Endogenous Price Flexibility, the Expenditure Switching Effect and Exchange Rate Regime Choice

Ozge Senay*and Alan Sutherland†

27 May 2004

Abstract

Endogenous price flexibility and the expenditure switching effect are analysed in a dynamic general equilibrium model of a small open economy where agents may choose the frequency of price changes. A fixed exchange rate is compared to inflation targeting and money targeting. A fixed rate generates more price flexibility than the other regimes when the expenditure switching effect is relatively weak, while money targeting generates more flexibility when the expenditure switching effect is strong. These endogenous changes in price flexibility can lead to significant changes in the welfare performance of regimes. But, for the model calibration considered here, a peg does not generate enough price flexibility to compensate for the loss of monetary independence. Inflation targeting yields the highest welfare level despite generating the least price flexibility of the three regimes considered.

Keywords: exchange rates, expenditure switching, welfare, endogenous price flexibility.

JEL: E52, F41, F42

*Department of Economics, Middle East Technical University, Ankara 06531, Turkey. E-mail: osenay@metu.edu.tr. Web: www.econ.metu.edu.tr/people/osenay

†Department of Economics, University of St Andrews, St Andrews, Fife, KY16 9AL, UK. Email: ajs10@st-and.ac.uk. Web: www.st-and.ac.uk/~ajs10/home.html

1 Introduction

This paper presents a welfare comparison between a fixed exchange rate and two alternative floating exchange rate regimes. The main focus of analysis is on the interaction between the choice of exchange rate regime and the endogenous determination of the degree of price flexibility.

Early proponents of floating exchange rates, such as Friedman (1953), argued that floating exchange rates are desirable because they provide a degree of insulation against foreign shocks. A floating rate regime allows a country to set its monetary policy independently from the monetary policy of other countries. This prevents the transmission of foreign shocks to the domestic economy. Thus, it was argued, floating exchange rates act as a 'shock absorber' which helps to stabilise the domestic economy. Recently an extensive literature has developed analysing the choice of exchange rate regime based on welfare comparisons in general equilibrium models with sticky-prices. This new literature has allowed a re-examination of the shock-absorber role of the exchange rate (see Devereux and Engel (1998, 2003), Devereux (2000, 2003, 2004) and Bachetta and van Wincoop (2000)). This new literature is, however, largely based on models where the degree of price flexibility is exogenously determined and does not change in response to a change in monetary regime.[1] The welfare comparison presented in this literature is therefore potentially subject to a form of the Lucas (1976) critique. The Lucas critique suggests that it is implausible that the degree of price flexibility remains unaffected if a change in monetary regime produces a large change in the volatility of output or other important macro variables. There are therefore strong theoretical reasons to investigate the endogenous determination of price flexibility. In addition to the theoretical motivation for considering endogenous price flexibility, there is a further motivation arising from the policy debate on the choice of monetary regime. It has been argued, for instance, that monetary union in Europe will encourage greater price flexibility which will partly (or completely) offset the loss of monetary independence. This argument can not be addressed within the theoretical structure adopted in most of the current literature.

This paper uses a sticky price general equilibrium model of a small open economy to analyse the implications of fixed and floating exchange rates. The model departs from much of the recent literature by allowing the degree of price flexibility to be determined endogenously. The home country is subject to stochastic shocks from a number of internal and external sources and the focus of interest is on the stabilisation and welfare implications of regime choice for the home country. Price setting is subject to Calvo-style price contracts but, unlike the standard Calvo (1983) structure, agents are allowed to choose the average frequency of price changes. Agents must balance the benefits of price flexibility against the costs involved in changing prices. Since the benefits of price flexibility depend in large part on the volatility

[1] The only exception is Devereux (2003). The differences between the current paper and Devereux's are discussed below.

of the macroeconomic environment, the optimally chosen degree of price flexibility differs between exchange rate regimes. The model is used to analyse the stabilising properties of each regime and to carry out a welfare comparison between fixed and floating exchange rates.

A second respect in which the model used in this paper departs from much of the recent literature is that the elasticity of substitution between home and foreign goods is allowed to differ from unity.[2] This makes it possible to analyse the implications of the expenditure switching effect for the choice of regime. There are good reasons to suppose that the strength of the expenditure switching effect may interact with the endogenous determination of price flexibility in ways which will affect the welfare comparison between regimes. In a previous paper (Senay and Sutherland (2004)) the impact of the expenditure switching effect was analysed using a model where the degree of price flexibility is *exogenously* fixed. There, it was shown that the expenditure switching effect can play a significant role in the welfare comparison between regimes. A floating exchange rate regime yields higher welfare when the expenditure switching effect is relatively weak, but a fixed exchange rate regime is superior when the expenditure switching effect is strong. It was found that the key mechanism which drives the relative welfare performances of the two regimes is the impact of regime choice on the volatility of output. The volatility of output is particularly sensitive to the choice of exchange rate regime when the expenditure switching effect is strong. These previous results suggest that, when the degree of price flexibility is endogenously determined, there may be an important interaction between the expenditure switching effect, the degree of price flexibility and the choice of exchange rate regime. The results of the current paper show that this interaction is indeed potentially important.

There have been a number of papers that have previously analysed the implications of endogenous price flexibility. These include De Long and Summers (1986), Ball and Romer (1989a, 1989b, 1990, 1991), Dotsey, King and Wolman (1999), Kiley (2000), Calmfors and Johansson (2002) and Devereux (2003). De Long and Summers (1986) investigate whether increased price and wage flexibility stabilises or destabilises macro variables. They show that increased price and wage flexibility may in fact be destabilising when there is a mixture of supply and demand shocks. Calmfors and Johansson (2002) analyse the stabilising properties of endogenising wage flexibility for a small open economy joining a monetary union. Given that joining a monetary union is believed to increase macro variability, a country facing the loss of monetary independence has an incentive to increase the degree of wage

[2]The empirical literature on the elasticity of substitution between home and foreign goods provides evidence to suggest that the expenditure switching effect may be much stronger than assumed in much of the recent open economy literature. Obstfeld and Rogoff (2000) briefly survey some of the relevant literature. They quote estimates for the elasticity ranging between 1.2 and 21.4 for individual goods (see Trefler and Lai (1999)). Typical estimates for the average elasticity across all traded goods lie in the range 5 to 6 (see for instance Hummels (2001)). Anderson and van Wincoop (2003) also survey the empirical literature on trade elasticities and conclude that a value between 5 and 10 is reasonable.

indexation. Calmfors and Johansson show, using a simple linear model with an *ad hoc* quadratic welfare function, that greater variability in prices which accompanies increased wage flexibility, may in fact be welfare decreasing.

Of the papers above, perhaps the one most closely related with the present paper is Devereux (2003).[3] This is the only paper to analyse the implications of exchange rate policy for the flexibility of prices in an open economy stochastic general equilibrium model. Devereux shows that a fixed rate regime followed by a single country tends to increase the degree of price flexibility within that country.[4] However, a fixed rate regime followed by two countries (a monetary union) is shown to reduce the degree of price flexibility to a level even below that of a floating regime. Before proceeding, it may be useful to emphasize the features of this paper that distinguish it from Devereux (2003). Devereux compares fixed and floating exchange rates in a single-period model where agents can choose in advance to set prices before or after exogenous shocks are realised. The model in this paper differs from the Devereux model in four important respects. Firstly, the model presented here is a fully dynamic framework with multi-period contracts. Secondly, the model allows the elasticity of substitution between home and foreign goods to differ from unity (whereas Devereux restricts this elasticity to unity). Thirdly, the model is one where a small open economy, facing a choice of alternative policy regimes interacts with a large foreign economy, whereas Devereux uses a model of two large countries. And finally, the analysis below presents a welfare comparison between monetary policy regimes (whereas Devereux focuses on a purely positive analysis).

The paper proceeds as follows. Section 2 presents the structure of the model. Section 3 describes the different policy regimes to be compared. Section 4 discusses the solution method and approximation of the model. Section 5 analyses the comparison between exchange rate regimes under exogenous and endogenous price flexibility, and section 6 concludes the paper.

2 The Model

The model is a variation of the sticky-price general equilibrium structure which has become standard in the recent open economy macroeconomics literature (following the approach developed by Obstfeld and Rogoff (1995, 1998)).[5] The world consists of two countries, which will be referred to as the home country and the foreign country. The world population is indexed on the unit interval with home agents

[3] Ball and Romer (1990), Dotsey, King and Wolman (1999) and Kiley (2000) analyse the impact and propagation of monetary shocks in models with endogenous price flexibility. They do not directly address any implications for welfare or the choice of monetary policy regime in such models.

[4] Devereux (2003) emphasizes the role of strategic complementarity in the incentive of price setters to re-adjust prices *ex post* and shows that strategic complementarity increases the degree of price flexibility.

