# Staggered Price Settings, Exchange Rates, and Monetary Policy

**Yongseung Jung***

This paper examines the effects of monetary policy in an optimizing two-country model in which monopolistically competitive firms set their prices in advance, so that the prices are sticky. The main findings of this paper are that there occurs an instantaneous depreciation of the exchange rates through a countercyclical response of a markup when there is a positive home monetary shock. The paper shows that the sticky price model cannot resolve the forward premium puzzle. The degree of depreciation depends on the degree of price stickiness as real variables become more volatile with stronger price stickiness. Finally, the nominal exchange and real exchange rates move very closely as in data when there is a substantial degree of price rigidity.

*Keywords*: Coutercyclical markup, Exchange rate, Monetary policy, Monopolistic competition

*JEL Classification*: E52, F31

## I. Introduction

In international finance, there is vast empirical literature that documents the failure of the flexible price general equilibrium model in that the forward exchange rate is not an unbiased predictor of the future spot exchange rate and a sizable time-varying foreign exchange risk premium exists. While some economists explain this failure as the market inefficiency, others make efforts to set up a general equilibrium cash-in-advance

*Associate Professor, Department of Economics, Kyunghee University, Seoul, South Korea, 130-701, (Tel) +82-2-961-0962, (E-mail) jungys@khu.ac.kr. I thank to Mark Bils and Alan Stock-man for helpful comments and conversations. All errors are my own.
[**Seoul Journal of Economics** 2003, Vol. 16, No. 4]

models and explain the excessive variation of exchange rates from this. Unfortunately, it is not easy to construct a model that fits the empirical facts. Even if one follows the literature, it is hard to produce sufficient variation in exchange rate without excessive variation in the expected consumption. In recent, Clarida and Gali (1993), Eichenbaum and Evans (1993), and Evans and Lothian (1993) found that the international transmission effects of monetary shocks are substantial. In particular, their new empirical results show that the expansionary monetary policy shocks in the US generate substantial, persistent depreciations in the US nominal and real exchange rates. They note that the effects of this monetary policy shocks can explain around thirty to forty percent of the exchange rate movements between the US and Germany, and the US and Japan. However the existing international finance models with flexible prices and continuously clearing markets, albeit useful as benchmarks, fail to address the sluggish price and relatively large output adjustments by exaggerating price level variability. The international stochastic dynamic general equilibrium (SDGE) models in which money is introduced simply by adding cash-in-advance constraints or transactions role for money with flexible prices imply a consumption decrease and exchange rate appreciation. Moreover, the more advanced international SDGE models in which money has liquidity effects through the imposition of portfolio or capital sluggishness also lack sufficient avenues for intertemporal propagation of monetary shocks. These models fail to account for long persistent effects of monetary shocks on exchange rates (Schlagenhauf and Wrase 1993). This leads Clarida and Gali (1993) to conclude that it is desirable to incorporate sluggish price adjustment into the model if one wishes to explain the hump-shaped short run exchange rate dynamics and the volatility of exchange rates. They support a stochastic rational expectations version of the Mundell-Fleming model.

This paper extends Svensson and van Wijinbergen (1989) and Stockman and Ohanian (1993) by utilizing monopolistically competitive firms with capital accumulations. Even though Clarida and Gali (1993) assert that the short run dynamics of exchange rates are consistent with the sticky price Mundell-Fleming model, the approach, although not built on microeconomic foundation, has a well known series of shortcomings.[1] It ignores intertemporal substitution of monetary shocks which can often affect quantitative results as argued by Svensson and van Wijnbergen (1989). They propose and international "sticky-price" monetary model built on monopolistic competition and cash-in-advance constraints. However, when they set up a model in which no capital exists and prices are fixed for one period to simplify the analysis, they cannot evaluate its quantitative success. Stockman and Ohanian (1993) also set up a "sticky-price" dynamic optimization model, but they do not prove the implications of their model with actual data because they treat "price-stickiness" as a black box.

Recent attempts to reconcile RBS (Real Business Cycle) models with New Keynesian Macroeconomics is attractive, because the "sticky-price" dynamic general equilibrium model can be quantitatively evaluated. Two models that show the importance of monetary policy in generating a business cycle are notable. Hairault and Portier (1993) assert that a dynamic extension of the Blanchard and Kiyotaki (1987) model with two independent shocks (real and monetary shocks) can answer some empirical puzzles that were unexplained by the traditional RBC models, given some adjustment costs in price setting. Yun (1994) also shows that a dynamic version of the Blanchard and Kiyotaki (1987) model with cash-in-advance constraints can generate a positive comovement of inflation and output. This comovement is impossible in the RBC model with flexible price, such as Cooley and Hansen (1989).

I begin by setting up a "sticky-price" dynamic general equilibrium model with monopolistic competition in a standard RBC framework. Then using this improved model, I investigate the following questions. First, I explore whether this model can generate a long and persistent hump-shaped exchange rate effect of monetary shocks. Second, I discuss whether this model can give rise to volatile exchange rate movements. Third, I Explore whether the comovements of exchange rates and other real variables are consistent in data.

The propagation mechanism as well as the implications contained in such a monopolistic competition model are different from those of the recent differential participation model such as Grilli and Roubini (1992), and Schlagenhauf and Wrase (1993). The latter is based on liquidity effects of monetary policy. Success of the sluggish portfolio or capital models is highly dependent on the

[1]See Svensson and van Wihnbergen (1989).

generation of depreciation effects from positive monetary shocks through liquidity effects. This models, however, are inconsistent with the data in that the monetary policy shock effects on exchange rates disappear after 1 or 2 quarters. These effects are not present in my model. It does generate long and persistent depreciation effects of expansionary monetary policy shocks which are consistent with the data. Another point of comparison is the propagation mechanism. They are usually different from those of the sluggish portfolio or capital models with flexible price. My model does not rely on the liquidity effect. But it does depend on the countercyclical response of markups through price rigidity which generate persistent depreciation effects. That is, the markup which is the ratio of price to marginal cost responds negatively to a positive monetary shock as price is sticky and marginal cost is flexible in the model. The degree of markup and real variables become stronger as the degree of price stickiness increases.

The main findings of this paper can be summarized as follows. First, when there exists a substantial degree of price rigidity in the economy, expansionary monetary shocks to the home country lead to an instantaneous depreciation of home real and nominal exchange rates. The result that the effects of monetary shocks on the exchange rates last long enough is in sharp contrast with Schlagenhauf and Wrase (1993)'s result which emphasizes the liquidity effects but fails to find such effects of monetary shocks. However, the sticky price model cannot resolve the so-called forward premium puzzle. Second, the degree of exchange rate depreciations on positive monetary shocks increase with the degree of price stickiness. At the same time, the variabilities of real variables also increase because more and more firms adjust their prices through the rule of thumb instead of optimal pricing rules. Finally, the correlation between nominal and real exchange rate increases as the nominal rigidity increases and it nicely matches with the data. The markup responds negatively to a positive monetary shock and positively to a positive real shock. This plays an important role in generating the persistent and volatile exchange rate effects of monetary shocks.

The organization of the paper is as follows. In section II, the model is presented. In section III, the equilibrium and the impulse response of some real variables to monetary shocks are analyzed. Various second moments of the model are compared with those of the data in section IV. Section V concludes the paper.

## II. Model

### *A. Monopolistic Competition Model with a Cash-in-Advance Constraint*

Consider a world economy with two-countries, two goods, and a flexible exchange rate between the two moneys. The home (foreign) country is completely specialized in the production of its own goods, $Y_h(Y_f)$. Here $h$ denotes the home country, and $f$ denotes the foreign country. The goods production is subject to the production shocks, $A_h$ and $A_f$ respectively. The two currencies, home and foreign, $M_h$ and $M_f$ are also subject to monetary shocks, $w_h$ and $w_f$. In this section, I present a two country model based on a dynamic extension of Blanchard and Kiyotaki (1987) and Stockman and Ohanian (1993), and Svensson and van Wijnbergen (1989). I extend their models by explicitly incorporating the monopolistic competition and staggered price setting rule as in Yun (1994).

The model in this paper is based on monopolistically competitive markets in which there exist a continuum of differentiated goods indexed by [0,1]. Assume that utilities of consumers and additions to the aggregate capital stock depend only on the amount of a single composite good. This is associated with introducing an aggregator of the differentiated goods. Consider the aggregator[2] suggested by Dixit and Stiglitz (1977) such that

$$J_t = [\int_0^1 d_t(j)^{1-\phi} dj]^{\frac{1}{1-\phi}}, \qquad 0 < \phi < 1, \tag{1}$$

where $J_t$ denotes the number of units of the composite good at time $t$, and $d_t(j)$ is the measure of the purchases of the $j$th good at time $t$.[3] Then the purchases of differentiated goods over [0,1] are the solutions to minimize the total cost of obtaining $J_t$ such that

$$\min. \int_0^1 P_t(j) d_t(j) dj \qquad s.t. \quad J_t \leq [\int_0^1 d_t(j)^{1-\phi} dj]^{\frac{1}{1-\phi}}, \tag{2}$$

[2]See Rotemberg and Woodford (1992) for a detailed discussion of the specification of the aggregator in monopolistically competitive goods market.

[3]I suppress a country subscript, *i.e.* $h$ and $f$ in the explanation of an aggregator.

where $P_t(j)$ is the price of the $j$th good at time $t$. The cost minimizing demand for each differentiated good and the minimized cost are

$$d_t^*(j) = \left[\frac{P_t(j)}{P_t}\right]^{-\frac{1}{\theta}} J_t, \qquad P_t = [\int_0^1 P_t(j)^{\frac{\theta-1}{\theta}} dj]^{\frac{\theta}{\theta-1}}$$

$$\int_0^1 P_t(j) d_t^*(j) dj = P_t J_t$$

The demand for each differentiated goods is determined by the above cost minimization when the demand for the composite good is given. This allows the following optimization problem of the household to be described in terms of the composite good only.

a) Households

Representative households in each country choose consumptions and portfolio allocation to maximize

$$E_0[\sum_{t=0}^{\infty} \beta^t u(C^d_{hh}(C_{1hht}, C_{2hht}), C^d_{hf}(C_{1hft}, C_{2hft}), L_{ht})], \quad 0 < \beta < 1, \tag{3}$$

where $E_0$ denotes the conditional expectations operator on the information available in period 0, and $C_{1hit}$ and $C_{2hit}$ $(i = h, f)$ denotes cash good and credit good consumption of the home resident at period $t$, respectively, as in Lucas and Stokey (1987). $L_{ht}$ represents the leisure of the home resident at time $t$. $C^d_{hh}(C_{1hht}, C_{2hht})$ and $C^d_{hf}(C_{1hft}, C_{2hft})$ is homogenous of degree one in both arguments respectively.[4] The agent also faces the time constraint such that

$$L_{th} + H_{ht} \leq \bar{H}_h, \tag{4}$$

where $H_{ht}$, $\bar{H}_h$ denote the hours worked and time endowment of the home resident. Since the timing of markets and the transactions facing the household need to be specified, I explain it in some detail for the case of the home household. The household starts with nominal wealth $\Theta_{ht}$, carried over from period $t-1$ and receives the lump-sum transfers of home and foreign currencies, $T_{hht}$, $T_{hft}$

[4] $C^d_{hh}(C_{1hht}, C_{2hht})$ is $C^2$, concave and homogenous of degree one in both arguments with $\lim_{C_{1hht}\to 0} C^d_{1hh}(C_{1hht}, C_{2hht}) = \infty$, $\lim_{C_{2hht}\to 0} C^d_{2hh}(C_{1hht}, C_{2hht}) = \infty$, $C^d_{1hh}(C_{1hht}, C_{2hht}) > 0$, $C^d_{2hh}(C_{1hht}, C_{2hht}) > 0$ for $C_{1hh}, C_{2hh} > 0$. The same also holds for $C^d_{hf}$.

before the asset market opens. Though it is not at all difficult to incorporate greater asset diversity and reformulate the model, I will assume that the representative household chooses four assets as in Obstfeld and Rogoff (1995, 1996), that is, home and foreign currencies, $M_{hht}$, $M_{hft}$ as well as one period nominal contigent home currency bonds, $B_{hht}$, $B_{hft}$ at the asset markets.[5]

$$M_{hht}+e_tM_{hft}+B_{hht}+B_{hft}\leq \Theta_{ht}+T_{ht}, \tag{5}$$

where $T_{ht}=T_{hht}+e_tT_{hft}$ and $e_t$ is the nominal exchange rate at time $t$. Here $x_t$ denotes the state of the economy at time $t$.

