not violate the requirements of bounded rationality. However, in two cases (inflation targeting with intermediate pass-through coefficients $\omega = 0.3$ and

$\omega = 0.9$) there is evidence that learning is not bounded rationality, in other words, the implied evolution of inflation is not easily captured by our vector-autoregressive model.

Table V: Durbin-Watson Statistics for Forecast Errors
Percentage in Lower and Upper Critical Region

	$\omega = 0.0$		$\omega = 0.3$	
Policy Regime	Inflation	Growth	Inflation	Growth
Inflation Targeting	0.0/0.1	–	0.0/28.0	–
Inflation/Growth Targeting	0.0/.3	1.6/.2	0.0/0.1	0.6/0.0
	$\omega = 0.9$		$\omega = 1.0$	
	Inflation	Growth	Inflation	Growth
Inflation Targeting	0.0/32.0	–	0.0/0.0	–
Inflation/Growth Targeting	0.0/0.1	0.7/0.0	0.0/0.1	0.0/0.0

4.4 Comparative Welfare Results

This section summarizes the results for 1000 alternate realizations of the terms-of-trade shocks (each realization contains 150 observations). Table VI presents the first two moments of the 1000 sample means for consumption, inflation, growth, the changes in the policy instrument - the interest rate - and the intertemporal welfare loss index (based on the discounted utility function). The welfare loss index is the percentage difference between the welfare under the different policy scenarios and the welfare index under the steady-state values of consumption. Results are presented for the 4 pass-through assumptions ($\omega = 0.0$, 0.3 and $\omega = 0.9$, 1.0) and the two alternative policy stances (targeting inflation π and targeting inflation and growth π, η).

Figure 3 presents the kernel estimates of the distribution of the sample means from each of the 1000 realizations for the relative welfare measure. It shows rather sharply that the welfare effects, relative to the steady state welfare, of inflation/growth targeting (dashed line) are either about the same or *better* for incomplete pass-through, but are either about the same or *worse* for the polar case of zero and perfect pass-through. Since these polar cases are least likely to match real world pass-through estimates, as cited by Campos and Goldberg (2002), our distributions appear to favor inflation/growth targeting over pure inflation targeting.

Table VI: Summary Statistics (1000 Simulations) First and Second Moments (in Parenthesis) of the sample means				
	$\omega = 0.0$		$\omega = 0.3$	
	Policy Regimes		Policy Regimes	
	π	π, η	π	π, η
Consumption (c)	2.021 (0.001)	2.019 (0.014)	2.022 (0.003)	2.022 (0.003)
Inflation Rate (π)%	-0.075 (0.131)	0.050 (0.140)	-0.098 (0.269)	-0.181 (0.192)
Growth Rate (η)%	-0.001 (0.003)	0.000 (0.000)	-0.004 (0.008)	-0.005 (0.005)
Interest Rate (Δi)%	0.052 (0.070)	0.053 (0.080)	0.056 (0.096)	0.053 (0.076)
Relative Welfare (W)%	-1.310 (0.060)	-1.391 (0.068)	-1.227 (0.125)	-1.262 (0.104)

Table VI: (cont'd) First and Second Moments (in Parenthesis) of the sample means				
Variable:	$\varpi = 0.9$		$\varpi = 1.0$	
	Policy Targets		Policy Targets	
	π	π, η	π	π, η
Consumption (c)	2.023 (0.002)	2.029 (0.004)	2.021 (0.002)	2.016 (0.005)
Inflation Rate (π)%	-0.074 (0.334)	-0.098 (0.236)	-0.125 (0.176)	-0.158 (0.205)
Growth Rate (η)%	0.000 (0.004)	0.003 (0.011)	-0.001 (0.003)	0.005 (0.009)
Interest Rate (Δi)%	0.029 (0.095)	0.056 (0.099)	0.050 (0.068)	0.032 (0.066)
Relative Welfare (W)%	-1.210 (0.088)	-1.37 (0.05)	-1.309 (0.062)	-1.563 (0.176)

Since Table V showed that the "learning" is more efficient, in terms of rationality, under imperfect pass-through, with inflation and growth targeting, it should not be surprising that this policy regime may outperform pure inflation targeting for overall welfare. The results show that the gains from incorporating the additional growth target for monetary policy are related in a non-linear way to the degree of exchange-rate pass through.