[5] See Lane (2001) for a recent survey of this literature.

indexed $h \in [0, n)$ and foreign agents indexed $f \in [n, 1]$. In the numerical exercises reported below n is chosen to be small.

The foreign monetary authority is assumed to be following a policy of strict targeting of producer-price inflation. The analysis focuses on the choice of monetary policy regime for the home economy. Three possible regimes are considered for the home economy. The specification of these regimes is described below.

The two economies are subject to labour supply and income tax shocks, while the foreign economy is also subject to random changes in its inflation target.

Agents consume a basket of goods containing all home and foreign produced goods. Each agent is a monopoly producer of a single differentiated product. Prices are set in the currency of the producer. Price setting follows the Calvo (1983) structure. In any given period agent j is allowed to change the price of good j with probability $(1 - \gamma_j)$.

The timing of events is as follows. In period 0 the home monetary authority makes its choice of monetary regime. Immediately following this policy decision, all agents in both countries are allowed to make a first choice of price for trade in period 1 (and possibly beyond). Simultaneously, all agents are also allowed the opportunity to make a once-and-for-all choice of Calvo-price-adjustment probability (i.e. γ_j). In each subsequent period, beginning with period 1, stochastic shocks are realised, individual agents receive their Calvo-price-adjustment signal (which is determined by their individual choices of γ, i.e. γ_j), those agents which are allowed to adjust their prices do so, and finally trade takes place.

The detailed structure of the home country is described below. The foreign country has an identical structure. Where appropriate, foreign real variables and foreign currency prices are indicated with an asterisk.

2.1 Preferences

All agents in the home economy have utility functions of the same form. The utility of agent h is given by

$$U_t(h) = E_t \left[\sum_{s=t}^{\infty} \beta^{s-t} \left(\frac{C_s^{1-\rho}(h)}{1-\rho} + \chi \log \frac{M_s(h)}{P_s} - \frac{K_s}{\mu} y_s^{\mu}(h) \right) \right] - A(\gamma_h) \tag{1}$$

where χ is a positive constant, C is a consumption index defined across all home and foreign goods, M denotes end-of-period nominal money holdings, P is the consumer price index, $y(h)$ is the output of good h and E is the expectations operator. K is a stochastic shock to labour supply preferences which evolves as follows

$$\log K_t = \zeta_K \log K_{t-1} + \varepsilon_{K,t} \tag{2}$$

where ε_K is symmetrically distributed over the interval $[-\epsilon, \epsilon]$ with $E[\varepsilon_K] = 0$ and $Var[\varepsilon_K] = \sigma_K^2$.

The expected costs of adjusting prices are represented by the function $A(\gamma_h)$. The form of this function is discussed in more detail below.

The consumption index C for home agents is defined as

$$C = \left[n^{\frac{1}{\theta}} C_H^{\frac{\theta-1}{\theta}} + (1-n)^{\frac{1}{\theta}} C_F^{\frac{\theta-1}{\theta}} \right]^{\frac{\theta}{\theta-1}} \tag{3}$$

where C_H and C_F are indices of home and foreign produced goods defined as follows

$$C_H = \left[\left(\frac{1}{n} \right)^{\frac{1}{\phi}} \int_0^n c_H(i)^{\frac{\phi-1}{\phi}} di \right]^{\frac{\phi}{\phi-1}}, \quad C_F = \left[\left(\frac{1}{1-n} \right)^{\frac{1}{\phi}} \int_n^1 c_F(j)^{\frac{\phi-1}{\phi}} dj \right]^{\frac{\phi}{\phi-1}} \tag{4}$$

where $\phi > 1$, $c_H(i)$ is consumption of home good i and $c_F(j)$ is consumption of foreign good j. The parameter θ is the elasticity of substitution between home and foreign goods. This is the key parameter which determines the strength of the expenditure switching effect.

2.2 Price Indices

The aggregate consumer price index for home agents is

$$P = \left[n P_H^{1-\theta} + (1-n) P_F^{1-\theta} \right]^{\frac{1}{1-\theta}} \tag{5}$$

where P_H and P_F are the price indices for home and foreign goods respectively defined as

$$P_H = \left[\frac{1}{n} \int_0^n p_H(i)^{1-\phi} di \right]^{\frac{1}{1-\phi}}, \quad P_F = \left[\frac{1}{1-n} \int_n^1 p_F(j)^{1-\phi} dj \right]^{\frac{1}{1-\phi}} \tag{6}$$

The law of one price is assumed to hold. This implies $p_H(i) = Sp_H^*(i)$ and $p_F(j) = Sp_F^*(j)$ for all i and j where an asterisk indicates a price measured in foreign currency and S is the exchange rate (defined as the domestic price of foreign currency). Purchasing power parity holds in terms of aggregate consumer price indices, $P = SP^*$.

2.3 Financial Markets

International financial trade is restricted to a risk free international real bond which is denominated in units of the consumption basket (which is identical in both countries). The budget constraint of agent h is given by

$$\begin{aligned} P_t B_t(h) + M_t(h) &= (1+r_t)\varphi_t P_t B_{t-1}(h) + M_{t-1}(h) + (1-\tau_t) p_{H,t}(h) y_t(h) \\ &\quad - P_t C_t(h) - T_t + R_t(h) \end{aligned} \tag{7}$$

where $B(h)$ is bond holdings, $M(h)$ is money holdings, T is a lump-sum government transfer, and P is the aggregate consumer price index. τ is an income tax rate which is assumed to evolve randomly as follows

$$\log(1-\tau_t) = \zeta_\tau \log(1-\tau_{t-1}) + \varepsilon_{\tau,t} \tag{8}$$

where ε_τ is symmetrically distributed over the interval $[-\epsilon, \epsilon]$ with $E[\varepsilon_\tau] = 0$ and $Var[\varepsilon_\tau] = \sigma_\tau^2$. These income tax disturbances represent a form of 'cost push' shock which affect prices but which do not affect the natural level of output. They differ from the labour supply shocks, K, which affect both prices and the natural level of output.

As is standard in much of the literature, individual agents are assumed to have access to a market for state-contingent assets which allows them to insure against the idiosyncratic income shocks implied by the Calvo pricing structure.[6] The payoff to agent h's portfolio of state-contingent assets is given by $R(h)$.

Bond holdings are subject to a cost which is related to the aggregate stock of bonds held. The holding cost is represented by the multiplicative term φ_t in the budget constraint where

$$\varphi_t = 1/(1+\delta B_{t-1}) \tag{9}$$

and B is the aggregate holding of bonds by the home population.

Home agents can also hold wealth in the form of a home nominal bond which is not internationally traded but which can be a substitute for the international bond amongst home agents. Likewise, foreign agents may hold a foreign nominal bond which is also not internationally traded but which can be a substitute for the international bond amongst foreign agents. The rate of return on the home nominal bond will be linked to the rate of return on the international bond by the generalised Fisher relationship as follows

$$(1+i_t) = (1+r_t)\frac{1}{P_t}\frac{E\left[C_{t+1}^{-\rho}\right]}{E\left[\frac{C_{t+1}^{-\rho}}{P_{t+1}}\right]} \tag{10}$$

An equivalent expression holds for the foreign nominal bond.

The government's budget constraint is

$$M_t - M_{t-1} + T_t + \tau_t P_{H_t} Y_t = 0 \tag{11}$$

Changes in the money supply are assumed to enter and leave the economy via changes in lump-sum transfers.

[6] There is a separate market for state-contingent assets in each country and there is no international trade in state-contingent assets.

2.4 Consumption Choices

The intertemporal dimension of home agents' consumption choices gives rise to the familiar consumption Euler equation

$$\frac{1}{C_t^{\rho}} = \beta(1+r_t)\varphi_t E_t\left[\frac{1}{C_{t+1}^{\rho}}\right] \tag{12}$$

A similar condition holds for foreign agents.

Individual home demands for representative home good, h, and foreign good, f, are given by

$$c_H(h) = C_H\left(\frac{p_H(h)}{P_H}\right)^{-\phi}, \quad c_F(f) = C_F\left(\frac{p_F(f)}{P_F}\right)^{-\phi} \tag{13}$$

where

$$C_H = nC\left(\frac{P_H}{P}\right)^{-\theta}, \quad C_F = (1-n)C\left(\frac{P_F}{P}\right)^{-\theta} \tag{14}$$

Foreign demands for home and foreign goods have an identical structure to the home demands. Individual foreign demand for representative home good, h, and foreign good, f, are given by

$$c_H^*(h) = C_H^*\left(\frac{p_H^*(h)}{P_H^*}\right)^{-\phi}, \quad c_F^*(f) = C_F^*\left(\frac{p_F^*(f)}{P_F^*}\right)^{-\phi} \tag{15}$$

where

$$C_H^* = nC^*\left(\frac{P_H^*}{P^*}\right)^{-\theta}, \quad C_F^* = (1-n)C^*\left(\frac{P_F^*}{P^*}\right)^{-\theta} \tag{16}$$

The total demand for home goods is $Y = nC_H + (1-n)C_H^*$ and the total demand for foreign goods is $Y^* = nC_F + (1-n)C_F^*$.

