

Central bank's objectives and the performance of monetary policies

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Abstract

This paper examines the effectiveness of targeting monetary policies in a dynamic optimizing model. Toward this end I develop a small open economy version of the New Neo-Classical Synthesis model and calibrate it to the recent Korean data. Then I explore the consequences of alternative specifications of the central bank's objectives by modeling the central bank as an optimizing agent with explicit weights on different components of the objective function. Policy simulations include variations on inflation targeting, nominal income growth targeting and exchange rate targeting. Simulation results suggest that inflation targeting is preferable to nominal income growth and exchange rate pegging in smoothing out fluctuations in inflation and the output-gap.

Key words: Targeting monetary policy, Inflation targeting.
JEL Classification: E5

1 Introduction

In recent years, several developed countries have adopted inflation targeting as their framework for monetary policies. A growing number of emerging market economies (EMEs) have been encouraged to adopt inflation targeting

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as well. Korea is also one of a number of EMEs that have adopted inflation targeting. This paper investigates the dynamics of the Korean economy since the implementation of inflation targeting, to assess its appropriateness for EMEs. While much of the previous literature has been conducted with closed economy models, increasing interest has been given to small open economies.

In the literature, we find that a broad consensus seems to have formed regarding the superiority of inflation targeting as a monetary framework. Nonetheless, some recent research has questioned the optimality of inflation targeting in all circumstances. Specifically focusing on small open economies, McCallum and Nelson (1999) argued in favor of nominal income growth targeting over inflation targeting. One attractive feature of their macroeconomic model is an emphasis on modeling imports as intermediate goods in production instead of components of consumption.¹: for Korea, consumer goods accounted for only 13% of imports in 2002; capital equipment and intermediate goods comprised the remaining 87%. In section 2, we start with the specification of McCallum and Nelson (1999) to develop a micro-founded dynamic stochastic model calibrated to the Korean economy.

However, in contrast with McCallum and Nelson (1999), we model the central bank as a dynamically optimizing agent acting under discretion, rather than imposing an estimated policy rule. The policy rule - a Taylor rule typed one single equation reaction function - has a limit in describing the behavior of the central bank. Inflation targeting is a statement about the objectives of the central bank. As such, under the assumption that the central bank is itself a rational, optimizing agent in the model, it is preferable to model the objective function of the central bank and then derive the resulting targeting rule, rather than specifying an exogenous, static policy reaction equation as they did.

We compare different primary objectives of the central bank. Thus, we can investigate its appropriateness of monetary policies by comparing the performance under different weights on the central bank's loss function. The performance of the monetary policies is evaluated how well they perform in smoothing out fluctuations in inflation, the output gap, or other macroeconomic variables. Policy simulations include variations on inflation targeting, nominal income growth targeting and exchange rate targeting. Simulation results suggest that inflation targeting is preferable to nominal

¹Most open economy literature that investigates the monetary policies, for example, Clarida et al. (2001), and Galí and Monacelli (2002), treats imported goods as final consumption goods.

income growth and exchange rate pegging in smoothing out fluctuations in inflation and the output-gap.

This paper is organized as follows. In Section 2, we start with a New Neo-Classical Synthesis model developed by McCallum and Nelson (1999).² The model presumes that economic agents are solving dynamic optimization problems with rational expectations, as in the Neo-Classical literature. In the model, however, prices are presumed not to adjust freely within each period but instead respond gradually. The specific price adjustment mechanism utilized here is a variant of Fuhrer & Moore (1995). We calibrate the model to Korean quarterly data from 1987.Q2 to 2000.Q4 by specifying the parameter values of the model in Section 3 and simulate it to evaluate targeting policies such as inflation targeting, nominal income growth targeting and exchange rate targeting in Section 4. Finally, Section 5 concludes the paper.

2 The Model

The model is a variant of a now standard New Neo-Classical Synthesis open-economy model, using McCallum and Nelson's (1999) formulation. The model is derived from the optimization of infinitely-lived households. The households consume a variety of goods, provide their labor in the factor market, and hold and trade domestic and foreign bonds. In addition, they serve as a sole provider of differentiated consumption goods, to be sold both domestically and abroad. To this end, they hire labor and import intermediates to produce output.