The result for the polar cases ($\omega = 0$ and $\omega = 1$) is similar to that obtained by Corsetti and Pesenti (2001), for incorporating binding international agreements in monetary policy. They found that under the extreme assumptions of complete and zero pass-through, monetary policies are "strategically independent" and "there are no policy spillovers", while "gains from cooperation materialize in economies with intermediate levels of pass-through" [Corsetti and Pesenti (2001): p. 2-3]. In a similar manner, in our framework, there

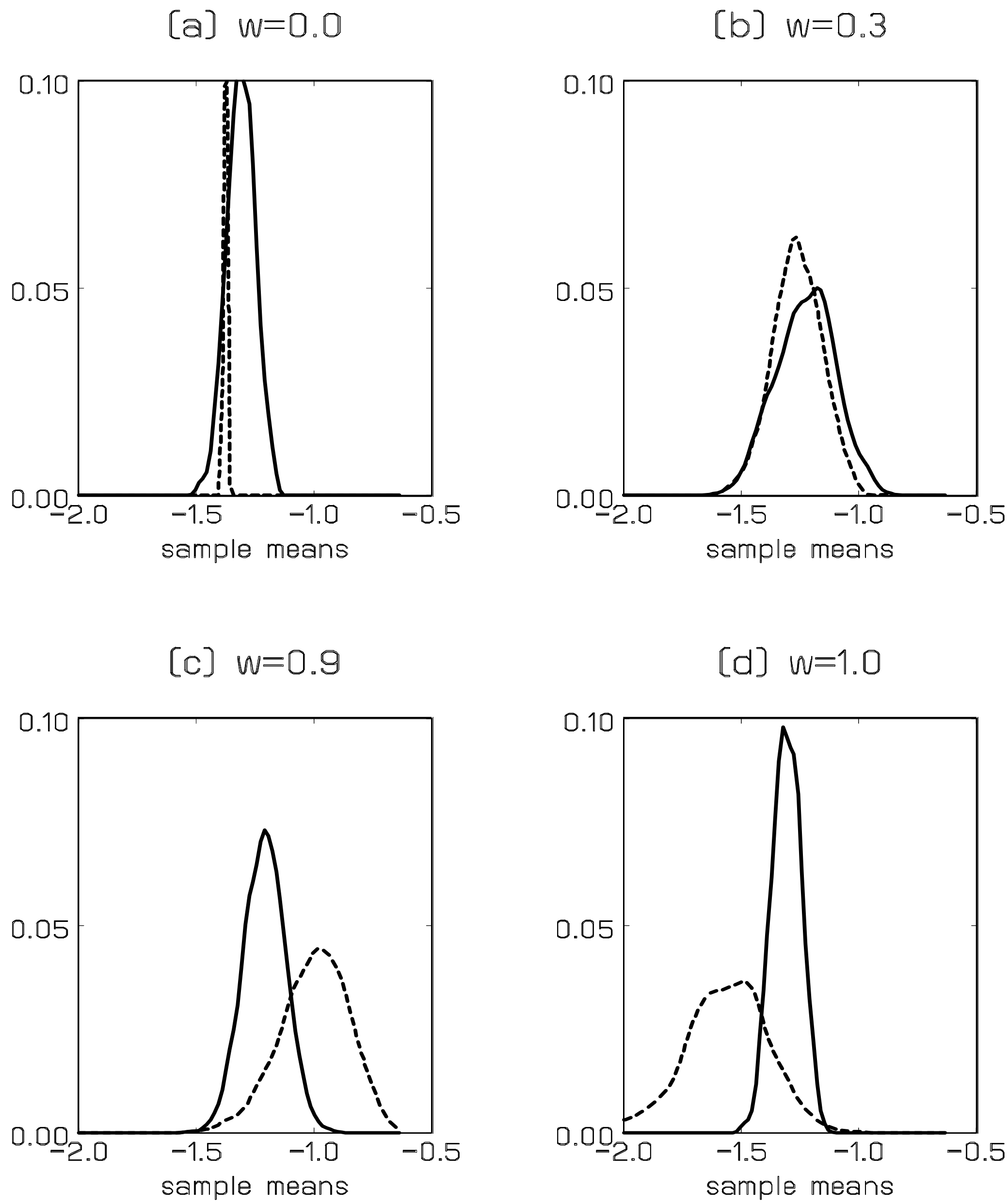


Figure 2: Distributions of Relative Welfare

are "information spillovers" between growth and inflation, to be exploited by inflation and growth targeting in the conduct of monetary policy, with intermediate levels of pass-through. To be sure, the welfare gains or losses are not dramatic, relative to the overall welfare measure, for the different policy regimes. This should not be surprising: we have only one shock, to the terms of trade, and only two forms of stickiness, through imperfect pass through, and through learning. So the scope of monetary policy for improving welfare is limited. On the contrary, it would be very surprising if alternative monetary policy regimes had markedly different effects on welfare. Nevertheless, there are differences, and there is a case for including growth as a target, in addition to inflation, when there are intermediate degrees of pass through.

4.5 Relation to Optimal Monetary Policy