2.5 Price Setting

In equilibrium, all home agents will choose the same value of γ_j, which will be denoted by γ_H. The determination of γ_H is discussed below. Thus, in any given period proportion $(1-\gamma_H)$ of home agents are allowed to reset their prices. All agents who set their price at time t choose the same price, denoted $p_{H,t}$ for the home country. The first-order condition for the choice of prices implies the following.

$$E_t\left\{\sum_{s=t}^{\infty}(\beta\gamma_H)^{s-t}\left[(\phi-1)(1-\tau_s)\frac{p_{H,t}y_{t,s}}{C_s^{\rho}P_s} - \phi K_s y_{t,s}^{\mu}\right]\right\} = 0 \tag{17}$$

where $y_{t,s} = Y_s(p_{H,t}/P_{H,s})^{-\phi}$ is the period-s output of a home agent whose price was last set in period t. It is possible to rewrite the expression for aggregate home producer prices as follows

$$P_{H,t} = \left[\sum_{s=0}^{\infty}(1-\gamma_H)\gamma_H^s p_{H,t-s}^{1-\phi}\right]^{\frac{1}{1-\phi}} \tag{18}$$

For the purposes of interpreting some of the results reported later, it proves useful to consider the price that an individual agent would choose if prices could be reset every period. For home agent j, this price is denoted $p^{o}_{H,t}(j)$ and is given by the expression

$$p^{o}_{H,t}(j) = \frac{\phi}{(\phi - 1)(1 - \tau_s)} K_s C_s^{\rho} P_s y_{t,s}^{\mu-1}(j) \tag{19}$$

2.6 Equilibrium Price Flexibility

Price flexibility is made endogenous in this model by allowing all agents to make a once-and-for-all choice of the Calvo-price-adjustment probability in period zero.[7] When making decisions with regard to price flexibility each agent acts as a Nash player. Given that all agents are infinitesimally small, the choice of individual γ is made while assuming that the aggregate choice of γ is fixed. The equilibrium γ is assumed to be the Nash equilibrium value (i.e. where the individual choice of γ coincides with the aggregate γ).

Agents make their choice of γ in order to maximise the discounted present value of expected utility. For simplicity, it is assumed that the utility of real balances is ignored for the purposes of determining the equilibrium value of γ.

From the point of view of the individual agent, the optimal γ is the one which equates the marginal benefits of price flexibility with the marginal cost of price adjustment. The benefits of price flexibility arise because a low value of γ implies that the individual price can more closely respond to shocks. The costs of price adjustment may take the form of menu costs, information costs, decision making costs and other similar costs. These costs of price adjustment are captured by the function $A(\gamma)$ in equation (1). It is assumed that the cost of price adjustment is proportional to the expected number of price changes per period. Thus $A(\gamma)$ is of the following form

$$A(\gamma) = \frac{\alpha}{1 - \beta}(1 - \gamma) \tag{20}$$

where α is a parameter which measures the cost of a single change in price and the factor $1/(1 - \beta)$ converts the per-period cost of price changes to the present discounted value at time zero. It is important to note that the cost of price changes is a function of the average rate of price adjustment, and is not linked to actual price changes.

As described above, individual agents are assumed to have access to insurance markets which allow them to insure against the idiosyncratic income shocks implied

[7] An alternative approach would be to assume that agents can choose a value for γ every time they reset their prices. A structure of this form would, however, be extremely difficult to solve because it would be necessary to track the distribution of γ's across the population of agents as the economy evolves. The solution of the model is made much more manageable by restricting the choice of γ to an initial once-and-for-all decision. Given that the main objective is to investigate how the choice of γ responds to the choice of monetary regime, and given that the choice of regime is itself a once-and-for-all decision, it seems unlikely that much is lost by restricting the choice of γ in this way.

by the Calvo pricing structure. It is important to specify that, in the case of the present model, these markets open *after* all agents have made their choices of price adjustment probability.

3 Monetary Policy

The main focus of attention in this paper is on the choice of monetary regime for the home economy. It is however necessary to specify the behaviour of the foreign monetary authority. The foreign monetary authority is assumed to adopt a rule for the foreign nominal interest rate which ensures that the rate of inflation of producer prices achieves a target rate π_t^*, thus

$$\frac{P_{F,t}^*}{P_{F,t-1}^*} = \pi_t^* \tag{21}$$

The inflation target in the foreign country is assumed to be subject to stochastic shocks such that π_t^* evolves as follows

$$\log \pi_t^* = \zeta_{\pi^*} \log \pi_{t-1}^* + \varepsilon_{\pi^*,t} \tag{22}$$

where ε_{π^*} is symmetrically distributed over the interval $[-\epsilon, \epsilon]$ with $E[\varepsilon_{\pi^*}] = 0$ and $Var[\varepsilon_{\pi^*}] = \sigma_{\pi^*}^2$. These stochastic shocks represent exogenous changes in policy which may arise from changes in political pressure on the foreign monetary authority or changes in the composition of its governing council or policymaking committee. Alternatively the shocks may represent policy mistakes made by the foreign monetary authority. In either case, the shocks are exogenous from the point of view of the home country.

The specification of home monetary policy is now described. The objective is to compare a fixed exchange rate regime with a floating exchange rate regime. The specification of a fixed exchange rate is simple. In this case the home monetary authority is assumed to vary the home nominal interest rate in order to maintain the exchange rate at a target rate, denoted $\bar{S}$. The fixed rate is therefore a unilateral (or one-sided) peg in the sense that it is the actions of the home monetary authority which sustain the regime.

While a fixed-rate regime is uniquely defined, there are many different forms of floating-rate regime which could be adopted by the home economy. Two alternatives are considered: money targeting and strict targeting of the rate of inflation of producer prices.

In the case of money targeting the home monetary authority fixes the level of the home money supply at $\bar{M}$ and allows the nominal interest rate to be determined by equilibrium in the market for real money balances. The demand for money is defined by the first-order condition for the choice of money holdings, which is given by the following

$$\chi \left(\frac{M_t}{P_t} \right)^{-1} = \left(\frac{i_t}{1 + i_t} \right) C_t^{-\rho} \tag{23}$$

In the case of strict targeting of producer-price inflation, the home monetary authority varies the home nominal interest rate to ensure that the rate of inflation of producer prices achieves a target rate of zero, thus

$$\frac{P_{H,t}}{P_{H,t-1}} = 1 \tag{24}$$

In what follows this regime will be referred to as 'inflation targeting'. It should be borne in mind, however, that this refers to targeting of producer-price inflation - not consumer-price inflation.

It is important to note that none of the three policy regimes just described is fully optimal for the home economy.[8] In principle, it would be possible to derive fully optimal monetary policy rules for the home and foreign economies. However, the complications caused by endogenous price flexibility make this infeasible given currently available solution techniques. Attention is therefore confined to a comparison of simple, but non-optimal, policy regimes.

4 Model Solution

It is not possible to derive an exact solution to the model described above. The model is therefore approximated around a non-stochastic equilibrium (defined as the solution which results when $K = K^* = (1-\tau) = (1-\tau^*) = \pi^* = 1$ and $\sigma_K^2 = \sigma_{K^*}^2 = \sigma_\tau^2 = \sigma_{\tau^*}^2 = \sigma_{\pi^*}^2 = 0$). For any variable X define $\hat{X} = \log\left(X/\bar{X}\right)$ where $\bar{X}$ is the value of variable X in the non-stochastic equilibrium. $\hat{X}$ is therefore the log-deviation of X from its value in the non-stochastic equilibrium.

Aggregate (per capita) home welfare in period t is defined as

$$w_t = \frac{1}{n} E_0 \left\{ \int_0^n \left(\frac{C_t^{1-\rho}(h)}{1-\rho} - \frac{K_t}{\mu} y_t^{\mu}(h) \right) dh \right\} - \alpha(1-\gamma) \tag{25}$$

where, for simplicity, the utility of real balances is excluded.