In particular, imports are treated not as final goods, as is typical in the literature, but instead as raw-material inputs or intermediates. Such a specification captures better the features of data especially to a small open economy, that of Korea. According to the Korean data on imports by use, as of 2002, consumption goods account for 13% of total imports whereas intermediates for 49%, and capital goods for 38%. In addition, this specification theoretically yields a behavior of inflation and exchange rate change, closer to that found in the data.³

² For the literature on New Neo-Classical Synthesis (or New Keynesian) stochastic dynamic models, see Goodfriend and King (1997), Lane (2000), and Clarida, Gali, and Gertler (1999)

³ McCallum and Nelson (2001) investigated whether the behavior of inflation and exchange rate movement changed under different treatment if imported goods. They compared two models. One is Gali and Monacelli (2002), in which imports enter as final goods. The other is McCallum and Nelson (1999), in which imports enter as raw materials and

Contrary to McCallum and Nelson (1999), this paper adopts a price adjustment mechanism from Fuhrer and Moore (1995), rather than Calvo (1982), which is adopted in McCallum and Nelson. As McCallum (1994) has criticized, Calvo's specification of inflation process violates the natural-rate hypothesis. Additionally, as Mankiw (2000) has discussed, far too little inertia in inflation dynamics is implied in the Calvo's specification, of which inflation process has only a forward-looking nature. Instead, in the Fuhrer and Moore's specification inflation process has an additional backward-looking nature. This nature yields inflation inertia since past inflation can not response to new information about current or future monetary policy. In addition, this paper has different features from McCallum and Nelson (1999) by dropping the assumption of habit formation of consumption.

In the following, I present a log-linearized version of the model. A detailed specification of the model is described in the Appendix. Finished consumption goods are produced by a Cobb-Douglas production function:

$$y_t = (1 - \alpha) a_t + (1 - \beta) n_t + \beta m_t; \quad (1)$$

where y_t represents output, a_t a stochastic technological shock, n_t labor, and m_t imported raw materials and intermediates.

Output is either consumed by domestic households or exported so that aggregate demand equation is described as

$$y_t = \left(\frac{1 - EX}{Y}\right) c_t + \left(\frac{EX}{Y}\right) ex_t; \quad (2)$$

where c_t represents domestic consumption, ex_t represents export, and $EX=Y$ represents the steady-state export-output ratio. Exports depend on the real exchange rate (q_t) and foreign output (y_t^*), the latter of which exogenously follows a stochastic process.

$$ex_t = \gamma_q q_t + \gamma_y y_t^* \quad (3)$$

The real exchange rate by definition equals the nominal exchange rate less the difference between the domestic and foreign price levels.

$$q_t = s_t + p_t^* - p_t \quad (4)$$

Consumption is determined by an Euler equation, as a function of next-period's expected consumption and the current ex ante real interest rate intermediates. They found that McCallum and Nelson (1999) generated a lower and more delayed correlation between inflation and exchange rate change.

(times the intertemporal elasticity of substitution), with an exogenously given preference shock (\hat{A}_t). The Fisher equation replaces the real interest rate with the current nominal rate (R_t) and expected inflation ($E_t \mu_{t+1}$), providing a direct channel for monetary policy in the real economy.

$$c_t = E_t c_{t+1} + (1-\beta) E_t \mu_{t+1} - (1-\beta) R_t + \hat{A}_t; \quad (5)$$

The uncovered interest rate parity condition is assumed to hold with an exogenous risk premium that follows an AR(1) process.

$$R_t = R_t^* + E_t \zeta_{t+1} + \rho \zeta_t; \quad (6)$$

where R_t^* represents foreign interest rate and ζ_t represents a risk premium shock.

In the following, we consider how the price is determined in the model. Following Fuhrer and Moore (1995), we consider a model of overlapping wage contracts. In a two-period contracting world, wages prevailing in the current period becomes the average of the contract wage negotiated in periods t (w_t) and $t-1$ (w_{t-1}). Thus the firm marks up the price as a following manner. In the following, we consider how the price is determined in the model.

$$p_t = \frac{1}{2}(w_t + w_{t-1}); \quad (7)$$

In the two-period contracting specification of Fuhrer and Moore (1995), agents care about relative real wages over the life of the wage contract. Thus, the current wage contract in real term is an average of the lagged and the expected future wage contracts in real term, adjusted for excess demand, $y_t - \bar{y}_t$.⁴

$$w_t - p_t = \frac{1}{2} f(w_{t-1} - p_{t-1}) + E_t (w_{t+1} - p_{t+1}) g + \frac{1}{2} (y_t - \bar{y}_t) + \frac{1}{2} (y_{t-1} - \bar{y}_{t-1}) g \quad (8)$$

Substituting w_t of the equation (7) with the equation (8), we get an inflation equation such as

$$\mu_t = \frac{1}{2} (\mu_{t-1} + E_t \mu_{t+1}) + \frac{1}{2} (y_t - \bar{y}_t) + \frac{1}{2} (y_{t-1} - \bar{y}_{t-1}) g \quad (9)$$

In this model, the central bank also behaves optimally, choosing the values of the instruments to minimize the loss function:

⁴ Note that the contracts are still negotiated in nominal terms.

$$L_0 = E_0 \sum_{t=0}^{\infty} \beta^t [\lambda \pi_t^2 + \alpha_x x_t^2 + \alpha_s s_t^2 + \gamma_i (\bar{y}_i - \bar{y}_t)^2 + \alpha_i i_t^2] \quad (10)$$

The loss function incorporates preferences for targeting inflation, the nominal income growth or the exchange rate. In addition, it incorporates preferences for output stability and smoothing the interest rates. The coefficients, λ , α_x , and α_s reflect the central bank's preference for inflation, the nominal income growth, and the exchange rate movement being at target, respectively. The coefficient, γ_i , represents a preference for maintaining output at potential. The coefficient, α_i , represents a preference for interest rate smoothing. This preference reflects the fact that especially for EMEs, the central bank has a tendency to smooth the interest rate change in order to maintain financial stability.