After the household's transactions on asset markets, that market closes, and the goods market opens. At the goods market, the household can buy home and foreign consumption goods with home currency and foreign currency as well as with credit. It must pay for home goods with home currency and for foreign goods with foreign currency. Thus it faces the following cash-in-advance constraints.

$$\begin{aligned} P_{ht}C_{1hht}&\leq M_{hht},\\ P_{ft}C_{1hft}&\leq M_{hft}, \end{aligned} \tag{6}$$

where $P_{ht}$ and $P_{ft}$ is the home currency price of home goods and the foreign currency price of foreign goods respectively.

Moreover, each country's household owns only its own country's capital stock to rent to its country's firm and there is no firm specific capital stock. Since we do not empirically observe large discrete capital stock adjustments, it is reasonable to introduce an adjustment cost in capital stock installments. If there are costs of installing capital, the capital stock will move more sluggishly. I assume that there are deadweight costs of installing capital stock.

[5]The outstanding assets are money, one period bond, and capital in each country. Obstfeld and Rogoff (1995, 1996) introduce only one period risk free bond in their sticky price model, saying that the assumption of complete asset markets would seem incongruous alongside the nominal rigidites. Chari, Kehoe, and McHrattan (1996) consider a complete asset market. Baxter and Crucini (1993) discuss the implications of complete and incomplete asset market structure in a international real business cycle model.

To preserve the simple model structure as far as possible, I will adopt the Uzawa-Lucas-Prescott form of investment adjustment costs.

$$K_{ht+1} = \psi(I_{ht}/K_{ht}) + (1-\delta_{hkt})K_{ht}, \tag{7}$$

where $\psi(I_{ht}/K_{ht})$ is a positive, concave function, and $I_{ht}$ is the composite investment of the home resident at period $t$, and $K_{ht}$ is the composite capital stock of the home resident at period $t$. At the end of each period, the household receives wages, rents for capital, and dividends from each firm. Thus her wealth at the beginning of the period $t+1$ is given by,

$$\begin{aligned} \Theta_{ht+1} = & M_{hht} + e_{t+1}M_{hft} + B_{hht}(1+i_{ht}) + B_{hft}(1+i_{ft}) \\ & - P_{ht}(C_{hht} + I_{ht}) - e_{t+1}P_{ft}C_{hft} + W_{ht} + R_{ht}K_{ht}. \end{aligned} \tag{8}$$

Here $i_{ht}$, $i_{ft}$ denote 1 period gross nominal interest rate of the home and the foreign country at period $t$, and $\Pi_{ht}$, $W_{ht}$, $R_{ht}$ denote the home country firm's nominal profits, nominal wages and nominal rental rate for capital stock given to the home residents respectively and $C_{hht} = C_{1hht} + C_{2hht}$, $C_{hft} = C_{1hft} + C_{2hft}$, $X_{ht} = I_{ht}/K_{ht}$.[6]

The relationship between cash and credit goods can be derived from the first order conditions. As $C^d_{hht}$ is assumed to be homogenous of degree one in its arguments, the ratio of domestic consumer's demand for cash goods to credit goods $(C_{1hht}/C_{2hht})$ can be expressed as a function of domestic nominal interest rate. The ratio of domestic consumer's demand for cash goods to total consumption goods is also a function of domestic nominal interest rate, *i.e.* $(C_{1hht}/C_{hht}) = h(i_{ht})$ and the function $C^d_{hht}$ can be decomposed into domestic consumer's demand for domestic consumption good, $C_{hht}$ and domestic nominal interest rate. That is, $C^d_{hh}(C_{1hht}, C_{2hht}) = C_{hht}\,\xi(i_{ht})$. With these relationship, I can simplify the first order conditions for domestic consumer's demand for domestic cash and credit goods as follows.

[6]Every differentiated consumption good can be purchased as a cash good and credit good. $C_{1hht} = (\int_0^1 C_{1hht}(j)^{1-\phi} dj)^{\frac{1}{1-\phi}}$ and $C_{2hht} = (\int_0^1 C_{2hht}(j)^{1-\phi} dj)^{\frac{1}{1-\phi}}$. The same holds for foreign consumption goods.

$$u_1(C^d_{hh}(C_{1hht},C_{2hht}),C^d_{hf}(C_{1hft},C_{2hft}),L_{ht})C^d_{hh1}(C_{1hht},C_{2hht})=\Lambda_{ht}i_{ht}, \tag{9}$$

$$\frac{C^d_{hh1}(C_{1hht},C_{2hht})}{C^d_{hh2}(C_{1hht},C_{2hht})}=i_{ht}, \tag{10}$$

where $\xi(i_{ht})=(i_{ht}/C^d_{hh1}(C_{1hht},C_{2hht}))$. Here $\Lambda_{ht}$ is defined as $\beta E_t\bar{\Lambda}_{ht+1}$, where $\bar{\Lambda}_{ht}$ is a Lagrange multiplier of the domestic household's budget constraint (5) and $u_i(\cdot)$ is a partial derivative of $u$ with respect to a variable $i$. $C^d_{hhi}$ is a partial derivative of $C^d_{hh}(C_{1hht},C_{2hht})$ with respect to a variable $i$.

Similarly, the relation between foreign cash and credit goods of the home resident is given by

$$u_2(C^d_{hh}(C_{1hht},C_{2hht}),C^d_{hf}(C_{1hft},C_{2hft}),L_{ht})C^d_{hh1}(C_{1hht},C_{2hht})=\Lambda_{ht}i_{ft}\,\varepsilon_t, \tag{11}$$

$$\frac{C^d_{hf1}(C_{1hft},C_{2hft})}{C^d_{hf2}(C_{1hht},C_{2hft})}=i_{ft}, \tag{12}$$

where $(C_{1hft}/C_{hft})=h(i_{ft})$, $(C^d_{hf}/C_{hft})=\xi(i_{ft})$, $\varepsilon_t=(e_tP_{ft}/P_{ht})$, $\xi(i_{ft})=(i_{ft}/C^d_{hf1}(C_{1hft},C_{2hft}))$.[7]

Without any artificial restriction on the asset transactions, I get the real exchange rate from (11) and (12). It is a function of the ratio of marginal utility of each country's consumption good, and interest rates as

$$\varepsilon_t=\frac{u_2(C^d_{hh},C^d_{hf})\,\xi(i_{ht})i_{ft}}{u_1(C^d_{hh},C^d_{hf})\,\xi(i_{ft})i_{ht}}. \tag{13}$$

The real exchange rate that is derived from the assumption that each household consumes cash and credit goods is very similar to the real exchange rate,[8] $\varepsilon_t=(u_2(i_{ft})/u_1(i_{ht}))$ that is derived under the

[7]From the assumption that $C^d_{ij}(i,j=h,f)$ is homogeneous of degree one in its arguments, I can derive the elasticity of substitution between cash goods and credit goods as $\xi'(i_t)=(h'(i_t)/1+h(i_t))$, where $h'=-(dlnh(i_t)/dlni_t)$.

[8]Grilli and Roubini (1992), Schlagenhauf and Wrase (1993) have extended the idea of liquidity effect that is emphasized as an additional source of interest rate movement to the monetary shock (Lucas 1990; Furest 1992;

assumption that individuals need cash to transact in asset markets as in Grilli and Roubini (1992). Next consider the first order conditions about domestic and foreign one-period nominal bonds that pay one certain unit of home and foreign currency at the beginning of period $t+1$.

$$\bar{\Lambda}_{ht} = \beta E_t[\bar{\Lambda}_{ht+1} i_{ht}] \tag{14}$$

$$\bar{\Lambda}_{ht} e_t = \beta E_t[\bar{\Lambda}_{ht+1} e_{t+1} i_{ft}] \tag{15}$$

As the marginal utility of wealth is given by the Lagrange multiplier of the budget constraint, the expected utility in period $t$ of the home currency bond is $\beta E_t[\bar{\Lambda}_{ht+1}]$ whose present value is $\beta E_t[\bar{\Lambda}_{ht+1}]/\bar{\Lambda}_{ht}$. Therefore the price of home currency one period nominal interest rate equals $\beta E_t[\bar{\Lambda}_{ht+1}]/\bar{\Lambda}_{ht}$. Similarly, the price of foreign currency one period nominal bond is given by $(\beta E_t[\bar{\Lambda}_{ht+1}/e_{t+1}])/(\bar{\Lambda}_{ht}/e_t)$ because the expected utility in period $t$ of foreign currency one period bond is $\beta E_t[\bar{\Lambda}_{ht+1}/e_{t+1}]$.[9]
With these and the first order condition of investment, the first order conditions for the household can be summarized as follows.

$$u_1(C^d_{hh}(C_{1hht}, C_{2hht}), C^d_{hf}(C_{1hft}, C_{2hft})), L_{ht}) C^d_{hh1}(C_{1hht}, C_{2hht}) = \Lambda_{ht} i_{ht}, \tag{16}$$

$$u_2(C^d_{hh}(C_{1hht}, C_{2hht}), C^d_{hf}(C_{1hft}, C_{2hft})), L_{ht}) C^d_{hh1}(C_{1hht}, C_{2hht})$$
$$= \Lambda_{ht}\, \xi(i_{ht})(i_{ht}/i_{ft})\, \varepsilon_t, \tag{17}$$

$$u_3(C^d_{hh}, C^d_{hf}, L_{ht}) = \Lambda_{ht} w_{ht}, \tag{18}$$

$$\Lambda_{ht} = \frac{\beta E_t[\Lambda_{ht+1} P_{ht+1} i_{ht+1}]}{P_{ht}}. \tag{19}$$

$$\Lambda_{ht} = \beta E_t\left[\frac{\varepsilon_{t+1}\Lambda_{ht+1} P_{ft} i_{ht+1} i_{ft}}{\varepsilon_t P_{ht} i_{ht}}\right]. \tag{20}$$

and Christiano and Eichenbaum 1992) to the exchange rate movement.