A second-order approximation of w_t can be written as follows

$$\begin{aligned} w_t - \bar{w} = \bar{C}^{1-\rho} E_0 \Bigg\{ & \hat{C}_t + \frac{1}{2}(1-\rho)\hat{C}_t^2 \\ & - \frac{\phi - 1}{\phi}\left[\hat{Y}_t + \frac{1}{2}\mu(\hat{Y}_t + \frac{1}{\mu}\hat{K}_t)^2 + \frac{1}{2}\phi\left(1 + \phi\left(\mu - 1\right)\right)\Pi_t \right] \Bigg\} \\ & - \alpha(\bar{\gamma} - \gamma) + O\left(\epsilon^3\right) \end{aligned} \tag{26}$$

[8] In particular, it should be noted that a policy of inflation stabilisation is not fully optimal for the home economy in this model. There are three reasons for this: the presence of cost-push shocks; the non-unit elasticity between home and foreign goods; and the incompleteness of international financial markets. Benigno and Benigno (2003) show that inflation stabilisation is not optimal in the presence of cost push shocks in an open economy, Sutherland (2004) shows that producer-price stabilisation is not optimal when the elasticity of substitution between home and foreign goods differs from unity, and Devereux (2004) and Benigno (2001) show that price or inflation stabilisation is not optimal when international financial markets are incomplete.

where

$$\Pi_t = \sum_{i=0}^{\infty} (1-\gamma)\gamma^i \left(\hat{p}_{H,t-i} - \hat{P}_{H,t}\right)^2 \tag{27}$$

where $O(\epsilon^3)$ contains terms of order higher than two in the variables of the model.[9]

In order to derive a solution to the endogenous price flexibility problem it is also necessary to consider the utility of a representative individual agent. A second-order approximation of period-t utility of agent h is

$$\begin{aligned} u_t(h) - \bar{u} = \bar{C}^{1-\rho} E_0 \Bigg\{ & \hat{C}_t(h) + \frac{1}{2}(1-\rho)\hat{C}_t^2(h) \\ & -\frac{\phi-1}{\phi}\left[\hat{y}_t(h) + \frac{1}{2}\mu\left(\hat{y}_t(h) + \frac{1}{\mu}\hat{K}_t\right)^2\right]\Bigg\} \\ & - \alpha(\bar{\gamma} - \gamma_h) + O\left(\epsilon^3\right) \end{aligned} \tag{28}$$

where $u_t(h)$ is period-t utility of agent h.

Note that the second-order approximations of both aggregate and individual utilities depend on the first and second moments of consumption and output. Aggregate utility also depends on the second moments of prices. In order to analyse aggregate and individual utility it is necessary to derive second-order accurate solutions for the first moments of the variables of the model. These solutions are obtained numerically using the technique described in Sutherland (2002).

A numerical search technique is used to locate Nash equilibria in the choice of γ. The procedure is as follows. An initial guess for the equilibrium γ is selected. The model is then solved for this value of γ and the discounted value of utility for an individual agent is calculated (using the expression for individual utility given in (28)). The model is then re-solved with a perturbed value of γ_h for a single individual, but with the value of γ for all other agents fixed. The discounted value of utility for individual h is then re-evaluated at this perturbed value of γ_h. This provides a measure of the incentive for individual h to deviate from the aggregate γ. If this incentive is non-zero, the procedure is repeated with a new choice of aggregate γ. The procedure is repeated until a value of γ is found where the incentive to deviate is zero - in which case a Nash equilibrium has been identified.

In all the examples considered below, the foreign country is large relative to the home country, so the foreign equilibrium value of γ does not depend on the home value of γ. The foreign γ is also invariant to the choice of monetary regime in the home country and to the value of θ (the elasticity of substitution between home and foreign goods). On the other hand, the equilibrium value of γ for the home economy depends on the choice of regime and the value of θ. The search procedure for the

[9] All log-deviations from the non-stochastic equilibrium are of the same order as the shocks, which (by assumption) are of maximum size ϵ. When presenting an equation which is approximated up to order two it is therefore possible to gather all terms of order higher than two in a single term denoted $O\left(\epsilon^3\right)$.

home economy must therefore be repeated for each policy regime and each value of θ.

The next section reports numerical solutions to the above model which allow a comparison to be made between the three monetary regimes. The numerical solutions are obtained using the set of parameter values in Table 1. The values for ρ, ϕ, μ and β are taken from Rotemberg and Woodford (1999). The value for δ is based on the calibration used by Benigno (2001). The value of α (i.e. the coefficient in the function determining the costs of price adjustment) is set at 0.003, which implies aggregate price adjustment costs of 0.075 per cent of GDP if prices are adjusted at an average rate of once every four quarters (which is consistent with $\gamma = 0.75$). The implications of setting α to 0.004 are also briefly considered. We consider a range of values of θ (i.e. the elasticity of substitution between home and foreign goods) between 0.5 and 6. The effects of changing the value of ϕ (the elasticity of substitution between individual goods) from 7.66 to 4.0 are also presented.

The numerical solutions to the model are presented in Figures 1 to 7. Figure 1 shows the equilibrium value of γ for each regime for a range of values of θ. In order to understand the results it is useful to compare the effects of endogenous price flexibility with a version of the model where the degree of price flexibility is fixed exogenously. Figures 2 to 7 therefore show this comparison. In each figure the left-hand panel shows results for exogenous price flexibility (where γ is fixed at 0.75) for a range of values of θ and the right-hand panel shows results for endogenous price flexibility for the same range of values for θ. Figure 2 shows results for welfare. Figures 3 to 7 show the volatilities of a number of relevant variables.

5 Comparison of Exchange Rate Regimes

5.1 Exogenous Price Flexibility

The comparison between the three monetary regimes is first considered in the case where price flexibility is exogenously determined (with $\gamma = 0.75$). Figure 2(a) shows the welfare comparison. There are three features of this comparison which are worth noting.

First, inflation targeting yields the highest welfare for values of θ greater than unity. As already emphasised, a number of features of the model imply that fully optimal monetary policy will generate some volatility in the producer price index. Inflation stabilisation is therefore not fully optimal. Nevertheless it is clear that, for the calibration illustrated and for values of θ greater than unity, inflation targeting is closer to the fully optimal policy than either of the other policy regimes considered. Thus, the presence of cost-push shocks, incomplete financial markets and a relatively powerful expenditure switching effect are not sufficient to make either of the other two regimes better than inflation targeting (for the parameter range considered).

The second feature of the welfare comparison in Figure 2(a) which should be noted is that a fixed exchange rate yields relatively low welfare for low values of θ, but it can yield higher welfare than money targeting for higher values of θ.[10] The welfare performance of money targeting declines quite sharply for high values of θ. This is because money targeting causes high volatility of output for high values of θ - as can be seen in Figure 3(a). This, in turn, is caused by relatively high volatility in the terms of trade for high values of θ - as shown in Figure 5(a). These effects are similar to those identified in Senay and Sutherland (2004).

The third feature of the welfare comparison in Figure 2(a) which should be noted is that the welfare ranking is partially inverted for values of θ less than unity. The contrast between $\theta > 1$ and $\theta < 1$ can be understood as follows. When θ is greater than unity, the home economy (when treated as a single entity) faces an elastic demand for its goods. In this case aggregate home real income is positively related to home real output. But when θ is less than unity the demand for home goods is inelastic and home real income is negatively related to home real output. Thus, when θ is greater than unity, it is welfare increasing to adopt policies which cause an expansion in the average level of home output, while, when θ is less than unity, it is welfare increasing to adopt policies which cause a contraction in the average level of home output. This inversion of the relationship between real income and real output can cause an inversion of the welfare ranking of policy regimes at $\theta = 1$.

5.2 Endogenous Price Flexibility

Now consider the implications of endogenising the degree of price flexibility. Recall that the degree of price flexibility is determined by the parameter γ. Low values of γ imply very flexible prices, while values of γ close to unity imply very rigid prices. The equilibrium degree of price flexibility depends on the interaction between many different factors. At the micro level, γ is determined by the balance between the benefits and costs of price adjustment. At this level, from the point of view of the individual agent, the benefits of price flexibility will be affected by factors such as the volatility of output, consumption and prices, as well as the covariances between these variables. In turn, at the macro level, the volatilities of these variables will be affected by the aggregate degree of price flexibility itself. Thus, the value of γ will be determined as part of the general equilibrium interaction of all these different factors. Furthermore, the equilibrium will be affected by strategic interaction between agents in their individual choices of γ's. It is likely that there is a strong degree of strategic complementarity between agents in their choice of γ - i.e. an individual agent's choice of γ will be positively related to the aggregate choice of γ.

Figure 1 plots the equilibrium values of γ for the home country for a range of values of θ. There are three features of this figure which should be noted. First, the equilibrium value of γ in the inflation targeting regime is unity. Second, money targeting leads to a negative relationship between γ and θ, with particularly low value of equilibrium γ for high values of θ. And third, the fixed exchange rate leads

[10] The latter point is true only for values of θ greater than approximately 6 (which are not plotted in the figures).

to a positive relationship between γ and θ, with particularly low values of equilibrium γ for low values of θ. (Notice also that, for some ranges of θ, both money targeting and the fixed rate give rise to corner solutions, where the equilibrium value of γ is either zero or unity.)

