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ABSTRACT

Volatility in exchange rates is a prominent feature of open economies, a fact which has motivated elaborate attempts in many countries at exchange rate management. This paper analyzes quantitatively the welfare effects of exchange rate risk in a general two-country environment. It finds that the effects of uncertainty tend to be small for the types of simplified cases considered in past literature. But it identifies other cases, not considered previously, in which these effects can be significantly larger. These include habit persistence, where agents are more sensitive to risk, and also incomplete asset market structures which allow for asymmetries between countries. The latter case suggests that countries which are hosts to an international reserve currency, such as the U.S. or members of the euro zone, may accrue significant benefits because of the enhanced ability to hedge against exchange rate risk.

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1 Introduction

Exchange rate variability is one of the most prominent features of open economy macroeconomics, and a desire to moderate this variability has been a motivation behind the managed exchange rate regimes of many countries as well as European monetary union. This paper conducts a model-consistent evaluation of optimal monetary policy rules in the context of a two-country general equilibrium model with sticky prices. It focuses on two questions. Firstly, what degree of exchange rate variability or stabilization is optimal for certain classes of economies? Secondly, for what types of economies does following an optimized stabilization policy yield the most significant benefits in terms of household utility?

Several recent papers have employed analytically solvable models to characterize the implications of alternative monetary policy rules and exchange rate arrangements in sticky price open economies. Bacchetta and van Wincoop (2000) demonstrate that monetary policy rules that stabilize the exchange rate do not necessarily increase household welfare or even trade, depending on the nature of preferences, the monetary policy rules, and the shocks. Devereux and Engel (2003) show that the degree to which optimal policy lets the exchange rate fluctuate depends on the currency in which prices are sticky. Gali and Monacelli (2005) study classes of policy rules in the form of inflation targeting and Taylor-type rules.[1]

This paper conducts a quantitative analysis of somewhat richer and more realistic economic environments, as permitted by calibration and numerical solution. For example, asset markets and preferences are not limited to cases that imply complete international risk sharing, which would imply the current account is restricted to zero balance. As a result, when the paper computes the effects of exchange rate variability, it takes into consideration the potentially important effects that exchange rates have on a country's current account. This numerical analysis is made possible by the second-order solution method developed in Kim et. al. (2004), which is also applied to an open economy setting in Kollmann (2002) and (2004).[2] The analysis here differs from Kollmann in that it studies alternative economic environments, and pays special attention to the size of quantitative implications from policy choices.

[1] For a sample of other related work, see Benigno (2004), Benigno and Benigno (2003), Carre and Collard (2003), Clarida, Gali and Gertler (2001), Corsetti and Pesenti (2001, 2004), Obstfeld and Rogoff (2002), Sutherland (2005).

[2] Related solution algorithms have been proposed in Schmitt-Grohe and Uribe (2004a), and Collard and Juillard (2001).

The paper begins by studying a generalized version of the standard model from the optimal policy literature, with calibrated parameters and augmented with incomplete asset markets. Experiments support the findings from simpler analytical models, in that the particular Taylor-type policy rule that is optimal prescribes aggressively stabilizing inflation. The optimized rule does not directly respond to exchange rate fluctuations, and it is optimal to let the exchange rate fluctuate in response to productivity shocks. However, the experiment highlights that the benefits from following an optimized stabilization policy are small in terms of representative household utility.

The paper goes on to study two new types of economic environments, where the utility benefits might be expected to be larger. The first of these cases is where household preferences exhibit habits. However, experiments indicate that the conclusions from the benchmark economy are little altered. Optimized policy continues to focus on inflation stabilization, and continues to allow substantial exchange rate variability. Further, while households with habits are by definition much more sensitive to certain types of variability, the utility gains from following an optimized stabilization policy increase only moderately.

The second alternative economic environment features one country unable to issue debt denominated in its own currency. Termed "original sin" in recent literature, this asset asymmetry makes it difficult for the country to respond to a stochastic environment through precautionary saving, since net foreign assets expose the country all the more to the effects of exchange rate variability. In this context the optimized cooperative policy rule puts substantial weight on exchange rate stabilization and virtually eliminates exchange rate fluctuations. The size of the utility gain for the sin country is about four times that for the benchmark economy above.

The next section of the paper presents the benchmark two-country model, calibration, and solution method. Section 3 presents results for the benchmark model and the two extensions. Section 4 concludes and makes suggestions for future research.

2 The Model

Consider a model of two countries, denoted home and foreign. Agents consume two final goods, where each country specializes in the production of one of these. Monopolistically competitive firms produce intermediates using capital and labor, and set prices sluggishly due to adjustment costs.