[9]These two equations imply the uncovered interest parity, $E_t[\bar{\Lambda}_{ht+1} i_{ht}] = E_t[\bar{\Lambda}_{ht+1} e_{t+1} i_{ht}]/e_t$.

$$\Lambda_{ht}\,\psi'^{-1}(X_{ht}) = \beta E_t[\Lambda_{ht+1}\,\psi'^{-1}(X_{ht+1})\,\chi(X_{ht+1}) + r_{ht+1}\Lambda_{ht+1}] \tag{21}$$

$$h(i_{ht})C_{hht} \le \frac{M_{hht}}{P_{ht}}, \quad = \text{ if } \; i_{ht} > 1 \tag{22}$$

$$h(i_{ft})C_{hft} \le \frac{M_{hft}}{P_{ft}}, \quad = \text{ if } \; i_{ft} > 1$$

$$C_{hht}(j) = \left(\frac{P_{ht}(j)}{P_{ht}}\right)^{-\theta} C_{hht}, \quad C_{hft}(j) = \left(\frac{P_{ft}(j)}{P_{ft}}\right)^{-\theta} C_{hft}, \quad I_h(j) = \left(\frac{P_{ht}(j)}{P_{ht}}\right)^{-\theta} I_{ht}, \tag{23}$$

where $\chi(X_{ht+1}) = \psi(X_{ht+1}) - \psi'(X_{ht+1})X_{ht+1} + 1 - \delta$, $\psi'^{-1}$ equals Tobin's $q$ which is the ratio of the price of installed capital to the price of replacement capital, and $r_{ht} = (R_{ht}/P_{ht})$, $w_{ht} = (W_{ht}/P_{ht})$. Equation (21) which is the first order condition with respect to the home representative household's investment represents the evolution of Tobin's $q$ over time. Though I need not specify the functional form for adjustment cost function, $\psi$, I should specify three parameters which describe the behavior around the steady state. First, I must specify the steady state value of Tobin's $q$ and the share of investment in national product. Since the steady state value of Tobin's $q$ is 1, I also set the value of this variable to 1.0 in steady state. And I will take the same investment share in steady state as in a model without adjustment cost. Next, I have to specify the parameter which determines the elasticity of marginal adjustment cost function. As there has been no study about this adjustment cost parameter value, I will present several results through sensitivity analysis in next section. Equation (23) says that the $j$th consumption goods and investment goods are determined by the cost minimization demands when the composite demands are given.

Next, I follow Rotemberg and Woodford (1993) in deriving the Frisch demand functions for consumption and leisure. This method allows one the convenience of making assumptions about these functions rather than about the parameters of preferences directly. From the above equations, I can derive the Frisch consumption demand and labor supply functions as

$$C_{hht} = C^{d}_{hh}(\Lambda_{ht}, w_{ht}, i_{ht}, i_{ft}, \varepsilon_t) \tag{24}$$

$$C_{hft} = C^{d}_{hf}(\Lambda_{ht}, w_{ht}, i_{ht}, i_{ft}, \varepsilon_t) \tag{25}$$

$$H_{ht} = H^{s}_{h}(\Lambda_{ht}, w_{ht}, i_{ht}, i_{ft}, \varepsilon_t) \tag{26}$$

In the above equation the effects of all future variables, *i.e.* their expectations are reflected in the marginal utility of wealth, $\Lambda_{ht}$. That is, the home household's demand for home and foreign consumption goods and labor supply depend on her own wealth, current wage rate, interest rate (home and foreign) as well as the spot real exchange rate. This is comparable to that of the traditional international IS-LM model.

Moreover, if I assume that the nominal interest rate is positive, then the cash-in-advance constraint is always binding, and this leads to the relationship that the real balance of each country is cointegrated with its own consumption.

$$\frac{M_{ht}}{P_{ht}} = h(i_{ht})C_h(\Lambda_{ht}, \Lambda_{ft}, w_{ht}, w_{ft}, i_{ht}, i_{ft}, \varepsilon_t), \tag{27}$$

where $C_h$ is the total consumption demand for home goods. Here I used the domestic money market equilibrium condition,

$$M^{s}_{ht} = M^{d}_{ht} = M_{hht} + M_{fht}, \tag{28}$$

where $M_{ht}$ denotes foreign representative household's demand for foreign currency.

b) Firms

In my model differentiated goods and monopolistic competition are introduced along the lines of Dixit and Stiglitz (1977). Suppose that there are a continuum of firms producing differentiated goods, and each firm indexed by $0 \leq j \leq 1$, produces its product with a constant returns to scale, concave production technology. Each firm $j$ takes $P_{ht}$ and the aggregate demand as given, and chooses its own product price $P_{ht}(j)$. Since the input markets are perfectly competitive, the demands for labor and capital are determined by its cost minimization as follows.

$$C(W_{ht},R_{ht},Y_{ht},H_{h0},z_{ht}) \equiv min_{H_{ht}(j),K_{ht}(j)}\{R_{ht}K_{ht}(j)+W_{ht}H_{ht}(j)\} \quad (29)$$

subject to

$$Y_{ht}(j) \leq A_{ht}F(K_{ht}(j),z_{ht}(H_{ht}(j)-H_{h0}))$$

Here $H_{h0}$, $z_{ht}$, and $A_{ht}$ are the home country resident's fixed overhead cost in units of labor hours, labor augmenting permanent technology progress, and transitory technology process at period $t$. $Y_{ht}(j)$[10] and $H_{ht}(j)$ are the output and total labor input of the $j$th firm in the home country respectively. I assume that the technology shock follows an AR(1) process. The permanent changes in the total factor productivity, $z_{ht}$ are taken as growing deterministically, *i.e.* $\gamma_h = (z_{ht}/z_{ht-1})$ for all $t$ as in King, Plosser and Rebelo (1988a, hereafter KPR (1988a)).

$$lnA_{ht} = \rho_h lnA_{ht-1} + \xi_{Aht}, \qquad -1 < \rho_h < 1, \quad (30)$$

where $E(\xi_{Aht})=0$ and $\xi_{Aht}$ is *i.i.d.* over time.
As the production function is CRS, marginal cost is independent of the level of output. Thus the firm's cost minimization conditions can be written as

$$R_{ht} = MC_{ht}A_{ht}F_1(K_{ht}(j),z_{ht}(H_{ht}(j)-H_{h0})) \quad (31)$$

$$W_{ht} = MC_{ht}A_{ht}F_2(K_{ht}(j),z_{ht}(H_{ht}(j)-H_{h0})), \quad (32)$$

where $MC_{ht}$ is the marginal cost of the firm at time $t$. Moreover, CRS of the production function implies that $((H_{ht}(j)-H_{h0})/K_{ht}(j)) = ((H_{ht}-H_{h0})/K_{ht})$ for all $j$ and thus the cost minimization conditions specified in the above equations hold for aggregate quantities.[11]

c) Staggered Price Setting

In this subsection, I use a discrete time version of Calvo (1983)-style staggering price setting rule. I follow Yun (1994)'s strategy to

[10] $Y_{ht}(j) = A_{ht}F(K_{ht}(j),z_{ht}(H_{ht}(j)-H_{h0}))$ is strictly concave, twice continuously differentiable, and CRS in $K_{ht}(j)$ and $H_{ht}(j)-H_0(j)$ but it is IRS in $K_{ht}(j)$ and $H_{ht}(j)$.

[11] Here $K_{ht} = \int_0^1 K_{ht}(j)dj$, $H_{ht}(j) = \int_0^1 H_{ht}(j)dj$.

model a monopolistically competitive firm's price setting rule, focusing on the monopolistic competitive firm in the home country. I will suppress the country subscript for simplicity. The monopolistic competition firms in the product markets set their own prices in advance by maximizing the present discounted value of profits. Suppose that only the fraction $(1-\alpha)$ of the firms sets the new price, $P_{t,t}$ and the other fraction of firms, $\alpha$ sets its price by multiplying the average inflation rate or average monetary growth rate $w$ by their previous price level. That is, suppose that individual firms have a constant probability $(\alpha)$ of adjusting their prices through the rule of thumb, though non-constant hazard rate is probably more plausible. Let $D_{t,t+k}$ denote the demands at period $t+k$ facing firms that set their prices at time $t$, and $P_{t,t+k}$ the prices at period at $t+k$ that are predetermined at time $t$. Since the probability that the firm sets its new price optimally is $(1-\alpha)$ in discrete time version of Calvo (1983) model,[12] and it is assumed that this probability of setting new price level for each firm is independent of the time elapsed since the last price change, the firm's maximization problem can be written as follows.

$$max.E_t\{\sum_{k=0}^{\infty}(\alpha\beta)^k[\frac{\Lambda_{t+k}P_t}{\Lambda_t P_{t+k}}(P_{t,t+k}D_{t,t+k}-MC_{t+k}D_{t,t+k})]\}, \tag{33}$$

where $P_{t,t+k}=\tilde{w}^k P_{t,t}$, $\tilde{w}=(w/\gamma)$, and $\Lambda_t$ and $\Lambda_{t+k}$ are the marginal utility of wealth at time $t$ and $t+k$ and $k=0,1,2,\cdots$.

The first order condition of this newly determined price at time is given by

[12]There is both microeconomic and macroeconomic evidence against the constant hazard (probability) model. This evidence favors models where the probability that a firm will change its price is increasing in the extent to which its price departs from its from *desired* price. Unfortunately, only restrictive models of this type have been solved to date. The most thoroughly studied case is by Caplin and Leathy (1992) who analyze a model of fixed cost of changing prices where money follows a random walk. But this study is unsatisfactory for my purpose, because it neglects a serial correlation in money growth rate, which from an empirical point of view, appears important.

$$P_{t,t}=\frac{E_t[\sum_{k=0}^{\infty}(\alpha\beta)^k\frac{\Lambda_{t+k}}{P_{t+k}}D_{t,t+k}MC_{t+k}]}{(1-\phi)E_t[\sum_{k=0}^{\infty}(\alpha\beta\tilde{\omega})^k\frac{\Lambda_{t+k}}{P_{t+k}}D_{t,t+k}]}. \tag{34}$$

Since $P^{-\varphi}=\sum_{s=0}^{\infty}u_s P^{\varphi}_{t-s,s}$ and $P_{t-s,s}=\tilde{\omega}^s P_{t-s,t-s}$, $s=0,1,2,\cdots,\infty$, and $u_s=\alpha^s u_0$, $u_0=1-\alpha$, the price level satisfies the recursive form such that

$$P_t^{-\varphi}=(1-\alpha)P_{t,t}^{-\varphi}+\alpha\tilde{\omega}P_{t-1}^{-\varphi} \tag{35}$$

When $\alpha=0$, the optimization conditions are reduced to that of flexible price level such that

$$P_t=\frac{MC_t}{1-\phi}. \tag{36}$$

If the price level is flexible, then the markup – the ratio of price to marginal cost – is constant at each period, while it responds to monetary and real shocks when prices are predetermined.

d) Monetary Authority

Suppose that the central bank of each country prints its own currency and distributes it to the whole world residents in lump-sum transfer fashion, $T_{ht}$, $T_{ft}$, before the opening of the asset markets at every period. That is, the home and foreign countries' money stock at time is given by

$$\begin{aligned} M^s_{ht}&=M^s_{ht-1}+T_{ht}, \quad T_{ht}\equiv T_{hht}+T_{hft}=(\omega_{ht}-1)M^s_{ht-1},\\ M^s_{ft}&=M^s_{ft-1}+T_{ht}, \quad T_{ft}\equiv T_{fft}+T_{fht}=(\omega_{ft}-1)M^s_{ft-1}. \end{aligned} \tag{37}$$

Moreover, I assume that the monetary authority of each country sets its own money supply growth rate according to an AR(1) process.