The model economy consists of the equations mentioned above as well as exogenous shock processes. If we describe the model in a state-space form, it can be written as

$$A_0 \begin{bmatrix} z_{1t+1} \\ E_t z_{2t+1} \end{bmatrix} = A_1 \begin{bmatrix} z_{1t} \\ z_{2t} \end{bmatrix} + B_1 u_t + \begin{bmatrix} z_{t+1} \\ 0_{n_2 \times 1} \end{bmatrix} \quad (11)$$

where z_{1t} is a vector containing predetermined variables.

$$z_{1t} = [a_t; \Delta_t; \tau_t; y_t^a; \pi_{t-1}; y_{t-1}; i_{t-1}; q_{t-1}; q_{t-1}; s_{t-1}]^0 \quad (12)$$

z_{2t} is a vector containing forward-looking variables such that

$$z_{2t} = [q_t; c_t; \pi_t]^0 \quad (13)$$

z_t is a vector of shocks which are assumed to follow an AR(1) process.

$$z_t = [z_{at}; z_{\Delta t}; z_{\tau t}; z_{y_t^a}; 0; 0; 0; 0; 0; 0; 0]^0 \quad (14)$$

Premultiply the above equation by A_0^{-1} , we get the following equation.

$$\begin{bmatrix} z_{1t+1} \\ E_t z_{2t+1} \end{bmatrix} = A \begin{bmatrix} z_{1t} \\ z_{2t} \end{bmatrix} + B u_t + \begin{bmatrix} z_{t+1} \\ 0 \end{bmatrix}; \quad (15)$$

where note that $A_0^{-1} [z_{t+1} \ 0]^0 = [z_{t+1} \ 0]^0$ for the model we consider. And the loss function can also be written in the matrix form.

$$L_t = Y_t^0 K Y_t; \quad (16)$$

where K is a diagonal matrix, with the preference weights on the diagonal. And Y_t is a vector containing policy variables such that

$$Y_t = [M_t; y_t; \bar{y}_t; x_t; s_t; i_t; i_t^*]; \quad (17)$$

which is also related with z_{1t} , z_{2t} and u_t such a following manner.

$$Y_t = C_z \begin{pmatrix} z_{1t} \\ z_{2t} \end{pmatrix} + C_u u_t; \quad (18)$$

And we consider the interest rate as a single instrument variable so that $u_t = i_t$:

We solve the model specified by the above state-space form by applying a method of linear rational expectations model proposed by Söderlind (1999).

3 Calibration

In this section, we calibrate the model economy developed in the previous section, and simulate the model economy. Towards this end, we set values for parameters used in the model economy. Table 1 presents specific values for parameters. Baseline parameter values for the model are chosen based on recent Korean data from 1987:Q2 to 2000:Q4.

In line with the literature, the time discount rate (β) and coefficient of relative risk aversion (γ) are assigned values of 0.99 and 5, respectively. Following Park and Shin (2000), I set the mark-up ratio ($\frac{\mu}{\mu-1}$) to 11% so that elasticity of demand for consumption varieties (μ) equals 10.09. The elasticity between domestic goods and imported goods in the production function, λ , is set to 5 so as to produce variability of the model economy comparable with that in the data. The average of the import share of GDP ($Q(\frac{IM}{Y})$) over this period was equal to 0.20, implying that $\lambda = (\frac{\mu}{\mu-1}) \times Q(\frac{IM}{Y})$ is 0.222. During the same period, the export-output ratio ($\frac{EX}{Y}$) was 0.214.

The elasticity of exports to the real exchange rate (ϵ_q) is set to 0.538, following Lee & Kim (1991). They estimated an export equation by regressing export volume on the real exchange rate and control variables. The estimated elasticity does not reflect changes in the price, implying that this is its maximum possible value. I set an elasticity of exports to the foreign income (ϵ_{y^*}) to 1, considering the fact that exports have a sizable effect on the Korean economy. The coefficient of the output-gap in the Phillips curve ($\frac{1}{2}$) is set to 0.086 as in McCallum & Nelson (2001).