Despite the potentially complex interactions which determine the equilibrium γ, it is possible to gain some insight into the mechanisms at work by considering the volatilities of some of the main macro variables shown in Figures 3 to 7. In particular, consider the volatility of the optimal price ($p^o_{H,t}$) plotted in Figure 4(a). The optimal price is the price that an individual agent would like to set if it was possible to reset prices every period. When this price is very volatile in the exogenous-price-flexibility case it indicates a strong (latent) incentive to vary prices. Conversely, when the optimal price is very stable there is little incentive to vary prices. Thus, for the inflation targeting regime, Figure 4(a) shows that the optimal price is completely stable. There is thus no pressure for agents to choose a high degree of price flexibility in this regime. This explains why the equilibrium γ in the inflation targeting case is unity (as shown in Figure 1). The equilibrium γ's in the other monetary regimes are also inversely related to the volatility of the optimal price. Money targeting causes high volatility of the optimal price at high values of θ and this translates into a low equilibrium value of γ, while the fixed rate regime causes a high volatility of the optimal price at low values of θ and this likewise leads to a low equilibrium value of γ.

The behaviour of the optimal price can, in turn, be traced to the behaviour of other variables. In the case of money targeting, the most important variable appears to be output. As previously explained, at high values of θ output is very volatile in the money targeting regime (see Figure 3(a)). Equation (19) shows that output is one of the main determinants of the optimal price, hence high output volatility leads to high volatility of the optimal price and a strong incentive to choose a low value of γ.

The explanation for the very low equilibrium value of γ in the fixed rate regime for low values of θ, is somewhat more complex. In a flexible price equilibrium, movements in the terms of trade would occur which would produce movements in output that are negatively correlated to the labour supply shocks. A fixed nominal exchange rate combined with sticky nominal prices tends to suppress the volatility of the terms of trade (as can be seen in Figure 5(a)). There is thus a strong latent incentive to adjust prices in order to generate the required movement in the terms of trade. This translates into a low equilibrium value of γ in the endogenous-price-flexibility case. This effect is strongest at low values of θ because the terms of trade movements necessary to produce the required movement in output are larger when θ is small (because the expenditure switching is relatively weak in this case).

The results just described for the fixed rate regime are consistent with the policy argument described in the introduction to the paper, namely that a fixed rate regime, such as the European monetary union, may lead to greater price flexibility, which, in turn, may offset the negative welfare effect of the loss of monetary policy independence.

Having constructed a model which generates an increase in price flexibility in a fixed rate regime, the crucial question which must now be considered is whether the increase in price flexibility leads to an improvement in the welfare performance of the fixed rate regime. This question can be addressed by considering Figure 2(b). This figure shows the welfare comparison between regimes in the endogenous-price-flexibility case. It is immediately apparent from this figure that endogenous price flexibility makes little difference to the first-ranked policy regime, i.e. inflation targeting continues to yield the highest level of welfare of the three regimes for values of θ greater than unity.

Despite the continued welfare superiority of inflation targeting, endogenous price flexibility does lead to a number of changes to the welfare performance of the other two regimes which are worth highlighting. Firstly, the extra price flexibility induced by money targeting at high levels of θ leads to a reduction in the level of welfare when compared to the exogenous-price-flexibility case (see Figures 2(a) and 2(b)). The greater price flexibility induced by money targeting does lead to lower output volatility for high levels of θ (as can be seen from a comparison between Figures 3(a) and 3(b)). This reduction in output volatility does have a positive welfare effect. But this is more than offset by the greater costs of price adjustment which are incurred when the equilibrium value of γ is low. The negative welfare effect of price flexibility is sufficiently strong so that the welfare ranking of money targeting relative to the fixed exchange rate regime is reversed for values of θ greater than (approximately) 4.5.

Figure 2(b) also shows that the extra price flexibility generated by the fixed exchange rate at low values of θ reduces the welfare yielded by the fixed rate. The extra price flexibility induced by the fixed rate does lead to more variability in the terms of trade (as can be seen from a comparison of Figures 5(a) and 5(b)). This has a positive welfare effect because the terms of trade can now respond more easily to labour supply shocks. But this welfare benefit is more than offset by the extra costs of price flexibility arising from the low value of γ. The net result is that the fixed exchange rate is significantly worse than both money targeting and inflation targeting at low values of θ.

Before concluding, it is necessary briefly to consider the extent to which the results just described are sensitive to variations in the parameters of the model. Two parameters are likely to be particularly important. One is α, which determines the costs of price flexibility. The other is ϕ, the elasticity of substitution between individual goods. The role of α is obvious: the more costly it is to have flexible prices the less the degree of price flexibility will change in response to a change in monetary regime. The role of ϕ is more subtle. The parameter ϕ determines the price elasticity of demand for individual goods. Thus, when ϕ is large, any increase in the degree of aggregate price flexibility, which is accompanied by an increase in aggregate price volatility, will generate a strong effect on the volatility of output for an individual agent. The presence of high aggregate price flexibility therefore creates a strong incentive for the individual agent also to choose a high degree of price flexibility. Thus, a high value of ϕ implies a high degree of strategic complementarity between agents in their choice of price flexibility.

Figures 8 and 9 show the implications of a higher value of α. For these figures α is set at 0.004 (which implies aggregate price adjustment costs of 0.1 per cent of GDP if prices are adjusted at an average rate of once every four quarters). Figure 8 shows the resulting equilibrium values of γ for the three monetary regimes. It is clear that the same general pattern of results emerges, except that the values of the equilibrium γ's are higher than in the benchmark case. Figure 9 shows the welfare comparison (where again the left panel shows the case of exogenous price flexibility and the right panel shows the case of endogenous price flexibility). The qualitative pattern of the welfare comparison is very similar to the benchmark case.

Figures 10 and 11 show the implications of a lower value of ϕ. For these figures ϕ is set at 4.0. As explained above, this reduces the degree of strategic complementarity between agents in their choices of γ. This implies that the equilibrium value of γ should be less sensitive to a change in monetary regime. This is confirmed in Figure 10. The qualitative pattern of the welfare comparison (shown in Figure 11) is again similar to the benchmark case.

6 Concluding Comments

This paper has analysed the implications of endogenous price flexibility in a general equilibrium model with staggered contracts where agents may choose the frequency of price changes. The welfare effects of three policy regimes are compared under both exogenous and endogenous determination of price flexibility. The Introduction to the paper outlined two reasons for considering these issues. One was related to the Lucas critique, i.e. does a change in policy regime lead to an endogenous change in price flexibility which alters the welfare performance of regimes? The second was a more policy related question, namely, does a fixed exchange rate generate sufficient price flexibility to offset the welfare cost of the loss of monetary independence? The results described above appear to confirm that endogenous price flexibility can lead to a significant change in the welfare performance of regimes. On the other hand, a fixed exchange rate does not generate enough price flexibility to compensate for the loss of monetary independence. In fact, when a fixed rate regime does generate more price flexibility, the overall impact on welfare appears to be negative.

Clearly, the results presented above are potentially highly dependent on the form of the model and the parameterisation used. A much more extensive sensitivity analysis is required before firmer conclusions can be drawn. The analysis has shown that the equilibrium degree of price flexibility is potentially very sensitive to the choice of regime, the costs of price adjustment and strategic complementarity effects (see Figures 1, 8 and 10). The sensitivity of price flexibility predicted by the model appears to be rather too high to be empirically plausible. This may be caused by the simple linear function used to model the costs of price flexibility. Experimentation with other functional forms for this cost function is therefore a priority. The determinants of the degree of strategic complementarity in the choice of price flexibility also require further investigation.

References

[1] Anderson, James and Eric van Wincoop (2003) "Trade Costs" Boston College and the University of Virginia, unpublished manuscript.

[2] Bachetta, Philippe and Eric van Wincoop (2000) "Does Exchange Rate Stability Increase Trade and Welfare?" *American Economic Review*, 90, 1093-1109.

[3] Ball, Laurence and N. Gregory Mankiw (1994) "Asymmetric Price Adjustment and Economic Fluctuations" *Economic Journal,* 104, 247-261.

[4] Ball, Laurence and David Romer (1989a) "The Equilibrium and Optimal Timing of Price Changes" *Review of Economic Studies*, 56, 179-198.

[5] Ball, Laurence and David Romer (1989b) "Are Prices too Sticky?" *Quarterly Journal of Economics*, 104, 507-524.

[6] Ball, Laurence and David Romer (1990) "Real Rigidities and the Non-neutrality of Money" *Review of Economic Studies*, 57, 183-203.

[7] Ball, Laurence and David Romer (1991) "Sticky Prices as Coordination Failure" *American Economic Review*, 81, 539-552.