## B. Equilibrium

I assume that the net supply of each bond is zero as in Obstfeld and Rogoff (1995). So that the home currency bond market clearing condition is given by

$$B_{hht}+B_{fht}=0. \tag{38}$$

As the net foreign asset holding changes is equal to the interest payment minus net exports of goods, the current account surplus (deficit) equals the capital account deficit (surplus).

$$P_{ht}C_{ht}-e_{t+1}P_{ft}C_{hft}=B_{fht+1}-e_{t+1}B_{hft+1}+i_{ht}B_{fht}-e_{t+1}i_{ft}B_{hft}. \tag{39}$$

With the home currency bond market clearing condition $B_{hht}=-B_{fht}$, the domestic financial asset accumulation and the overall balance of payments[13] imply that

$$A_{ht}F(K_{ht},z_{ht}(H_{ht}-H_{h0}))=C_{ht}+I_{ht}, \tag{40}$$

where $C_{ht}=C_{hht}+C_{fht}$. Similarly, the foreign currency bond market clearing condition and the budget constraint imply that

$$A_{ft}F(K_{ft},z_{ft}(H_{ft}-H_{f0}))=C_{ft}+I_{ft}, \tag{41}$$

where $C_{ft}=C_{fft}+C_{hft}$. As I will focus on the symmetric equilibrium in which all agents in the same country make the same decisions in what follows, I will define a symmetric equilibrium. The symmetric equilibrium conditions consist of the efficiency conditions of the home and foreign consumers and firms, and each goods market, capital rental market, labor market, money and bond market in each country clear.[14]

Specifically, a symmetric equilibrium is an allocation of home agents $\{C_{hht},C_{hft},K_{ht+1},X_{ht},H_{ht}\}_{t=0}^{\infty}$, a sequence of prices and costate variables for the home country $\{P_{ht,t},P_{ht},R_{ht},\Lambda_{ht},W_{ht},MC_{ht},i_{ht}\}_{t=0}^{\infty}$, satisfying equilibrium conditions (19)-(21), (24)-(27), (31)-(32),

[13]Here the overall balance of payments is zero, because the sum of the current account surplus and the net change in foreign debt which is defined as the overall balance of payments is always zero.

[14]The aggregate output in each country, is given by $Y_t=(\int_0^1 F(K_t(j),z_t(H_t(j)-H_0))^{1-\phi}dj)^{1/(1-\phi)}$. But this is not a convenient form because it is desirable to express aggregate output as a function of aggregate factors only. This can be done easily if we define an alternative price index as $P_t=(\int_0^1 P_t(j)^{1-\phi}dj)^{1/(1-\phi)}$.

(34)-(35), and (40) as well as the corresponding foreign conditions given $K_{h0}, P_{h-1}, K_{h-1}, P_{f-1}$ and $\{M^s_{ht}, M^s_{ft}, A_{ht}, A_{ft}\}^{\infty}_{t=0}$.

As I am interested in a stationary equilibrium, I make the economy stationary by deflating all nominal variables with the level of the relevant money supply. After that, I approximate a stationary equilibrium involving small fluctuations around it by the solution of the log-linear approximation to the equilibrium condition as in KPR (1988a).

## III. Quantitative Evaluation of the Model

### A. Parameter Values

To get the quantitative implications of the model, I will utilize the following CES subutility function which satisfies the condition of balanced growth path

$$u(C^d_{hh}, C^d_{hf}, L_h) = \begin{cases} \dfrac{U(C^d_{hh}, C^d_{hf})^{1-\sigma_{ch}}}{1-\sigma_{ch}} v(L), & \sigma_{ch} \neq 1, \ \sigma_{ch} > 0, \\ lnU(C^d_{hh}, C^d_{hf}) + v(L) & \sigma_{ch} = 1, \end{cases} \tag{42}$$

where

$$U(C^d_{hh}, C^d_{hf}) = \begin{cases} [\theta(C^d_{hh})^{1-sh} + (1-\theta(C^d_{hf})^{1-sh})]^{(1/(1-sh))}, & s_h > 0, \ s_h \neq 1, \\ (C^d_{hh})^{\theta}(C^d_{hf})^{1-\theta}, & s_h = 1. \end{cases} \tag{43}$$

Here $\sigma^{-1}_{ch}$ and $s^{-1}_h$ is the intertemporal and intratemporal elasticity of substitution in consumption between home and foreign goods of the home household respectively. As noted by Svensson and van Wijnbergen (1989), the sign of a cross derivative $u_{12}$ is determined by the relative size of the intertemporal and intratemporal elasticities of substitution, *i.e.* $sgn(u_{12}) = sgn(\sigma^{-1}_{ch} - s^{-1}_h)$. With this temporal utility function, I can determine the parameter values which will be used in the simulation. Because I set up a two country world with the same features, I will use the same values for each parameter.[15] $h(i_h)$ in equation (27) is determined by an average velocity of money in the home country.

$$v(i_i) = h(i_i)^{-1} \rightarrow \frac{dlnv}{dlni_i} = -\frac{dlnh}{dlni_i}, \quad \text{for} \quad i = h, f.$$

Since money is defined as $M_1$, I have $M/PC = 0.34$. From the fact that consumption is subject to cash-in-advance constraints, and $C_h = s_{ch}Y_{ch}$ at steady state, it follows that

$$h(i_i) = \frac{M_h}{s_{ch}P_hY_h} \rightarrow ln\left(\frac{M_h}{P_h}\right) = lns_{ch} + lnh(i_i) + lnY_h.$$

Lucas (1987) found that the long-run income elasticity of money is 1 and the long-run interest rate semi-elasticity is $-0.07$ for 1958-85 and $-0.09$ for 1900-85 for $M_1$. I will take Lucas (1987)'s estimate of the elasticity of money with respect to interest rate. In sensitivity analysis, I will also use a much smaller value of interest elasticity of money demand $-0.01$ because the degree of money demand over the business cycle is much smaller than in the long run as in King and Watson (1995). That is, $h'(i_i) = -7$ and $-1$. The monetary growth rate is estimated using US monetary base data for a domestic monetary policy. Assuming that a monetary base growth rate of US follows AR(1), its estimates over 1972:1-1994:1 is given by

$$ln\omega_{ht} = 0.00146_{(0.00646)} + 0.08674_{(0.60569)}ln\omega_{ht-1} + \xi_{Mht}, \quad \hat{\sigma}_{Mht} = 0.00813, \tag{44}$$

where the numbers in the parenthesis represent the standard errors and $\hat{\sigma}_{Mht}$ is the standard deviation of home country money growth rate. Though it is desirable to estimate the corresponding monetary base measure of foreign countries, some countries do not have the comparable measure for US monetary base. Moreover, since Schlagenhauf and Wrase's (1993) results, which were obtained from the estimation of a bivariate monetary base growth process by excluding those countries that do not have the corresponding monetary measure show that the estimates are

[15]The steady state relations also provide the restrictions on the other parameter values used in the calibration. For the home country case, $i_{ht} = \gamma_h^{1-\sigma_{sh}}(\omega_h/\beta)$, $s_{ch} = 1 - \gamma_h^{-\sigma_{ch}}((1-\sigma_{ch})(\gamma_h - 1 + \delta)/(r_h - \theta))$, and $\beta = \gamma_h^{-\sigma_{ch}}(1+r_h)^{1}$.

**TABLE 1**

THE CALIBRATED PARAMETERS

| Parameter | Value | Description of Parameters |
|---|---|---|
| $\gamma$ | 1.004 | steady state quarterly growth rate of technology |
| $s_H$ | 0.58 | steady state labor share |
| $\delta$ | 0.025 | rate of depreciation of capital stock |
| $r_h$ | 0.016 | steady state rate of return |
| $\varepsilon_C(\sigma_{ch}^{-1})$ | 1, 1/2 | intertemporal elasticity of consumption |
| $\varepsilon_w$ | 1, 2 | intratemporal elasticity of labor supply |
| $s_h^{-1}$ | 1/2 | intratemporal elasticity of consumption |
| $h_i$ | -1, -7 | semi-elasticity of demand for money(percent) |
| $h(i)$ | 0.34 | inverse of steady state consumption velocity |
| $\mu$ | 1.1, 1.5 | steady state markup |
| $\eta_q$ | 1 | elasticity of substitution between capital and labor |
| $\varepsilon_{HK}$ | 1, 5, 10, 100 | elasticity of $i/k$ to Tobin's $q$ |

Notes: Country subscripts $(h,f)$ are suppressed. The same parameter values are used in the home country and the foreign country.

Technology Shock*: $\begin{bmatrix} \rho^A_{hh} & \rho^A_{hf} \\ \rho^A_{fh} & \rho^A_{ff} \end{bmatrix} = \begin{bmatrix} 0.906 & 0.088 \\ 0.088 & 0.906 \end{bmatrix}$, $\begin{bmatrix} \sigma^A_{hh} & \sigma^A_{hf} \\ \sigma^A_{fh} & \sigma^A_{ff} \end{bmatrix} = \begin{bmatrix} 0.00852 & 0.258 \\ 0.258 & 0.00852 \end{bmatrix}$

Monetary Shock: $\begin{bmatrix} \rho^M_{hh} & \rho^M_{hf} \\ \rho^M_{fh} & \rho^M_{ff} \end{bmatrix} = \begin{bmatrix} 0.600 & 0.000 \\ 0.000 & 0.600 \end{bmatrix}$, $\begin{bmatrix} \sigma^M_{hh} & \sigma^M_{hf} \\ \sigma^M_{fh} & \sigma^M_{ff} \end{bmatrix} = \begin{bmatrix} 0.00813 & 0.000 \\ 0.000 & 0.00813 \end{bmatrix}$

* $\sigma_{ij}$ represents the covariance between variables $i, j$.

similar to those of the US, it is not unreasonable to assume that the foreign country follows the same monetary growth process. That is, I assume for simplification that each country's monetary policy is carried out independently.[16]

As stated above, this paper assumes a two country world with identical features as in Grilli and Roubini (1992) and Schlagenhauf and Wrase (1993). For this reason, I will use the same parameter values of the US economy for the home country as well as for the foreign country. All parameter values used in this paper are

[16]The estimated indirect spillover effects of monetary policy is so small as to be negligible as in Schlagenhauf and Wrase (1993). Chari, Kehoe, and McGrattan (1996) also assumed that the monetary policy is mutually independent between countries.

reported in Table 1. Most of them are taken from KPR (1988a), Lucas (1988), and Rotemberg and Woodford (1992). In particular, one needs to note the intertemporal elasticities of consumption and labor supply because these parameter values are important in the quantitative implications of the model. I will suppress a country subscript $(h,f)$ from now on. Even though many RBC models assume that unit elasticity of intertemporal substitution ($\varepsilon_C = \sigma_{ch}^{-1} = 1$) which is taken from Hansen and Singleton (1982), many empirical studies on consumption tell us to be more cautious and conservative in choosing the value. Thus the baseline model of this paper takes lower values of intertemporal elasticity of consumption, $\sigma_{ch} = 2$, *i.e.* $\varepsilon_C = 1/2$ and the intratemporal elasticity of consumption $s_h^{-1} = 1/2$. I also choose a conservative intertemporal elasticity of labor supply, $\varepsilon_w(H_w)$ equal to 1 which is much lower than those of KPR (1988a) and Rotemberg and Woodford (1993) and Yun (1994). Of course, I will use alternative parameter values, $\sigma_{ch} = 1$, $\varepsilon_w = 2$ to see how robust the implications of the model are in the sensitivity analysis. The value of elasticity of $i/k$ with respect to Tobin's $q$, $\eta_q$ is the adjustment cost elasticity which reflects the volatility of investment. Though many studies have estimated this adjustment cost parameter, there is still a lot of uncertainty on the size about the adjustments cost. I will choose 5 as the benchmark parameter value.[17] This parameter value has important implications of the various second moments. When a very high value of elasticity is taken with a high degree of nominal rigidity, then the output as well as employment become volatile as the investments respond more to shocks.[18]

To discuss the implications of the adjustment cost elasticity, I will report results for a wide range of the elasticity, *i.e.* when $\eta_q = 1, 10, 100$ in Table 4. The nominal rigidity parameter value is also uncertain because the empirical value of this parameter changes depending on the period of an interest and the estimation method. I will report results for a wide range of the nominal rigidity, while I

[17]Baxter and Crucini (1993) used the elasticity of 15 as a benchmark parameter value. But most empirical studies suggest a lower value than this one. See Chirinko (1993) for detail.