Following Nam & Pyo (1997), I specify domestic and foreign technological shock processes such that AR(1) coefficient of a domestic technological

shock ($\frac{1}{2}_a$) is given as 0.89, and that of a foreign technological shock ($\frac{1}{2}_{y^*}$) is given as 0.81. And their standard deviations of domestic ($\frac{3}{4}_a$) and foreign technological shocks ($\frac{3}{4}_{y^*}$) are given as 0.02 and 0.0075, respectively.

The AR(1) coefficient of preference shock process ($\frac{1}{2}_A$) is set to 0.3 and its standard deviation ($\frac{3}{4}_A$) to 0.01. Those values are close to values reported by MaCallum and Nelson (1998). The AR(1) coefficient of risk premium process ($\frac{1}{2}$) is set to 0.50 and its standard deviation ($\frac{3}{4}$) to 0.04, following MaCallum and Nelson (1999).

4 Experiments

In this section, we simulate the model economy to evaluate targeting monetary policies. We consider several targeting policies – inflation, nominal income growth, and exchange rate. In henceforth, we abbreviate Inflation Targeting to IT, Nominal Income Growth Targeting to NIGT, and Exchange Rate Targeting to ET. we assess how well a targeting policy succeed in smoothing out fluctuations in inflation, the output-gap, the nominal income growth rate, and variability of exchange rates. The less volatile are those macroeconomic variables, the more successful, we conclude, is a targeting policy. A targeting policy adjusts an interest rate instrument when a targeted variable deviates its target as well as when output deviates the natural rate. Specific policy rules of IT, NIGT and ET are specified by putting weights on components of the central bank’s loss function. Under a specific policy rule, the weights of the loss function has the following values.

IT: $\frac{1}{4} = 1$; $\frac{1}{4}_x = 0$; and $\frac{1}{4}_s = 0$:

NIGT: $\frac{1}{4} = 0$; $\frac{1}{4}_x = 1$; and $\frac{1}{4}_s = 0$:

ET: $\frac{1}{4} = 0$; $\frac{1}{4}_x = 0$; and $\frac{1}{4}_s = 1$:

For example, IT puts the weight on its target variable, i.e., inflation ($\frac{1}{4}$), but does not put the weight on other variables such as the nominal income growth ($\frac{1}{4}_x$) and the exchange rate movement ($\frac{1}{4}_s$). On the other hand, NIGT puts the weight only on its target variable, i.e. the nominal income growth ($\frac{1}{4}_x$), but does not put the weight on inflation ($\frac{1}{4}$) and the exchange rate movement ($\frac{1}{4}_s$). And ET puts the weight only on its target variable, i.e. the exchange rate movement ($\frac{1}{4}_s$), but does not put the weight on inflation ($\frac{1}{4}$) and the nominal income growth ($\frac{1}{4}_x$).

Table 2 through 4 provide the simulation results. Table 2 presents the simulation result of strict targeting, which implies that the central bank is

only concerned about its target variable. Thus, the central bank does not pay attention to the gdp-gap, that is, $\alpha_{y_i \bar{y}} = 0$.

The third through fifth columns of table 2 present the standard deviations of the artificial data under IT, NIGT, and ET, respectively. The variables of which standard deviations are reported in the table are the annualized inflation ($\Delta \pi$), the gdp-gap ($y_i - \bar{y}$), the nominal income growth (Δx), and the exchange rate movement (Δs). The first column shows which value of the weight ($\alpha_{\Delta \pi}$) is put on the interest rate change in the central bank's loss function. The first panel of the table reports the simulation results of the case of $\alpha_{\Delta \pi} = 0.01$. From the first panel we find that for inflation, IT gets the lowest s.d. (0.5022). For the output-gap, IT also gets the lowest s.d. (0.5742). But, for the nominal income growth rate, NIGT gets the lowest s.d. (0.8724). ET also gets the lowest s.d. (0.0001) for the nominal exchange rate variability.

The second to the fourth panel of the table varies the weight on the interest rate change from 0 to 1. We find the same results as found in the first panel. For inflation, IT gets the lowest standard deviation. For the output-gap, IT also gets the lowest standard deviation. But, for the nominal income growth rate, NIGT gets the lowest standard deviation. ET also gets the lowest standard deviation for the nominal exchange rate variability.

Table 3 and 4 present the simulation result of flexible targeting. Under flexible targeting regime, the central bank is concerned about its target variable as well as the output-gap. Table 3 represents the simulation results of the flexible targeting regime with the weight on the output-gap equal to 0.25, i.e., $\alpha_{y_i \bar{y}} = 0.25$. And table 4 represents the case of the weight on the output-gap equal to 1, i.e., $\alpha_{y_i \bar{y}} = 1$. From table 3 through 4, we find the same results as found in table 2. That is, IT is superior in smoothing out fluctuations in inflation and the output-gap. In the meantime, NIGT is superior in lowering the variability of the nominal income growth. And ET yields a more stable movement in the nominal exchange rate than IT and NIGT.