To better assess our results, we compare the welfare estimates obtained under learning with those given by optimal monetary policy. The optimal monetary policy we take as the benchmark is the use of a Taylor rule, in which the change in the interest rate, $i_{t+1} - i_t$, responds to the difference between actual inflation at time t, π_t,and target inflation, π^*, as well as between actual growth, η_t, and target growth, η^* :

$$i_{t+1} - i_t = \lambda_\pi(\pi_t - \pi^*) + \lambda_\eta(\eta_t - \eta^*) \tag{54}$$

In this case, the coefficients λ_π and λ_η are estimated with the other PEA coefficients yielding the optimal decision-rules for consumption, for the expected exchange rate, and the expected values of Tobin's Q, through the parameterized expectations algorithm. These coefficients are set optimally for the intertemporal welfare optimization.

We compare the welfare outcomes under learning under two versions of the optimal Taylor rule: one in which $\lambda_\pi \neq 0$, $\lambda_\eta = 0$, i.e., a restricted Taylor rule, in which interest rates only respond to inflation targets; and one in which $\lambda_\pi \neq 0$, $\lambda_\eta \neq 0$, i.e, an unrestricted Taylor rule, in which interest rates respond to both inflation and growth targets. While this very simplified Taylor rule is only one among many for the computation of optimal monetary policy, it serves as a ready benchmark for determining how well the learning process and recursive updating of feedback coefficients will converge to the welfare obtained by an optimal monetary policy framework where the monetary authorities act to maximize overall welfare.

Figure 4 pictures the distributions of the two optimal Taylor-type feedback monetary policy rules. A number of conclusions emerge. One is that