[8] Benigno, Pierpaolo (2001) "Price Stability with Imperfect Financial Integration" CEPR Discussion Paper No. 2854.

[9] Benigno, Gianluca and Pierpaolo Benigno (2003) "Designing Rules for International Monetary Policy Cooperation" European Central Bank Working Paper No. 279.

[10] Calmfors, Lars and Asa Johansson (2002) "Nominal Wage Flexibility, Wage Indexation and Monetary Union" IIES Seminar Paper No. 716.

[11] Calvo, Guillermo A (1983) "Staggered Prices in a Utility-Maximising Framework" *Journal of Monetary Economics,* 12, 383-398.

[12] De Long, J. Bradford and Lawrence H. Summers (1986) "Is Increased Price Flexibility Stabilizing?" *American Economic Review*, 76, 1031-1044.

[13] Devereux, Michael B. (2000) "A Simple Dynamic General Equilibrium Model of the Trade-off between Fixed and Floating Exchange Rates" CEPR Discussion Paper No. 2403.

[14] Devereux, Michael B. (2003) "Exchange Rate Policy and Endogenous Price Flexibility", University of British Columbia, unpublished manuscript.

[15] Devereux, Michael B. (2004) "Should the Exchange Rate be a Shock Absorber?" *Journal of International Economics,* 62, 359-377.

[16] Devereux, Michael B. and Charles Engel (1998) "Fixed vs. Floating Exchange Rates: How Price Setting Affects the Optimal Choice of Exchange Rate Regime" NBER Working Paper No. 6867.

[17] Devereux, Michael B. and Charles Engel (2003) "Monetary Policy in an Open Economy Revisited: Price Setting and Exchange Rate Flexibility" *Review of Economic Studies*, 70, 765-783.

[18] Devereux, Michael B. and Henry E. Siu (2004) "State Dependent Pricing and Business Cycle Asymmetries" University of British Columbia, unpublished manuscript.

[19] Dotsey, Michael, Robert King and Alexander L. Wolman (1999) "State Dependent Pricing and the General Equilibrium Dynamics of Money and Output" *Quarterly Journal of Economics,* 114, 655-690.

[20] Friedman, Milton (1953) "The Case for Flexible Exchange Rates" in Milton Friedman (ed) *Essays in Positive Economics*, University of Chicago Press, Chicago.

[21] Hummels, David (2001) "Towards a Geography of Trade Costs" Purdue University, unpublished manuscript.

[22] Kiley, Michael T (2000) "Endogenous Price Stickiness and Business Cycle Persistence" *Journal of Money, Credit and Banking*, 32, 28-53.

[23] Lane, Philip (2001) "The New Open Economy Macroeconomics: A Survey" *Journal of International Economics*, 54, 235-266.

[24] Lucas, Robert E (1976) "Econometric Policy Evaluation: A Critique" *Carnegie-Rochester Conference Series on Public Policy,* 1, 19-46.

[25] Obstfeld, Maurice and Kenneth Rogoff (1995) "Exchange Rate Dynamics Redux" *Journal of Political Economy*, 103, 624-660.

[26] Obstfeld, Maurice and Kenneth Rogoff (1998) "Risk and Exchange Rates" NBER Working Paper No. 6694.

[27] Obstfeld, Maurice and Kenneth Rogoff (2000) "The Six Major Puzzles in International Macroeconomics: Is There a Common Cause?" *NBER Macroeconomics Annual*, 15, 339-390.

[28] Rotemberg, Julio J and Michael Woodford (1999) "Interest Rate Rules in an Estimated Sticky Price Model" in John B Taylor (ed) *Monetary Policy Rules*, University of Chicago Press, Chicago.

[29] Senay, Ozge and Alan Sutherland (2004) "The Expenditure Switching Effect and Fixed versus Floating Exchange Rates" CEPR Discussion Paper No. 4300.

[30] Sutherland, Alan (2002) "A Simple Second-Order Solution Method for Dynamic General Equilibrium Models" CEPR Discussion Paper No. 3554.

[31] Sutherland, Alan (2004) "The Expenditure Switching Effect, Welfare and Monetary Policy in a Small Open Economy" University of St Andrews, unpublished manuscript.

[32] Trefler, Daniel and Huiwen Lai (1999) "The Gains from Trade: Standard errors with the CES Monopolistic Competition Model" University of Toronto, unpublished manuscript.

Discount factor	$\beta = 0.99$
Elasticity of substitution for individual goods	$\phi = 7.66$
Work effort preference parameter	$\mu = 1.47$
Elasticity of intertemporal substitution	$\rho = 1$
Bond holding costs	$\delta = 0.0005$
Price adjustment costs	$\alpha = 0.003$
Labour supply shocks	$\zeta_K = \zeta_{K^*} = 0.9$, $\sigma_K = \sigma_{K^*} = 0.01$
Income tax shocks	$\zeta_\tau = \zeta_{\tau^*} = 0.9$, $\sigma_\tau = \sigma_{\tau^*} = 0.01$
Foreign inflation shocks	$\zeta_{\pi^*} = 0.9$, $\sigma_{\pi^*} = 0.001$
Home country size	$n = 0.001$

Table 1: Parameter Values

Fig 1: Equilibrium degree of price stickiness (α=0.003 ϕ=7.66)

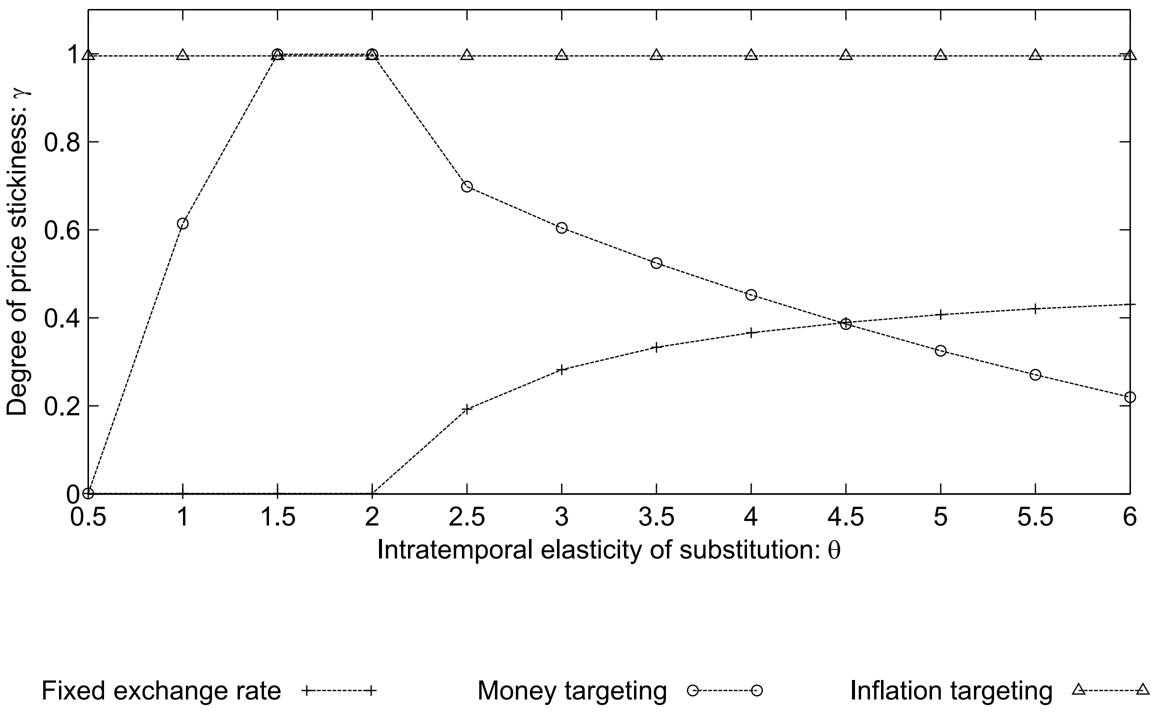


Fig 2: Welfare (α=0.003 ϕ=7.66)