[18]In Chari, Kehoe, and McGrattan (1996), the standard deviation of output is 13 when firms preset prices for 6 quarters and the capital adjustment cost is low in a Taylor-type sticky price model.

will set $\alpha=1/2$ in the sensitivity analysis.[19] Finally, I will choose 1.1 as the benchmark average size of markup, $\mu$. Though this value is much lower than the value that many sources of evidence suggest,[20] it is consistent with the average markup estimates in Basu and Fernald (1993). As this average markup value is also conservative, I will use a higher markup value $\mu$ of 1.5 in the sensitivity analysis to check whether there are any substantial difference in the implications of monopolistic competition model with sticky prices.

## B. Implications of the Model

In this subsection I review the main goal of this paper and see whether the nominal price rigidity model with monopolistic competition can explain the persistence effect of monetary shocks on the exchange rate as well as the sharp responses of the exchange rate. In particular, I compare the moments of the model with properties of data drawn from major industrial economies.

a) Some Intuition

As the cash in advance constraint is binding in equilibrium, the money market equilibrium conditions imply equation (27) and the corresponding one of the foreign country. The difference of these log-linearized equations and the uncovered interest parity condition lead to

$$\hat{M}^s_{ht}-\hat{M}^s_{ft}-(\hat{P}_{ht}-\hat{P}_{ft})=h'(i_{ht})(E_t\hat{e}_{t+1}-\hat{e}_t)+(\hat{C}_{ht}-\hat{C}_{ft}), \tag{45}$$

where $\hat{x}_t$ is the percentage of deviation of $X_t$ from its stationary value $\bar{X}$. The response of nominal exchange rate to a positive home monetary shock depends on the response of price level as well as that of consumption in each country to the shock. When prices are flexible and some consumption goods are subject to inflation tax via cash in advance constraints, the consumption for home goods

[19]There is a lot of uncertainty in the degree of price rigidities. The range of empirical values for the degree of price rigidities ($\alpha$) are estimated around 0.75 or 0.85. Yun (1994) set $\alpha=0.82$, for his endogenous money supply model in his paper. King and Watson (1995) used 0.9 as a benchmark parameter value in a Calvo-style sticky price model.

[20]See Rotemberg and Woodford (1992) for more detailed discussion and references about markup.

will decrease to a positive home monetary shock. The above equation implies that the nominal exchange rate will depreciate $(\hat{e}_t > E_t\hat{e}_{t+1})$ because the semi-interest elasticity of money demand is negative and the real balance in each country responds little to the shock. When prices are sticky, the positive effect of real balance dominates the negative effect of inflation tax on consumption so that real balance and consumption increase together. Moreover, the above equation says that the nominal exchange will overshoot to a positive home monetary shock and its response will increase as the price stickiness increases.

Next, the let's consider the response of real exchange rate to a positive home monetary shock. Because the real exchange rate is defined as $\varepsilon_t = (e_t P_{ft}/P_{ht})$, the response of real exchange rate to a positive home monetary shock can be read from

$$\hat{\varepsilon}_t = \hat{e}_t + \hat{P}_{ft} - \hat{P}_{ft}. \tag{46}$$

The response of real exchange rate depends on not only the response of nominal exchange rate, but also the response of price level. The nominal exchange rate depreciates to a positive home monetary shock whether prices are sticky or flexible. But as equation (46) shows, the response of the real exchange rate to a positive monetary shock is determined by the relative response size of the nominal exchange rate and price level to the shock. If prices are either fully flexible or just a little bit sticky, then the effect of price increase will dominate that of nominal exchange rate depreciation. As the nominal rigidity increases, however, the price effect decreases and the effect of the nominal exchange rate depreciation dominates the price effect, which leads to the real exchange rate depreciation. Moreover, as the real exchange is a ratio of a marginal utility of foreign consumption goods to that of home consumption goods, the monetary shock can generate a hump-shaped real exchange effect in sticky prices model when consumption responds slowly to the shock. As households cannot adjust their money demands to a positive monetary shock so flexibly in the short run, the interest elasticity of money demand can be lower than in the long run. In this case, a positive monetary shock leads to a hump-shaped consumption response and thus a hump-shaped real exchange rate response. In next subsection, the real exchange shows a hump-shaped response to a positive home monetary shock when the interest rate elasticity of money demand takes a lower value than the long run value as in King and Watson (1995).

b) Persistent Effects of Home Monetary Shock

The first issue that I address is if actual data impulses correspond to the dynamic responses of exchange rates and real activities to monetary shocks implied by this "sticky-price" model. The main results of Clarida and Gali (1993)'s SVAR and Eichenbaum and Evans (1993)'s VAR[21] can be summarized as follows. A positive shock to the US monetary policy is associated with persistent nominal and real depreciations of the US dollar vis a vis each foreign currency considered, and increased US output. The maximum depreciation of exchange rates occur at two to four quarters following a monetary shock. Here I discuss the model's implications.

First, let's consider the response of the real exchange rate to monetary shocks. In the flexible price international monetary model with no sluggish adjustment in portfolio, when there is a positive monetary shock in the home country, consumption falls, while investment increases. This is easily explained. An increase in the inflation rate acts like tax on cash good consumption and like a subsidy on credit good (credit good consumption and investment). Thus the real exchange rate which is a ratio of a marginal utility of foreign consumption goods to that of home consumption goods appreciates as home goods consumption decreases to a positive monetary shock in the home country as Figure 1 shows. The inflation rate goes up more than the increase in the money growth rate at the moment of a monetary shock in the flexible price model. The impulse responses of the endogenous variables to monetary shocks change little even when I use different values of elasticity of $i/k$ with respect to Tobin's $q$ in the flexible price case. This relationship reverses, however, and the response of inflation rate to a monetary shock weakens as prices become sticky.

[21]Eichenbaum and Evans (1993) use NBR (Non Borrowed Reserves), NBRX (ratio of NBR to Total Reserves), and Romer and Romer index to measure monetary shocks. Their empirical results are robust to the measure of a monetary policy shock.

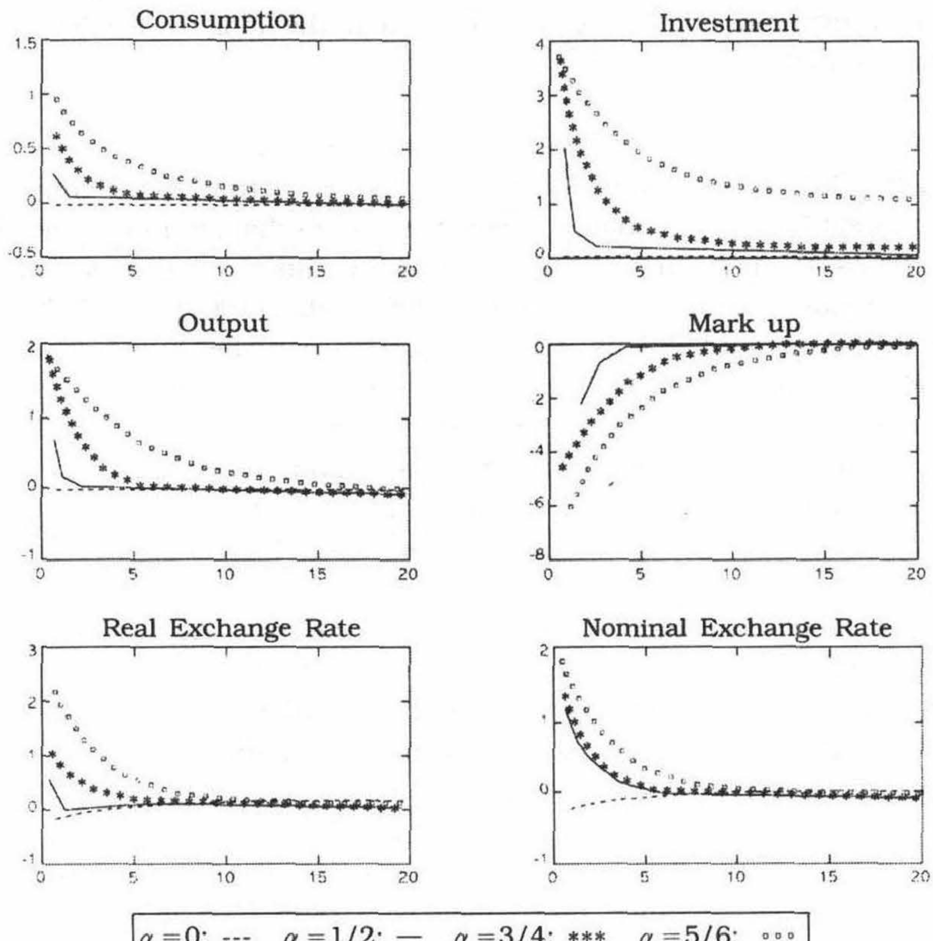


**FIGURE 1**

The impulse response of the endogenous variables to exogenous shocks varies depending on the degree of nominal rigidity in the model as well as some deep parameter values such as intertemporal elasticities of labor supply and consumption. As the degree of nominal rigidity increases, the endogenous variables which are the household's decision rules respond more to a monetary shock. This result is due to the fact that the sluggish price adjustment to a positive monetary shock causes the markup to move much more negatively as the degree of price rigidity increases, and this leads the demand for labor to move upward more as the markup adjusts more negatively. Thus both investment and output increase as marginal product of capital goes up with the increase in labor demand. Since the home country firms are more directly affected by the home monetary shock than the foreign country firms, they respond more actively to the shock by adjusting their markup more aggressively. So the responses of investment and output in the home country to a positive monetary shock of the home country are greater than those of the foreign country. Similarly, as consumption for home goods is directly affected by home monetary shock and the price adjusts slowly to this shock, consumption of home goods increases more than that of foreign goods, and so the real exchange rate depreciates. This response of real variables to a positive home monetary shock becomes stronger as more and more firms depend on rule of thumb markup adjustments rather than optimal price setting rules as shown in Figure 1 with $\sigma_C=2$ and $\eta_q=5$. With these responses of markup and labor to a monetary shock, the reactions of capital stock and output also become much more volatile as the degree of price rigidity increases. Thus as the real quantities respond more to monetary shocks, price responds less to monetary shocks with the increase of price rigidity $\alpha$.