Thus we can summarize the simulation results found from table 2 through 4 as in the following. A targeting policy performs well in smoothing out fluctuations of its own target. That is, IT produces a more stable inflation, NIGT produces a more stable nominal income growth, and ET produces a more stable movement of the nominal exchange rate.

In addition, IT has an advantage in lowering the variability of the output-gap against NIGT and ET. Regardless of the weight on the output-gap in the loss function - that is, strict targeting or flexible targeting - this fact is found.

Therefore, if we evaluate a targeting policy by looking at how inflation and the output-gap are stabilized, IT seems to be the best performer.

5 Conclusion

This paper investigates the appropriateness of targeting monetary policies in a small open economy, that of Korea. To this end, we develop a dynamic optimizing model developed by McCallum and Nelson (1999). However, in contrast with McCallum and Nelson (1999), we model the central bank as a dynamically optimizing agent acting under discretion, rather than imposing an estimated policy rule.

We compare different primary objectives of the central bank, which are represented on the weight in the loss function. We investigate its appropriateness of monetary policies by comparing the performance under different weights on the central bank's loss function. The performance of the monetary policies is evaluated how well they perform in smoothing out fluctuations in inflation, the output gap, or other macroeconomic variables. Policy simulations include variations on inflation targeting, nominal income growth targeting and exchange rate targeting.

In order to calibrate the model economy, we take some parameter values from the literature on the Korean economy, and from the Korean data from 1987.Q2 to 2000.Q4. From the simulation results, we find that a targeting policy performs well in smoothing out fluctuations of its own target. That is, IT produces a more stable inflation, NIGT produces a more stable nominal income growth, and ET produces a more stable movement of the nominal exchange rate. In addition, IT has an advantage in lowering the variability of the output-gap against NIGT and ET. Regardless of the weight on the output-gap - that is, strict targeting or flexible targeting - these facts are found. Therefore, simulation results suggest that inflation targeting is preferable to nominal income growth and exchange rate pegging in smoothing out fluctuations in inflation and the output-gap.

6 Appendix: The Model in detail

In this section, we develop a model economy to be used in our simulations. Following McCallum & Nelson (1999), we assume that in a small open economy in which economic agents decide production and consumption over the infinite life horizon. Contrary to McCallum & Nelson, we simplify the utility function by dropping the assumption of habit formation of consumption.

Especially, we adopt a price adjustment mechanism from Fuhrer and Moore (1995), rather than Calvo (1982), which is adopted in McCallum and Nelson. Finally, we try some forms of interest rate rule different from them.

In the model economy there exist a continuum of households of measure 1, and they consume a variety of goods, provide labor in the factor market, and hold and trade bonds. In addition, they are only a provider of differentiated consumption goods that are consumed both in the domestic and on the abroad. A typical household maximizes discounted sum of streams of present and future consumption, $E_0 \sum_{t=0}^{\infty} \beta^t U(C_t)$, where consumption, C_t ; as shown in the below, is a composite consumption of differentiated good produced in the domestic: $C_t = [\int_0^1 C_t(j)^{(\mu_i - 1) = \mu} dj]^{\mu = (\mu_i - 1)}$:

Domestic residents don't import foreign goods for the purpose of consumption. All imported goods are to be used for intermediates in the production process. This assumption is compatible with the fact that most of imported goods are used for materials or intermediates rather than used for final goods in Korea.

When consumption is given as a sort of Dixit-Stiglitz, the price index comparable with composite consumption has the following form: $P_t^A = [\int_0^1 P_t(j)^{1 - \mu} dj]^{1/(1 - \mu)}$:

A household also holds bonds – both domestic currency denominated one (B_t) and foreign currency denominated one (B_t^*). Domestic and foreign currency denominated bonds pay the real interests, r_t and r_t^* respectively in maturity. Foreign currency denominated bond pays risk premium, τ_t as well.

In addition, a household, as a producer of a differentiated consumption good, hires labor (N_t) and pays wage (W_t) for using labor. The household produces a good using a technology given as $Y_t = f(A_t; N_t; IM_t)$. A_t represents a technology shock, and IM_t represents intermediates utilized in the production of final goods.