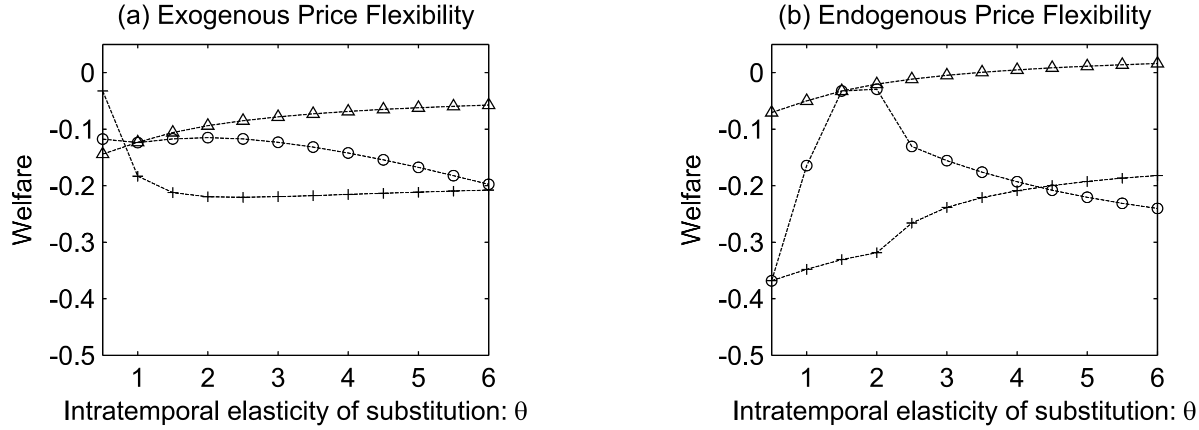


Fig 3: Standard Deviation of Output (α=0.003 ϕ=7.66)

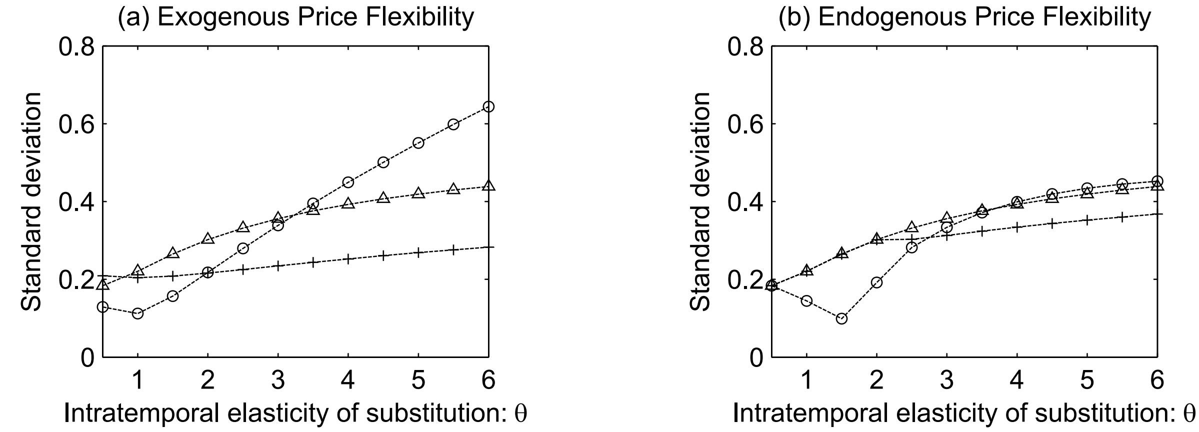
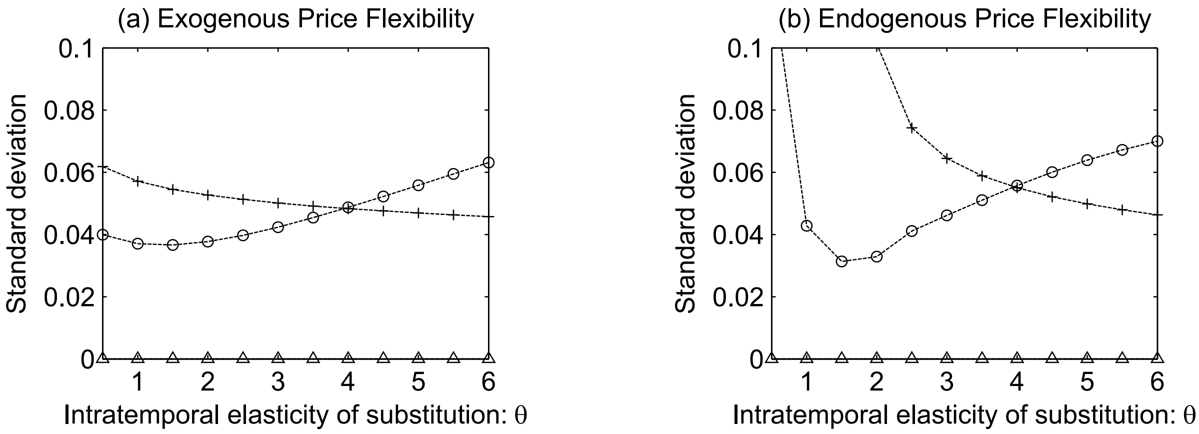


Fig 4: Standard Deviation of Optimal Price (α=0.003 ϕ=7.66)



Fixed exchange rate +-------+ Money targeting o-------o Inflation targeting △-------△

Fig 5: Standard Deviation of the Terms of Trade (α=0.003 ϕ=7.66)

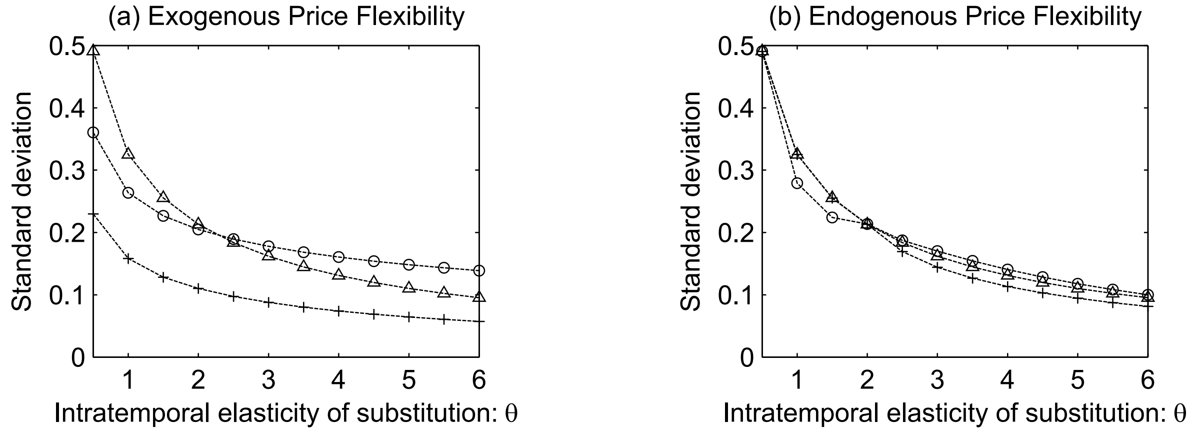


Fig 6: Standard Deviation of Producer Price Inflation (α=0.003 ϕ=7.66)

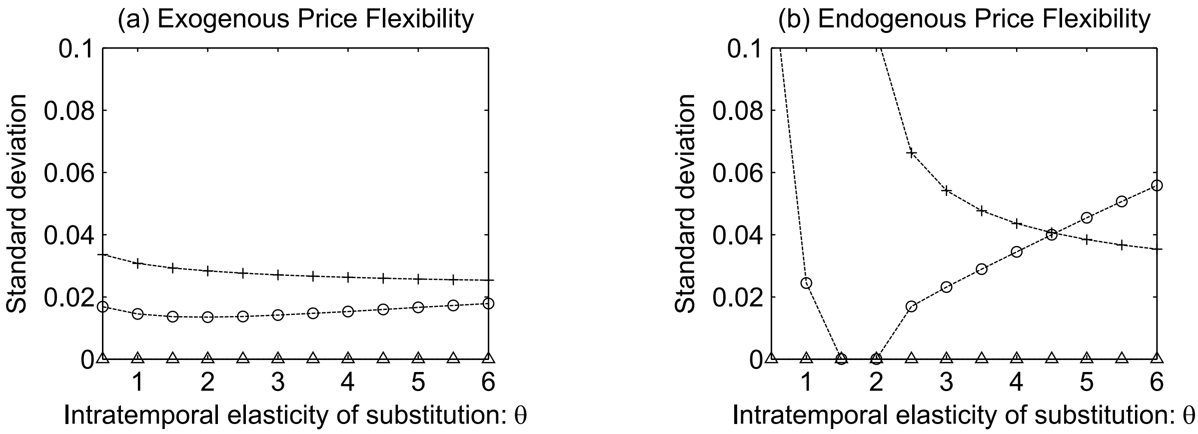
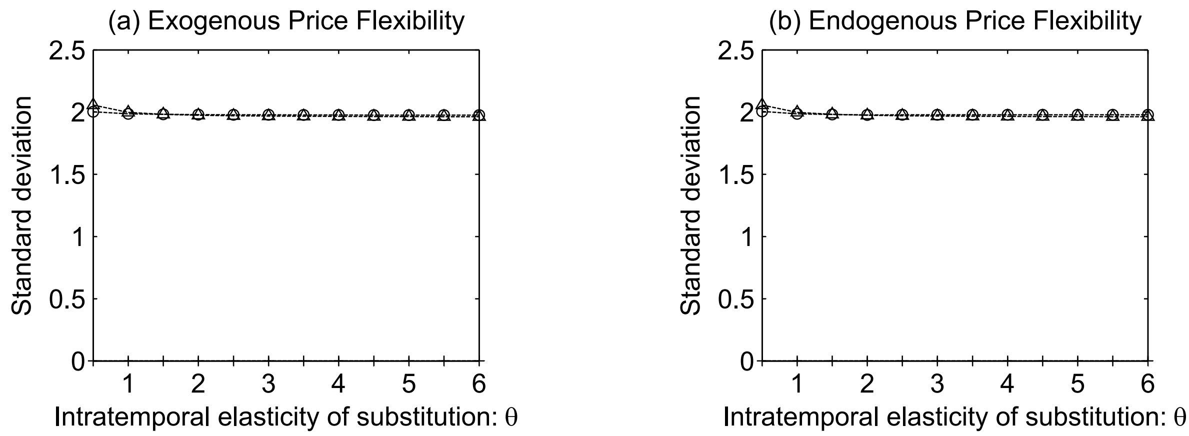