Though there is only a negligible difference in the degree of nominal exchange rate depreciation whether one assumes a flexible price model or a sticky price model as Schlagenhauf and Wrase (1993) note, the response of nominal exchange to a monetary shock increases as the nominal rigidity increases. As shown, the degree of real exchange rate depreciation becomes higher and higher as the degree of nominal rigidity $\alpha$ increases. These properties change little even when some sensitivity analysis is performed by changing the intertemporal elasticities of consumption and labor supply, and the average markup values. Overall, the sticky price models with monopolistic competition seem to perform better than flexible price models with competition in that the former implies that real exchange rate depreciates to a positive home monetary shock for longer periods than the expected price presetting periods. By contrast, a flexible price model, whether it is a full information model or some sluggish model, implies a distorting appreciation or depreciation of real exchange rate only 1 quarter, at most. These findings of sticky price model match well with both Clarida and Gali (1993)'s SVAR result and Eichenbaum and Evans (1993)'s VAR result. However, it is still unsatisfactory that the time at which the maximum depreciation rate to positive monetary shocks occurs is not 2 or 3 quarters after shocks, but only at the moment of shocks. The impulse responses of nominal exchange rates are not satisfactory in that the maximum depreciation to a positive monetary shock occurs in the period of the monetary shock irrespective of the parameter values. Overall, the sticky price model with monopolistic competition performs better than the flexible price model.

c) Variabilities and Serial Correlations

In this subsection, I compare volatilities and serial correlations of the real variables of baseline model with those of data to see the overall performance of the model. The column labelled 'Data' in Table 2 is reproduced from Baxter and Crucini (1993) and Schlagenhauf and Wrase (1993) where moments are calculated for actual time series that have been Hodrick-Prescott filtered. This column reports composite data moments of six countries (Canada, France, Germany, Japan, United Kingdom, and United States).

First, consider the standard deviation of the variables in model and data. A prominent feature about the exchange rate movement is its (excessive) volatility relative to other real variables as can be seen in Table 2 where some selected moments of data are presented. While the standard deviation of nominal and real exchange rates in data is 7.32 and 6.95, respectively, the maximal standard deviations of each variable in the baseline model is 2.56 and 4.13, respectively. However, when firms can fully adjust their prices every period and there is no capital adjustment cost, the standard deviation of real and nominal exchange rate is 0.82 and 1.59 respectively. Their relative volatilities to output are 0.45 and 0.84 whose values are very low compared to those of data. The volatilities of the other variables are comparable to those of the flexible price model of Schlagenhauf and Wrase (1993). When half of firms in the economy adjust their prices optimally, and the other half adjusts their prices by a simple markup with previous prices, *i.e.* when $\alpha=0.5$, the standard deviation of real and nominal exchange rates increases to 1.87 and 1.69 respectively. This is because firms cannot adjust price as well as capital optimally when there are substantial adjustment costs of capital ($\eta_q=5$) and price. It is noteworthy that the volatilities of real and nominal exchange rates increase as the degree of price stickiness increases. This is due to the fact that markups respond more to monetary shocks

**TABLE 2**
MOMENTS OF DATA

| Variable | Std. Dev. (Relative) | Autocorr. | | Cross corr. with GDP | | | | |
|---|---|---|---|---|---|---|---|---|
| | | $t-1$ | $t-2$ | $X_{t-4}$ | $X_{t-1}$ | $X_t$ | $X_{t+1}$ | $X_{t+4}$ |
| Domestic Output | 1.88(1.00) | 0.87 | 0.67 | 0.26 | 0.87 | 1.00 | 0.87 | 0.26 |
| Domestic Consumption | 1.43(0.76) | 0.86 | 0.71 | 0.50 | 0.89 | 0.88 | 0.71 | 0.12 |
| Domestic Investment | 6.32(3.37) | 0.91 | 0.73 | 0.24 | 0.83 | 0.95 | 0.88 | 0.33 |
| Real Exchange Rate ($\varepsilon$) | 6.95(3.70) | 0.81 | 0.60 | 0.07 | 0.26 | 0.26 | 0.30 | 0.38 |
| Nominal Exchange Rate ($e$) | 7.32(3.90) | 0.83 | 0.63 | 0.22 | 0.22 | 0.25 | 0.32 | 0.42 |
| Cross Corr. ($e$, $\varepsilon$) | 0.99 | | | | | | | |

and to real shocks as the degree of nominal rigidity increases. The relative volatilities of real and nominal exchange rates decrease if I use higher values of the elasticity in the sensitivity analysis, *i.e.* if there is little adjustment cost in capital installment. This is because the investment responds more to a positive monetary shock and thus labor employment and output respond very excessively to the shock.

Next, note that the autocorrelations of the model have the same sign as those of data, although the values are a little bit lower compared to data. One quantitative issue that I address is whether exchange rates drawn from simulations of this model are as highly persistent as in the actual data. Actual exchange rate movements are highly persistent as indicated by first-order autocorrelation coefficients for nominal and real exchange rates of 0.8. (See Table 2). The first-order autocorrelation coefficients for exchange rates drawn from the model are in the range of 0.7 and 0.6 whose values are comparable to those of data. These values do not change in the sensitivity analysis. In the contemporaneous correlation with output, consumption and investment comove similarly with output as data.

Finally, I will go over the contemporaneous correlation between real and nominal exchange rates. In the data, nominal and real exchange rates are highly correlated (0.99), while in the flexible price model without adjustment cost the correlation is negligible (−0.06). In the sticky price model, the correlation between nominal and real exchange rate increases as the nominal rigidity increase.

**TABLE 3**
MOMENTS OF BENCHMARK MODEL

| Variable | Std. Dev. (Relative) | Autocorr. $t-1$ | $t-2$ | Cross corr. with GDP $X_{t-4}$ | $X_{t-1}$ | $X_t$ | $X_{t+1}$ | $X_{t+4}$ |
|---|---|---|---|---|---|---|---|---|
| $\varepsilon_C=1/2$ $\mu=1.1$ | $\varepsilon_w=4$ | $\eta_q=\infty$ | | | $s_h=2$ | | | |
| $\alpha=0$ | | | | | | | | |
| Domestic Output | 1.89(1.00) | 0.76 | 0.56 | 0.26 | 0.76 | 1.00 | 0.76 | 0.26 |
| Domestic Consumption | 1.07(0.63) | 0.82 | 0.66 | 0.38 | 0.73 | 0.87 | 0.67 | 0.21 |
| Domestic Investment | 4.36(2.31) | 0.72 | 0.50 | 0.15 | 0.69 | 0.96 | 0.73 | 0.25 |
| Real Exchange Rate ($\varepsilon$) | 0.82(0.43) | 0.87 | 0.71 | 0.29 | 0.38 | 0.38 | 0.19 | -0.02 |
| Nominal Exchange Rate ($e$) | 1.51(0.84) | 0.52 | 0.23 | 0.06 | 0.10 | 0.11 | 0.07 | -0.02 |
| Cross Corr. ($e$, $\varepsilon$) | -0.06 | | | | | | | |
| $\varepsilon_C=1/2$ $\mu=1.1$ | $\varepsilon_w=1$ | $\eta_q=5$ | | | $s_h=2$ | | | |
| $\alpha=0.5$ | | | | | | | | |
| Domestic Output | 1.02(1.00) | 0.55 | 0.34 | 0.11 | 0.55 | 1.00 | 0.55 | 0.11 |
| Domestic Consumption | 0.90(0.88) | 0.77 | 0.57 | 0.12 | 0.54 | 0.83 | 0.67 | 0.24 |
| Domestic Investment | 2.07(2.03) | 0.26 | 0.05 | 0.05 | 0.35 | 0.81 | 0.22 | -0.07 |
| Real Exchange Rate ($\varepsilon$) | 1.87(1.84) | 0.70 | 0.46 | 0.04 | 0.38 | 0.63 | 0.49 | 0.13 |
| Nominal Exchange Rate ($e$) | 1.69(1.65) | 0.51 | 0.22 | 0.00 | 0.33 | 0.59 | 0.21 | 0.10 |
| Cross Corr. ($e$, $\varepsilon$) | 0.56 | | | | | | | |
| $\varepsilon_C=1/2$ $\mu=1.1$ | $\varepsilon_w=1$ | $\eta_q=5$ | | | $s_h=2$ | | | |
| $\alpha=0.75$ | | | | | | | | |
| Domestic Output | 1.58(1.00) | 0.55 | 0.27 | 0.00 | 0.55 | 1.00 | 0.55 | 0.00 |
| Domestic Consumption | 0.99(0.63) | 0.71 | 0.49 | 0.01 | 0.47 | 0.82 | 0.56 | 0.13 |
| Domestic Investment | 3.66(2.33) | 0.50 | 0.21 | -0.01 | 0.50 | 0.93 | 0.44 | -0.09 |
| Real Exchange Rate ($\varepsilon$) | 2.38(1.51) | 0.63 | 0.36 | -0.04 | 0.35 | 0.63 | 0.39 | 0.04 |
| Nominal Exchange Rate ($e$) | 1.92(1.22) | 0.52 | 0.22 | -0.05 | 0.35 | 0.71 | 0.38 | -0.01 |
| Cross Corr. ($e$, $\varepsilon$) | 0.92 | | | | | | | |
| $\varepsilon_C=1/2$ $\mu=1.1$ | $\varepsilon_w=1$ | $\eta_q=5$ | | | $s_h=2$ | | | |
| $\alpha=0.9$ | | | | | | | | |
| Domestic Output | 2.09(1.00) | 0.73 | 0.49 | 0.14 | 0.73 | 1.00 | 0.73 | 0.14 |
| Domestic Consumption | 1.41(0.67) | 0.74 | 0.51 | 0.10 | 0.67 | 0.94 | 0.41 | 0.05 |
| Domestic Investment | 4.10(1.97) | 0.72 | 0.49 | 0.16 | 0.71 | 0.96 | 0.68 | 0.09 |
| Real Exchange Rate ($\varepsilon$) | 4.13(1.98) | 0.73 | 0.50 | 0.08 | 0.52 | 0.73 | 0.53 | 0.10 |
| Nominal Exchange Rate ($e$) | 2.56(1.22) | 0.57 | 0.30 | -0.06 | 0.37 | 0.71 | 0.54 | 0.14 |
| Cross Corr. ($e$, $\varepsilon$) | 0.95 | | | | | | | |

Note: $\alpha$ denotes the probability that a firm sets its price through rule of thumb.

As equation (46) shows, when price stickiness increases the real and nominal exchange rates move very closely. Table 4 reports that when 25% of price discrepancies are eliminated in each period, the correlation between nominal and real exchange is 0.92. It increases to 0.95 when 10% of price discrepancies are eliminated in each period, which nicely matches with to data.

d) Sensitivity Analysis

In this subsection, some sensitivity analysis is performed by changing some important parameter values. These are the intertemporal elasticities of consumption and labor supply, and the elasticity of $i/k$ with respect to Tobin's $q$ and the average markups. Tables 4 and 5 report the results of sensitivity analysis conducted with respect to the supposedly critical parameter values when $\alpha$ equals 0.5.