On the other hand, the household sells a differentiated final good at the price, P_t , and at that price it produces the good as much as consumers demand. The demand for the good consists of two parts. One part is from the domestic (D_t), and the other is from the foreign (EX_t). Also the household provides labor in the domestic labor market. A resource constraint which the household faces is shown in the below.

$$(A1) P_t(D_t + EX_t) + W_t N_t^S + P_t^A B_t(1 + r_t) + P_t^A Q_t B_t^*(1 + r_t^*)(1 + \tau_t) = P_t^A C_t + W_t N_t + P_t^A Q_t IM_t + P_t^A B_{t+1} + P_t^A Q_t B_{t+1}^*$$

where Q_t represents real exchange rate. Putting λ_t as the Lagrange multiplier to the resource constraint divided by the aggregate price (P_t^A), μ_t as the Lagrange multiplier to the production function, the F.O.C.s for C_t ,

B_{t+1} , B_{t+1}^a , N_t , and IM_t becomes respectively.

$$(A2) U_1(C_t) = \lambda_t$$

$$(A3) \lambda_t = \beta E_t \lambda_{t+1} (1 + r_t)$$

$$(A4) Q_{t,t} = \beta E_t Q_{t+1,t+1} (1 + r_t^a) (1 + \pi_t)$$

$$(A5) W_t = P_t = f_2(A_t; N_t; IM_t)$$

$$(A6) Q_t = f_3(A_t; N_t; IM_t)$$

The transversality conditions for asset stock of the household as well as the optimization conditions also should be satisfied.

$$(A7) \lim_{t \rightarrow \infty} \beta^t \lambda_t B_{t+1} = 0$$

$$(A8) \lim_{t \rightarrow \infty} \beta^t \lambda_t Q_t B_{t+1}^a = 0$$

The nominal bond denominated by domestic currency is associated in the following manner with the real bond denominated by domestic currency.

$$(A9) (1 + R_t) = E_t (P_{t+1}^A = P_t^A) (1 + r_t),$$

where R_t is the nominal interest which is redeemed to the nominal bond denominated by domestic currency. We specify a spontaneous utility function in the following form: $U(C_t) = e^{\epsilon_t} C_t^{1-\gamma} = (1-\gamma)^{-1} \epsilon_t$, where ϵ_t is a preference shock, that is, a sort of demand shock. From Equation (A2), (A3), and (A9), we get a relationship between consumption, inflation, and the nominal interest rate.

$$(A10) c_t = E_t c_{t+1} + (1-\gamma) E_t \epsilon_{t+1} (1-\gamma) R_t + \Delta_t,$$

where $c_t = \log C_t$, and $\Delta_t = \gamma (1-\gamma) (E_t \epsilon_{t+1} - \epsilon_t)$ is assumed to follow an AR(1) process.

$$(A11) \Delta_t = \rho_A \Delta_{t-1} + \eta_{A,t}; \quad \eta_{A,t} \sim N(0; \sigma_A^2)$$

From Equation (A3), (A4), and (A9), we get the uncovered interest parity.

$$(A12) R_t = R_t^a + E_t \pi_{t+1} + \pi_t,$$

where $\pi_t = \log S_t$, and S_t is the nominal exchange rate and defined as $S_t = Q_t P_t^A = P_t^a$. π_t is a risk premium shock, and is assumed to follow an AR(1) process.

$$(A13) \pi_t = \rho_\pi \pi_{t-1} + \eta_{\pi,t}; \quad \eta_{\pi,t} \sim N(0; \sigma_\pi^2)$$

Now let's look at the production activity of a household. The household is a producer of a differentiated good. It has monopolistic power over its product so that it sets the price on it. At the price it sets, it decides the amount of production corresponding to demand. And we assume the domestic and foreign demand function have a form of Dixit-Stiglitz.

$$(A14) D_t = (P_t = P_t^A)^{-\mu} D_t^A$$

$$(A15) EX_t = (P_t = P_t^A)^{-\mu} EX_t^A,$$

where $\mu > 1$, and D_t^A and EX_t^A are an aggregate of D_t and EX_t , respectively. Taking a log on two equations on the above, we get the following

equations.

$$(A16) \quad d_t = \mu(p_t | p_t^A) + d_t^A$$

$$(A17) \quad ex_t = \mu(p_t | p_t^A) + ex_t^A$$

The following equation shows how demand for a differentiated good consists of domestic demand and foreign demand.

$$(A18) \quad y_t = \left(\frac{1-EX}{Y}\right)d_t + \left(\frac{EX}{Y}\right)ex_t,$$

where $y_t = \log Y_t$, $d_t = \log D_t$, and $ex_t = \log EX_t$. $EX=Y$ is the steady-state ratio of exports to output. Foreign demand for the domestic good is assumed to have the following function.

$$(A19) \quad EX_t = Q_t^q Y_t^{y^a}$$

Taking a log on the above equation gives

$$(A20) \quad ex_t = \hat{q}_t + \hat{y}_t^{y^a},$$

where \hat{q}_t represents the elasticity of exports to the real exchange rate, and $\hat{y}_t^{y^a}$ represents the elasticity of exports to the foreign income.