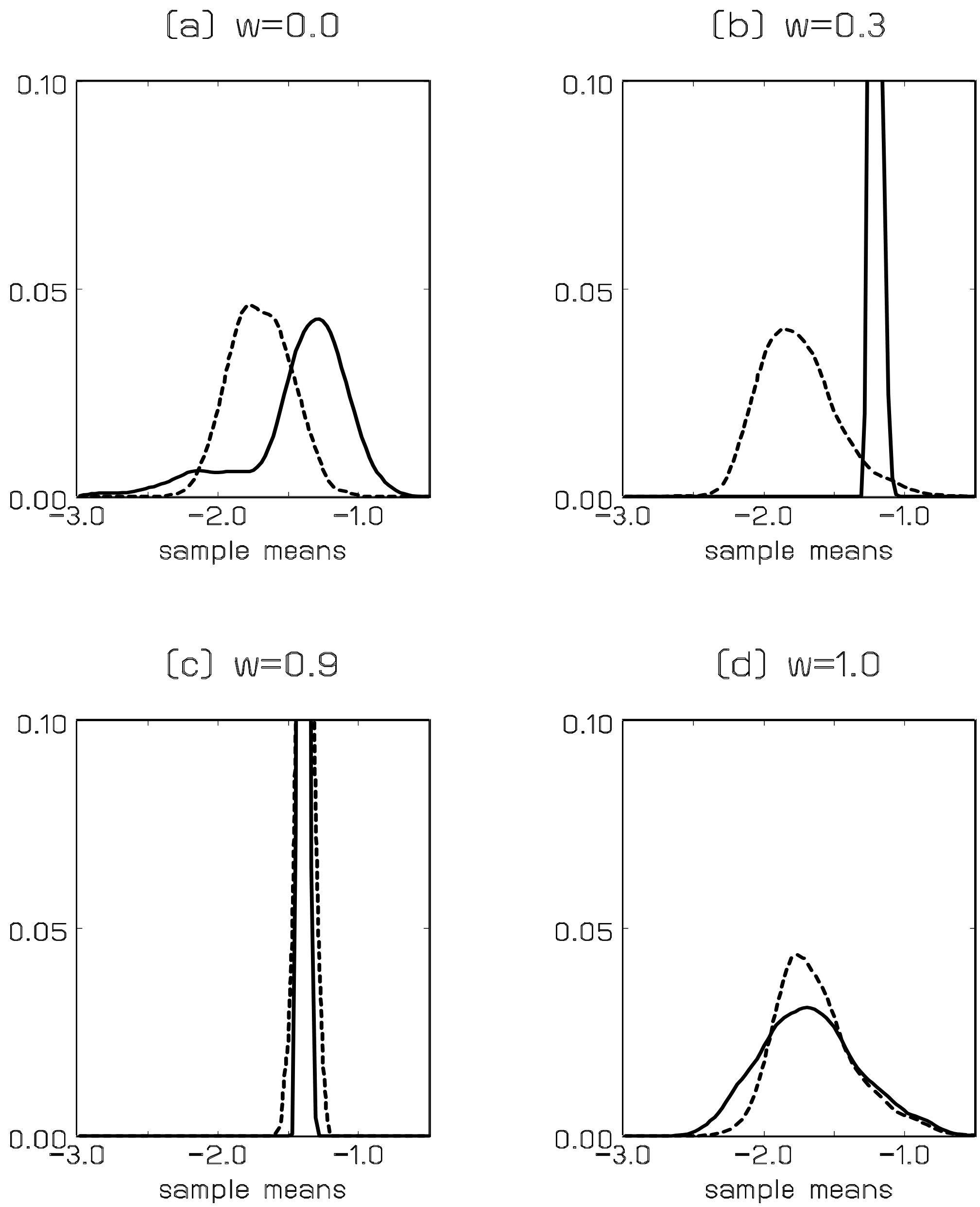


Figure 3: Distributions of Relative Welfare

under high to complete pass through (and thus high price flexibility), it does not matter which monetary policy rule is used. However for zero or relatively low-pass through, the restricted inflation-only rule dominates the rule based on inflation and growth feedback. Optimal monetary policy rules, based on simple Taylor formulations, in our model, do not give much support for inflation as well as growth in the interest-rate rule.

However, there is one other conclusion which comes from a comparison of Figures 3 and 4. The overall welfare distributions obtained under learning are not worse, and in some cases better, than the welfare distributions generated by optimal monetary policy with the simple Taylor framework. This indicates that the learning mechanism, with the continuous updating of the laws of motion of inflation and growth dynamics, as well as the revision of the interest-rate rule, is approximating a more complex optimal Taylor framework. Central bank learning rules can bring the economy to welfare outcomes which do at least as well or better than the simplified optimal Taylor rules. In this sense, the learning mechanism provides an attractive "robust decision-making framework" for monetary policy, since it appears to be capable of tracking an unspecified more complex Taylor rule which dominates optimal rules based on current inflation and growth variables.

5 Conclusions

This paper has produced some evidence in favor of "flexible" inflation targeting in countries where there is incomplete pass-through of exchange rate effects. This result is consistent with many of the results obtained by the "new neo-classical synthesis" literature in macroeconomics. Following Canzoneri, Cumby and Diba (2002), we offer a case in which inflation targeting "need not be seen as a choice that excludes Keynesian stabilization", so that it may not be necessary to give price stability exclusive focus as in the statutes of the new central bank of Europe, nor in small commodity-producing countries subject to terms-of-trade shocks with incomplete or intermediate pass-through.

However, we stress that the case for inflation/growth targeting depends on the stickiness in learning as well as the intermediate ranges for the pass-through coefficient. Of course, in this paper, we have only some "price stickiness" (when we allow incomplete pass through in the traded goods sector), and some "learning", by the policy makers at the central bank. There is no wage-setting stickiness with its ensuing effects on employment and production. And the learning mechanism of the central bank may be made even more accurate through more sophisticated forecasting methods, such as Kalman filtering. But even in our set-up, with linear least-squares learning, it is illustrative to see how stickiness in learning affects the policy stance of the monetary authority, and can deliver welfare distributions which dominate even optimal policy rules based on simplified Taylor frameworks.

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