First, Table 4 reports the results when $\eta_q$ takes a variety of values, both much smaller and much larger than benchmark value, *i.e.* when there are relatively much more adjustment cost and much less adjustment cost in capital stock installment. When the capital stock adjustment cost is much larger, for example $\eta_q=1$, capital stock responds very little to monetary shocks as it is costly to adjust capital stock, and thus the relative volatility of consumption is much higher than that of data, while this relation is reversed in investment. These phenomena change when the adjustment cost becomes smaller. When there is less adjustment cost in capital stock installment, the firm can adjust its capital stock more flexibly to a monetary shock without much adjustment of a markup, the volatility of investment increases while that of consumption decreases. As a result, the ratio of a marginal utility of home consumption good to that of foreign consumption good moves less to a monetary shock. It is noteworthy that when the interest rate elasticity of money demand is small and 10 of price discrepancies are eliminated every period ($\alpha=0.9$), the response of exchange rates to monetary shocks becomes volatile. Figure 2 shows the impulse response function to a domestic monetary shock: Short dashed lines with $\alpha=0.9$ and $\eta_q=1$, circled lines with $\alpha=0.75$ and $\eta_q=5$, and real lines with $\alpha=0.75$ and $\eta_q=10$. The size of an impulse response decreases when the capital adjustment cost increases. This result is due to the fact that firms cannot instantly adjust their capital stocks, and thus their outputs to

**TABLE 4**
MOMENTS OF ALTERNATIVE PARAMETER VALUES (II)

| Variable | Std. Dev. (Relative) | Autocorr. $t-1$ | $t-2$ | Cross corr. with GDP $X_{t-4}$ | $X_{t-1}$ | $X_t$ | $X_{t+1}$ | $X_{t+4}$ |
|---|---|---|---|---|---|---|---|---|
| $\varepsilon_C=1/2$ $\mu=1.1$ | $\varepsilon_w=1$ | $\eta_q=1$ | | | | $s_h=2$ | | |
| $\alpha=0.5$ | | | | | | | | |
| Domestic Output | 0.82(1.00) | 0.68 | 0.47 | 0.18 | 0.68 | 1.00 | 0.68 | 0.18 |
| Domestic Consumption | 0.95(1.16) | 0.78 | 0.57 | 0.17 | 0.66 | 0.93 | 0.75 | 0.26 |
| Domestic Investment | 1.05(1.27) | 0.34 | 0.08 | 0.10 | 0.38 | 0.63 | 0.19 | -0.10 |
| Real Exchange Rate ($\varepsilon$) | 2.10(2.56) | 0.71 | 0.46 | 0.05 | 0.45 | 0.69 | 0.53 | 0.13 |
| Nominal Exchange Rate ($e$) | 1.72(2.09) | 0.51 | 0.22 | 0.01 | 0.33 | 0.57 | 0.27 | 0.01 |
| Cross Corr. ($e$, $\varepsilon$) | 0.63 | | | | | | | |
| $\varepsilon_C=1/2$ $\mu=1.1$ | $\varepsilon_w=1$ | $\eta_q=10$ | | | | $s_h=2$ | | |
| $\alpha=0.5$ | | | | | | | | |
| Domestic Output | 1.24(1.00) | 0.44 | 0.26 | 0.07 | 0.44 | 1.00 | 0.44 | 0.07 |
| Domestic Consumption | 0.84(0.60) | 0.77 | 0.58 | 0.11 | 0.46 | 0.75 | 0.59 | 0.21 |
| Domestic Investment | 2.99(2.42) | 0.22 | 0.05 | 0.03 | 0.30 | 0.90 | 0.22 | -0.04 |
| Real Exchange Rate ($\varepsilon$) | 1.59(1.28) | 0.70 | 0.45 | 0.04 | 0.34 | 0.57 | 0.46 | 0.11 |
| Nominal Exchange Rate ($e$) | 1.66(1.34) | 0.50 | 0.21 | 0.00 | 0.32 | 0.58 | 0.16 | -0.01 |
| Cross Corr. ($e$, $\varepsilon$) | 0.47 | | | | | | | |
| $\varepsilon_C=1/2$ $\mu=1.1$ | $\varepsilon_w=1$ | $\eta_q=100$ | | | | $s_h=2$ | | |
| $\alpha=0.5$ | | | | | | | | |
| Domestic Output | 1.73(1.00) | 0.31 | 0.20 | 0.06 | 0.31 | 1.00 | 0.31 | 0.06 |
| Domestic Consumption | 0.69(0.40) | 0.77 | 0.59 | 0.16 | 0.40 | 0.65 | 0.43 | 0.13 |
| Domestic Investment | 4.97(2.86) | 0.19 | 0.10 | 0.02 | 0.23 | 0.97 | 0.22 | 0.03 |
| Real Exchange Rate ($\varepsilon$) | 1.23(0.73) | 0.79 | 0.61 | 0.22 | 0.37 | 0.44 | 0.33 | -0.01 |
| Nominal Exchange Rate ($e$) | 1.63(0.94) | 0.51 | 0.22 | 0.03 | 0.31 | 0.54 | 0.04 | -0.04 |
| Cross Corr. ($e$, $\varepsilon$) | 0.18 | | | | | | | |
| $\varepsilon_C=1/2$ $\mu=1.1$ | $\varepsilon_w=1$ | $\eta_q=5$ | | | | $s_h=2$ | | |
| $\alpha=0.9$ | $h_t=-1$ | | | | | | | |
| Domestic Output | 2.15(1.00) | 0.80 | 0.58 | 0.18 | 0.80 | 1.00 | 0.80 | 0.18 |
| Domestic Consumption | 1.41(0.66) | 0.80 | 0.58 | 0.11 | 0.70 | 0.92 | 0.78 | 0.24 |
| Domestic Investment | 4.36(2.03) | 0.79 | 0.56 | 0.22 | 0.79 | 0.95 | 0.73 | 0.11 |
| Real Exchange Rate ($\varepsilon$) | 3.98(1.86) | 0.82 | 0.60 | 0.09 | 0.68 | 0.60 | 0.49 | 0.13 |
| Nominal Exchange Rate ($e$) | 2.27(1.06) | 0.74 | 0.51 | 0.03 | 0.41 | 0.60 | 0.51 | 0.15 |
| Cross Corr. ($e$, $\varepsilon$) | 0.98 | | | | | | | |

**TABLE 5**

MOMENTS OF ALTERNATIVE PARAMETER VALUES (III)

| Variable | Std. Dev. | Autocorr. | | Cross corr. with GDP | | | | |
|---|---|---|---|---|---|---|---|---|
| | (Relative) | $t-1$ | $t-2$ | $X_{t-4}$ | $X_{t-1}$ | $X_t$ | $X_{t+1}$ | $X_{t+4}$ |
| $\varepsilon_C=1/2$ $\mu=1.1$ | $\varepsilon_w=2$ | $\eta_q=5$ | | | | $s_h=2$ | | |
| $\alpha=0.5$ | | | | | | | | |
| Domestic Output | 1.21(1.00) | 0.57 | 0.35 | 0.14 | 0.57 | 1.00 | 0.57 | 0.14 |
| Domestic Consumption | 1.15(0.95) | 0.79 | 0.59 | 0.14 | 0.55 | 0.84 | 0.69 | 0.26 |
| Domestic Investment | 2.34(1.93) | 0.28 | 0.05 | 0.05 | 0.34 | 0.77 | 0.19 | -0.10 |
| Real Exchange Rate ($\varepsilon$) | 1.80(1.48) | 0.68 | 0.43 | 0.01 | 0.29 | 0.53 | 0.40 | 0.11 |
| Nominal Exchange Rate ($e$) | 1.69(1.40) | 0.50 | 0.21 | -0.01 | 0.29 | 0.54 | 0.19 | -0.01 |
| Cross Corr. ($e$, $\varepsilon$) | 0.63 | | | | | | | |
| $\varepsilon_C=1/2$ $\mu=1.1$ | $\varepsilon_w=2$ | $\eta_q=5$ | | | | $s_h=2$ | | |
| $\alpha=0.5$ | | | | | | | | |
| Domestic Output | 1.31(1.00) | 0.65 | 0.45 | 0.18 | 0.65 | 1.00 | 0.65 | 0.18 |
| Domestic Consumption | 1.46(1.11) | 0.79 | 0.59 | 0.18 | 0.64 | 0.91 | 0.76 | 0.28 |
| Domestic Investment | 1.90(1.45) | 0.22 | 0.03 | 0.10 | 0.35 | 0.67 | 0.13 | -0.08 |
| Real Exchange Rate ($\varepsilon$) | 1.31(1.00) | 0.70 | 0.45 | 0.02 | 0.30 | 0.53 | 0.38 | 0.07 |
| Nominal Exchange Rate ($e$) | 1.59(1.19) | 0.50 | 0.20 | -0.01 | 0.19 | 0.38 | 0.06 | -0.03 |
| Cross Corr. ($e$, $\varepsilon$) | 0.27 | | | | | | | |
| $\varepsilon_C=1/2$ $\mu=1.1$ | $\varepsilon_w=2$ | $\eta_q=5$ | | | | $s_h=2$ | | |
| $\alpha=0.9$ | $h_i=-1$ | | | | | | | |
| Domestic Output | 2.10(1.00) | 0.81 | 0.63 | 0.24 | 0.81 | 1.00 | 0.81 | 0.24 |
| Domestic Consumption | 1.71(0.81) | 0.82 | 0.61 | 0.15 | 0.74 | 0.95 | 0.84 | 0.31 |
| Domestic Investment | 3.49(1.66) | 0.82 | 0.61 | 0.31 | 0.84 | 0.93 | 0.73 | 0.12 |
| Real Exchange Rate ($\varepsilon$) | 4.07(1.94) | 0.82 | 0.61 | 0.12 | 0.55 | 0.68 | 0.57 | 0.17 |
| Nominal Exchange Rate ($e$) | 2.31(1.10) | 0.75 | 0.51 | 0.04 | 0.47 | 0.67 | 0.58 | 0.19 |
| Cross Corr. ($e$, $\varepsilon$) | 0.98 | | | | | | | |
| $\varepsilon_C=1/2$ $\mu=1.1$ | $\varepsilon_w=1$ | $\eta_q=5$ | | | | $s_h=2$ | | |
| $\alpha=0.5$ | | | | | | | | |
| Domestic Output | 1.01(1.00) | 0.59 | 0.38 | 0.14 | 0.59 | 1.00 | 0.59 | 0.14 |
| Domestic Consumption | 0.96(0.95) | 0.78 | 0.58 | 0.15 | 0.58 | 0.84 | 0.70 | 0.25 |
| Domestic Investment | 1.94(1.93) | 0.26 | 0.06 | 0.06 | 0.35 | 0.77 | 0.21 | -0.06 |
| Real Exchange Rate ($\varepsilon$) | 1.91(1.90) | 0.71 | 0.46 | 0.06 | 0.42 | 0.66 | 0.53 | 0.14 |
| Nominal Exchange Rate ($e$) | 1.70(1.69) | 0.51 | 0.22 | 0.01 | 0.34 | 0.59 | 0.23 | 0.02 |
| Cross Corr. ($e$, $\varepsilon$) | 0.56 | | | | | | | |