And we consider the foreign nominal interest rate (R_t^a) and the foreign income (Y_t^a) taken as given exogenously. The foreign income is assumed to follow an AR(1) process.

$$(A21) \quad y_t^a = \frac{1}{2} y_{t-1}^a + \epsilon_{y^a,t}; \quad \epsilon_{y^a,t} \sim N(0; \frac{1}{4} \sigma_{y^a}^2).$$

Until now we consider how y_t is determined when p_t is set. Now look at how p_t is set. From the Equation (A16), (A17), and (A18), we get

$$(A22) \quad y_t | y_t^A = \mu(p_t | p_t^A).$$

And the following equation holds as well.

$$(A23) \quad y_t | \bar{y}_t^A = \mu(p_t | \bar{p}_t^A),$$

where \bar{p}_t^A is the price level corresponding to the potential income level, \bar{y}_t^A .

The price mechanism follows Fuhrer and Moore, where wage negotiations are conducted in terms of the wage relative to an average of real contract wages in effect over the life of a contract. In a consequence inflation process has a characteristic of inertia, and the current inflation has the following form.

$$(A24) \quad \pi_t = \frac{1}{2} [\pi_{t-1} + E_t \pi_{t+1}] + \lambda (f(y_t | \bar{y}_t) + (y_{t-1} | \bar{y}_{t-1})g$$

That is, inflation (π_t) depends on both realized inflation of the previous period and expected inflation of the next period.

Now let's look at how the potential output is determined when the price is flexible. The production is assumed to have the following form.

$$(A25) \quad Y_t = [(A_t N_t)^{\alpha} + (1 - \alpha) I M_t^{\alpha}]^{\frac{1}{1-\alpha}}$$

Taking a log of the above equation, we get

$$(A26) \quad y_t = (1 - \alpha) a_t + (1 - \alpha) n_t + \alpha im_t,$$

where $\pm = (1 - \alpha)(IM=Y)^{\frac{1}{1-\alpha}}$. A technological shock (a_t) is assumed to follow an AR(1) process.

$$(A27) a_t = \frac{1}{2} a_{t-1} + \varepsilon_{a,t}; \quad \varepsilon_{a,t} \sim N(0; \frac{1}{4} \sigma_a^2)$$

When the price is flexible, output reaches to the potential level ($Y_t = \bar{Y}_t$), the equation (A26) becomes to

$$(A28) \bar{y}_t = (1 - \beta) a_t + \beta \bar{m}_t$$

if the equilibrium is symmetric, that is, $\bar{Y}_t = \bar{Y}_t^A$.

Taking a log on the equation (A6) gives the following equation

$$(A29) q_t = \log(\mu_{t-1}) + (1 + \beta)(\bar{m}_t - y_t).$$

When the price is flexible, the mark-up rate is constant so that the following equation holds

$$(A30) \bar{m}_t = \bar{y}_t + \frac{1}{1+\beta} q_t$$

Substituting the equation (A28) for the above equation, we get the equation for the potential output.

$$(A31) \bar{y}_t = a_t + \frac{1}{1+\beta} \frac{1}{1-\beta} q_t.$$

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< Table 1 > Values of Parameters

Parameter	Description	Value
β	Time discount rate	0.99
γ	Coefficient of relative risk aversion	5
μ	Elasticity of demand for consumption varieties	10.09
$\frac{1}{2}$	Production elasticity b/w domestic and imported goods	5
$\frac{1}{2}$	Slope of Phillips curve	0.086
$Q(\frac{IM}{Y})$	import share of GDP	0.20
$\frac{EX}{Y}$	export-output ratio	0.214
η	Elasticity of exports to real exchange rate	0.538
η^*	Elasticity of exports to foreign income	1
$\frac{1}{2}a$	AR(1) coefficient of productivity process, a_t	0.89
$\frac{1}{2}A$	AR(1) coefficient of preference process, A_t	0.30
$\frac{1}{2}$	AR(1) coefficient of risk premium process, \cdot_t	0.50
$\frac{1}{2}y^*$	AR(1) coefficient of foreign income process, y_t^*	0.81
$\frac{3}{4}a$	Standard deviation of productivity shock, $\epsilon_{a,t}$	0.02
$\frac{3}{4}A$	Standard deviation of preference shock, $\epsilon_{A,t}$	0.01
$\frac{3}{4}\cdot$	Standard deviation of risk premium shock, $\epsilon_{\cdot,t}$	0.04
$\frac{3}{4}y^*$	Standard deviation of foreign income shock, $\epsilon_{y^*,t}$	0.0075

<Table 2> Experiment 1 ($\sum y_i \bar{y} = 0$)