Fig 7: Standard Deviation of the Nominal Exchange Rate (α=0.003 ϕ=7.66)



Fixed exchange rate +-----+ Money targeting o-----o Inflation targeting △-----△

Fig 8: Equilibrium degree of price stickiness (α=0.004 ϕ=7.66)

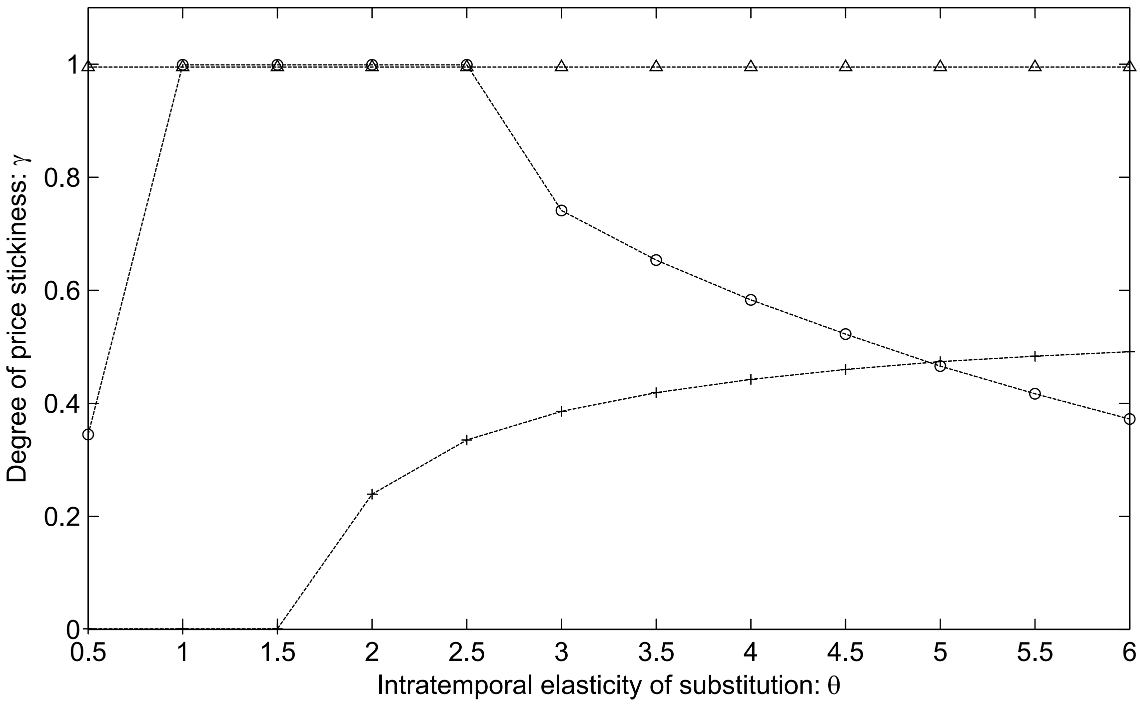
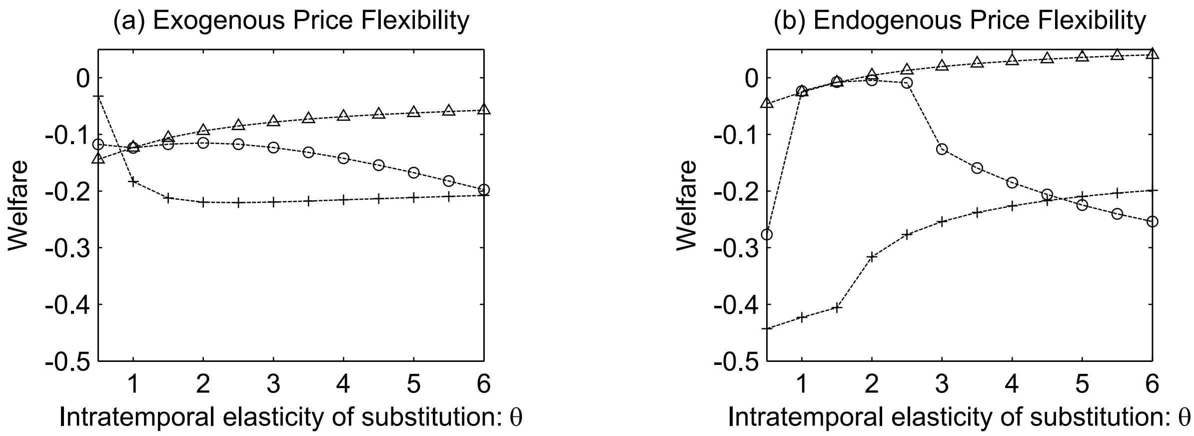


Fig 9: Welfare (α=0.004 ϕ=7.66)



Fixed exchange rate —+— Money targeting —○— Inflation targeting —△—

Fig 10: Equilibrium degree of price stickiness (α=0.003 ϕ=4.0)

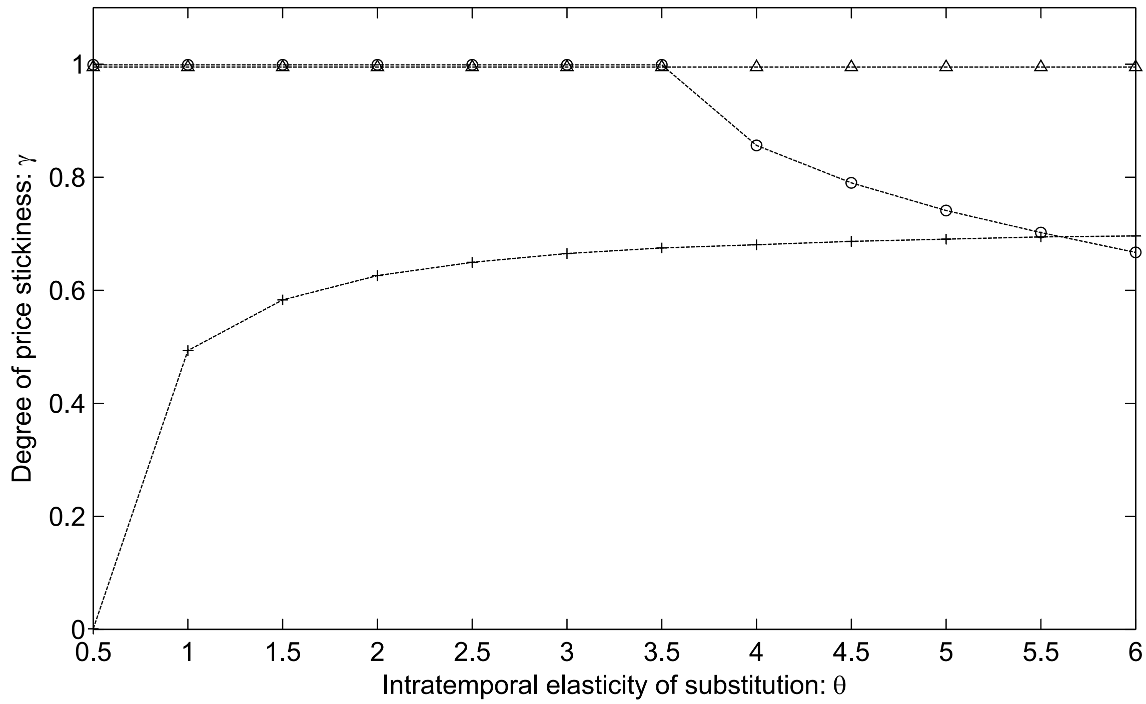


Fig 11: Welfare (α=0.003 ϕ=4.0)