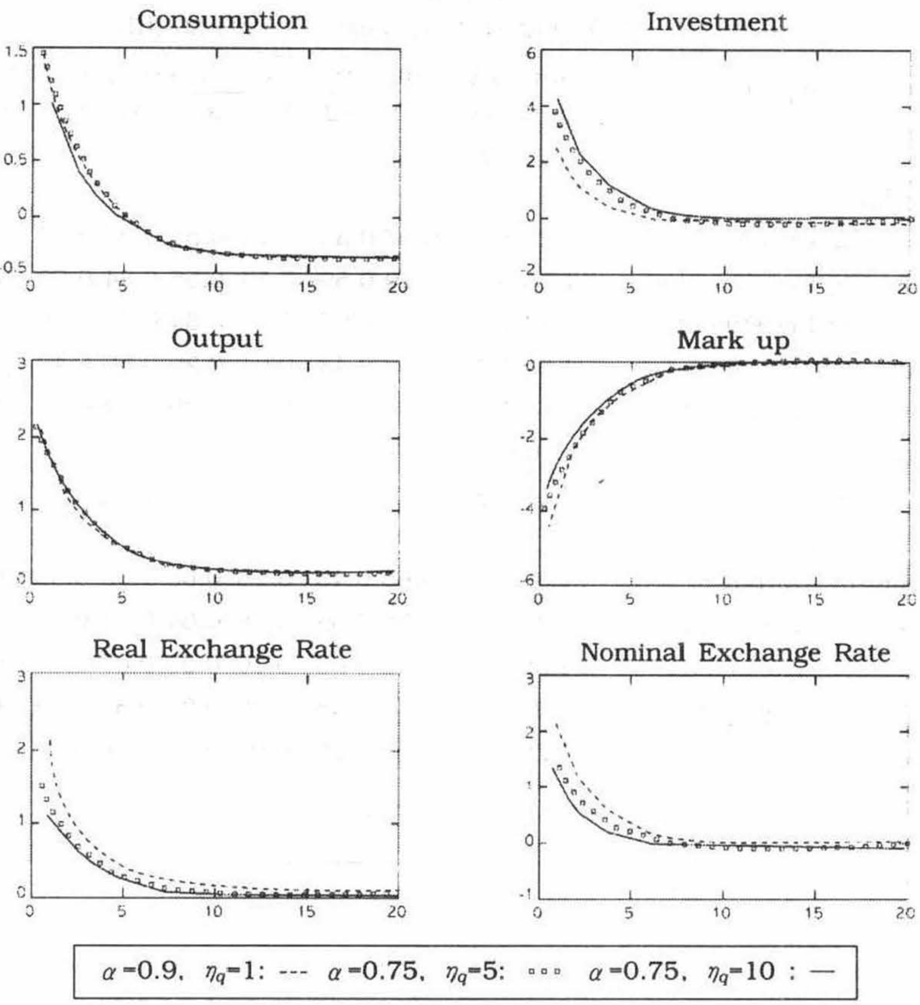


**FIGURE 2**

monetary shocks. The response of exchange rates increases as the degree of nominal rigidities ($\alpha$) and the capital adjustment cost ($\eta_q^{-1}$) increase, because price responds more slowly to the monetary, while consumption and output adjust more volatile to the monetary shock to clear the money market. As a result, the real exchange rate which is the ratio of a marginal utility of home consumption good to that of foreign consumption good also moves volatile.

Second, Table 5 reports the result when the intertemporal elasticity of labor supply ($\varepsilon_w$) increases from 1 to 2. The standard deviation of output and investment increase because the household can supply its labor more elastically to the wage rate change, while the standard deviation of consumption, and therefore those of real and nominal exchange rates change little.

Finally, Table 5 also reports the results when the intertemporal elasticity of consumption ($\sigma_{ch}^{-1}$) is larger than the intratemporal elasticity of consumption ($s_h^{-1}$). As one can see, there is little difference in the responses of the real variables. That is, the effect of price stickiness outweighs the effect of different intertemporal and intratemporal elasticity of consumption. Thus, it seems that there is no much quantitative difference in the response of real variables when two elasticities are not so different. In addition, Table 5 reports the results when a steady state markup value equals 1.5. The overall properties of the benchmark model are maintained throughout in this case.

## IV. Concluding Remarks

This paper investigates whether the monopolistic competition model with sticky prices can generate persistent exchange rate effects from monetary shocks, and whether it can have volatile exchange rate movements. Consumption for domestic goods decreases and real exchange rates appreciate in response to a positive home monetary shock when there is little price stickiness in the economy. But when price becomes more sticky, the demand for domestic consumption goods increases and its increase becomes larger than that of foreign consumption goods. So the real exchange rate depreciates more persistently following a positive home monetary shock since the markup responds more negatively to the shock. The volatility of exchange rates also increases as the degree of price stickiness increases. For example, the standard deviation of real exchange rate of the model becomes two thirds of that in data when the degree of price stickiness ($\alpha$) is 0.9. This trend becomes distorted as markups respond more excessively to a monetary shock when the degree of capital stock rigidity becomes smaller and smaller and firms can adjust their capital more flexibly to a shock. This is the shortcoming of the staggered price model without any other friction.

Despite the model's successes on exchange rate movements, the maximum depreciation of the home real exchange rate in response to a positive home monetary shock mostly occurs at the time of a monetary shock. This still leaves a room for other frictions to resolve the so-called forward premium puzzle. The serial correlation of variables and the correlation between real and nominal exchange rates match well with data when the degree of price stickiness is high. In the sticky price model, the correlation between nominal and real exchange rate increases as the nominal rigidity increase and it nicely matches to data. Overall, I find that the markup responds negatively to a positive home monetary shock and positively to a positive home real shock. This plays a pivotal role in generating a persistent exchange rate effects from monetary shocks as well as the volatile movements of the exchange rates.

It is desirable to pay more attention to heterogeneous consumers, in particular, the different liquidity levels of each consumer. As economic agents consider not only their past behavior, but also the average behavior of the economy, it is desirable to incorporate either external or internal habit formation such as Abel (1990) an Campbell and Cochrane (1995) as an additional source of exchange rate volatility. To set up a dynamic general equilibrium model with this feature and analyze the effects of this liquidity constraint on the exchange rate movements will be an interesting undertaking for future research.

(*Received 30 september 2003; Revised 23 August 2004*)

## References

Abel, Andrew. B. "Asset Prices under Habit Formation and Catching up with the Joneses." *American Economic Review Papers and Proceedings* 80 (1990): 38-42.

Basu, Susanto, and Fernald, J. G. "Constant Returns and Small Markups in US Manufacturing." Mimeograph, University of Michigan, 1993.

Baxter, M., and Crucini, M. J. "Explaining Saving-Investment Correlations." *American Economic Review* 83 (No. 2 1993): 416-36.

Blanchard, O. J., and Kahn, C. M. "The Solution of Linear Difference Models under Rational Expectations." *Econometrica*

48 (No. 5 1980): 1305-11.

Blanchard, O. J., and Kiyotaki, N. "Monopolistic Competition and the Effects of Aggregate Demand." *American Economic Review* 77 (No. 4 1987): 647-66.

Calvo, G. A. "Staggered Prices in a Utility-Maximizing Framework." *Journal of Monetary Economics* 12 (No. 3 1983): 383-98.

Campbell, John. Y., and Cochrane, John H. "By Force of Habit: A Consumption-Based Explanation of Aggregate Stock Market Behavior." *Journal of Political Economy* 107 (No. 2 1999): 205-51.

Caplin, A., and Leathy, J. "Aggregation and Optimization with State Dependent Pricing." Mimeograph, 1992.

Chari, V. V., Kehoe, P. J., and McGrattan, E. R. "Monetary Shocks and Real Exchange Rates in Sticky Price Models of International Business Cycles." Federal Reserve Bank of Minneapolis Working Paper, 1996.

Chirinko, R. S. "Business Fixed Investment Spending: A Critical Survey of Modeling Strategies, Empirical Results and Policy Implications." *Journal of Economic Literature* 31 (No. 4 1993): 1875-911.

Christiano, L., and Eichenbaum, M. "Liquidity Effects, and the Monetary Transmission Mechanism." NBER Working Paper 4129, 1992.

Clarida, R., and Gali, J. "Sources of Real Exchange Rate Fluctuations: How Important Are Nominal Shocks?" Carnegie-Rochester Conference Series on Public Policy, 1993.

Cooley, T. F., and Hansen, G. D. "The Inflation Tax in a Real Business Cycle Model." *American Economic Review* 79 (No. 4 1989): 733-48.

Dixit, A. K., and Stiglitz, J. E. "Monopolistic Competition and Optimum Product Diversity." *American Economic Review* 67 (No. 3 1977): 297-308.

Dornbusch, R. "Expectations and Exchange Rate Dynamics." *Journal of Political Economy* 84 (No. 6 1976): 1161-76.

Eichenbaum, M., and Evans, C. "Some Empirical Evidence on the Effects of Monetary Policy Shocks on the Exchange Rates." Mimeograph, FRB Chicago, December, 1993.

Evans, M., and Lothian, J. "The Response of Exchange Rates to Permanent and Transitory Shocks under Floating Exchange Rates." Mimeograph, Stern School of Business, April, 1993.

Fuerst, T. S. "Liquidity, Loanable Funds and Real Activity." *Journal of Monetary Economics* 29 (No. 1 1992): 3-24.

Grilli, V., and Roubini, N. "Liquidity and Exchange Rates." *Journal of International Economics* 32 (No. 2 1992): 339-52.

Hairault, J. O., and Portier, F. "Money, New-Keynesian Macroeconomics and the Business Cycle." *European Economic Review* 37 (No. 6 1993): 1533-68.

King, R. G., Plosser, C., and Rebelo, S. T. "Production, Growth and Business Cycles: I. The Basic Neoclassical Model." *Journal of Monetary Economics* 21 (Nos. 2-3 1988a): 195-232.

________. "Production, Growth and Business Cycles: II. New Directions." *Journal of Monetary Economics* 21 (Nos. 2-3 1988b): 309-42.

King, R. G., and Watson, M. W. "Money, Prices, Interest Rates and the Business Cycle." Federal Reserve Bank of Chicago Working Paper, 1995.

Lucas, R. E., Jr., and Stokey, N. L. "Money Demand in the United State: A Quantitative Review." Carnegie-Rochester Conference Series on Public 21 (1980): 137-67.

________. "Money and Interest in a Cash-in-Advance Economy." *Econometrica* 55 (1987): 491-514.

Lucas, R. E. Jr. "Liquidity and Interest Rates." *Journal of Economic Theory* 50 (1990): 237-64.

Obstfeld, M., and Rogoff, K. "Exchange Rate Dynamics Redux." *Journal of Political Economy* 103 (No. 3 1995): 624-60.

________. *Foundations of International Macroeconomics*. Cambridge: MIT Press, 1996.

Rotemberg, J. J. "Prices and Output: An Empirical Analysis Based on a Sticky Price Model." Mimeograph, MIT, 1994.

Rotemberg, J. J., and Woodford, M. "Oligopolistic Pricing and the Effects of Aggregate Demand on Economic Activity." *Journal of Political Economy* 100 (No. 5 1992):1153-207.

________. "Dynamic General Equilibrium Models with Imperfectly Competitive Product Markets." Mimeograph, 1993.

Schlagenhauf, D. E., and Wrase, J. M. "Liquidity and Real Activity in a Simple Open Economy Model." Mimeograph, Arizona State University, 1993.

Stockman, A., and Ohanian, L. E. "Short-Run Independence of Monetary Policy under Pegged Exchange Rates and Effects of Money on Exchange Rates and Interest Rates." Mimeograph, University of Rochester, 1993.

Svensson, Lars, E. O., and Wijnbergen, S. "Excess Capacity, Monopolistic Competition, and International Transmission of Monetary Disturbances." *The Economic Journal* 99 (1989): 785-805.

Yun, T. "Monetary Business Cycles and Price Setting under Monopolistic Competition." Mimeograph, University of Chicago, 1994.