		$\sum \frac{1}{4} = 1$	$\sum c_x = 1$	$\sum c_s = 1$
$\sum c_i = 0:01$	$\frac{3}{4}(4 \bar{E} \frac{1}{4})$	0.5022	5.0852	10.4249
	$\frac{3}{4}(y_i \bar{y})$	0.5742	2.5267	2.7825
	$\frac{3}{4}(c_x)$	1.8482	0.8724	2.7805
	$\frac{3}{4}(c_s)$	8.9280	8.3653	0.0001
$\sum c_i = 0$	$\frac{3}{4}(4 \bar{E} \frac{1}{4})$	0.0000	5.3077	10.4249
	$\frac{3}{4}(y_i \bar{y})$	0.0000	2.6402	2.7825
	$\frac{3}{4}(c_x)$	1.7797	0.9844	2.7805
	$\frac{3}{4}(c_s)$	8.9643	8.5175	0.0001
$\sum c_i = 0:5$	$\frac{3}{4}(4 \bar{E} \frac{1}{4})$	1.9568	2.9724	10.4249
	$\frac{3}{4}(y_i \bar{y})$	1.1529	1.4656	2.7825
	$\frac{3}{4}(c_x)$	1.9911	1.2645	2.7805
	$\frac{3}{4}(c_s)$	9.4628	8.2617	0.0001
$\sum c_i = 1$	$\frac{3}{4}(4 \bar{E} \frac{1}{4})$	2.4419	3.0234	10.4249
	$\frac{3}{4}(y_i \bar{y})$	1.2805	1.4750	2.7825
	$\frac{3}{4}(c_x)$	2.0317	1.5726	2.7805
	$\frac{3}{4}(c_s)$	9.6014	8.7866	0.0001

<Table 3> Experiment 2 ($\sum y_i \bar{y} = 0:25$)

		$\sum c_p = 1$	$\sum c_x = 1$	$\sum c_s = 1$
$\sum c_i = 0:01$	$\frac{3}{4}(4 \bar{E} \frac{1}{4})$	0.2682	2.8539	9.8023
	$\frac{3}{4}(y_i \bar{y})$	0.2921	1.4561	2.6766
	$\frac{3}{4}(c_x)$	1.7806	0.3324	2.6578
	$\frac{3}{4}(c_s)$	8.8341	7.6496	0.2821
$\sum c_i = 0$	$\frac{3}{4}(4 \bar{E} \frac{1}{4})$	0.0000	2.9103	9.8026
	$\frac{3}{4}(y_i \bar{y})$	0.0000	1.4925	2.6767
	$\frac{3}{4}(c_x)$	1.7797	0.3058	2.6580
	$\frac{3}{4}(c_s)$	8.9643	7.6921	0.2817
$\sum c_i = 0:5$	$\frac{3}{4}(4 \bar{E} \frac{1}{4})$	1.7521	2.4228	9.7872
	$\frac{3}{4}(y_i \bar{y})$	1.0389	1.2157	2.6681
	$\frac{3}{4}(c_x)$	1.9501	1.3523	2.6478
	$\frac{3}{4}(c_s)$	9.3159	8.2979	0.3076
$\sum c_i = 1$	$\frac{3}{4}(4 \bar{E} \frac{1}{4})$	2.2510	2.6489	9.7723
	$\frac{3}{4}(y_i \bar{y})$	1.1861	1.3081	2.6597
	$\frac{3}{4}(c_x)$	1.9980	1.6005	2.6378
	$\frac{3}{4}(c_s)$	9.4757	8.7623	0.3419

< Table 4> Experiment 3 ($\sum y_i \bar{y} = 1$)

		$\sum c_p = 1$	$\sum c_x = 1$	$\sum c_s = 1$
$\sum c_i = 0:01$	$\frac{3}{4}(4 \text{ E } \frac{1}{4})$	0.1215	1.4521	8.3396
	$\frac{3}{4}(y_i \bar{y})$	0.1221	0.7352	2.4162
	$\frac{3}{4}(c_x)$	1.7710	0.9927	2.3812
	$\frac{3}{4}(c_s)$	8.8807	7.9272	0.9869
$\sum c_i = 0$	$\frac{3}{4}(4 \text{ E } \frac{1}{4})$	0.0003	1.4662	8.3408
	$\frac{3}{4}(y_i \bar{y})$	0.0000	0.7520	2.4169
	$\frac{3}{4}(c_x)$	1.7797	0.9749	2.3819
	$\frac{3}{4}(c_s)$	8.9644	7.9491	0.9853
$\sum c_i = 0:5$	$\frac{3}{4}(4 \text{ E } \frac{1}{4})$	1.3941	1.7406	8.2853
	$\frac{3}{4}(y_i \bar{y})$	0.8367	0.8889	2.3847
	$\frac{3}{4}(c_x)$	1.8854	1.4862	2.3459
	$\frac{3}{4}(c_s)$	9.0939	8.4028	1.0822
$\sum c_i = 1$	$\frac{3}{4}(4 \text{ E } \frac{1}{4})$	1.8859	2.0859	8.2369
	$\frac{3}{4}(y_i \bar{y})$	1.0036	1.0437	2.3550
	$\frac{3}{4}(c_x)$	1.9374	1.6482	2.3129
	$\frac{3}{4}(c_s)$	9.2548	8.7341	1.2015