2.1 Goods market structure

Final goods (F) are a CES index over sub-indexes of the home (F_H) and foreign (F_F) intermediates. The aggregation technology for final goods is:

$$F_t = \left[a^{\frac{1}{m}} F_{H,t}^{\frac{m-1}{m}} + (1-a)^{\frac{1}{m}} F_{F,t}^{\frac{m-1}{m}} \right]^{\frac{m}{m-1}}, \text{ where} \tag{1}$$

$$F_{H,t} = \left(\int_0^1 f_{H,t}(i)^{\frac{l-1}{l}} di \right)^{\frac{l}{l-1}} \tag{2}$$

$$F_{F,t} = \left(\int_0^1 f_{F,t}(j)^{\frac{l-1}{l}} dj \right)^{\frac{l}{l-1}}, \tag{3}$$

where a lower case represents output of the individual firms.

Final goods producers behave competitively, maximizing profit each period:

$$\Pi_t = \max\left[P_t F_t - P_{H,t} F_{H,t} - P_{F,t} F_{F,t} \right] \tag{4}$$

where P is the overall price index of the final good, P_H is the price index of home goods in home currency units, and P_F of foreign goods in foreign currency units. The price indexes may be defined:

$$P_t = \left[a P_{H,t}^{1-m} + (1-a) P_{F,t}^{1-m} \right]^{\frac{1}{1-m}}, \text{ where} \tag{5}$$

$$P_{H,t} = \left(\int_0^1 p_{H,t}(i)^{1-l} di \right)^{\frac{1}{1-l}} \qquad P_{F,t} = \left(\int_0^1 p_{F,t}(j)^{1-l} di \right)^{\frac{1}{1-l}}. \tag{6,7}$$

Given the aggregation functions above, demand will be allocated between home and foreign goods according to

$$F_{H,t} = a\left(\frac{P_{H,t}}{P_t} \right)^{-m} F_t \qquad F_{F,t} = (1-a)\left(\frac{P_{F,t}}{P_t} \right)^{-m} F_t, \tag{8,9}$$

with demands for individual goods:

$$f_{H,t}(i) = \left(\frac{p_{H,t}(i)}{P_{H,t}} \right)^{-l} F_{H,t} \qquad f_{F,t}(j) = \left(\frac{p_{F,t}(j)}{P_{F,t}} \right)^{-l} F_{F,t}. \tag{10,11}$$

Analogous definitions apply to the foreign country.

2.2 Home household problem

The representative home household derives utility from consumption (*C*), real money balances (*M/P*), and labor (*H*). Households derive income by selling their labor (*H*) at the nominal wage rate (*W*), renting out capital to firms at the real rental rate (*r*), receiving real profits from home firms (Π), and from government transfers (*T*). In addition to money, households can hold a noncontingent nominal bond denominated in home currency (B_H) which pays an interest rate (*i*), or a bond denominated in foreign currency (B_F) which pays an interest rate (i^*), where *S* is the home currency price of a unit of foreign currency. The household determines capital accumulation (*K*), which involves a quadratic adjustment cost that depends upon the parameter y_I and a constant rate of depreciation (d).

Household optimization for the home country may be written:

$$\max E_0 \sum_{t=0}^{\infty} b^t U\left(C_t, \frac{M_t}{P_t}, H_t \right)$$

subject to the budget constraint:

$$\begin{aligned} &P_t C_t + P_t \left(K_{t+1} - \left(1-d\right) K_t \right) + P_t AC_{I,t} + M_t + B_{H,t} + S_t B_{F,t} + AC_{B,t} \\ &= \left(1+i_{t-1}\right) B_{H,t-1} + S_t \left(1+i^*_{t-1}\right) B_{F,t-1} + M_{t-1} + W_t H_t + P_t r_t K_t + T_t + \Pi_t \end{aligned}$$

where

$$U_t = \frac{C_t^{1-r}}{1-r} + \frac{c_t}{1-e} \left(\frac{M_t}{P_t} \right)^{1-e} - \frac{H_t^{1+y}}{1+y} \qquad (12)$$

and

$$AC_{I,t} = \frac{y_I}{2} \frac{\left(K_{t+1} - K_t\right)^2}{K_t} \qquad (13)$$

$$AC_{B,t} = \frac{y_B}{2} \frac{\left(S_t \left(B_{F,t} - \bar{B}_F \right) \right)^2}{P_{H,t} Y_t} \; .$$

Money demand shocks are represented by shifts in c_t. There is a small adjustment cost on bond holdings, AC_B, to ensure stationarity in the net foreign asset position.[3] Later sections of the paper will consider a more general form of preferences featuring habits. Later sections also consider an alternative asset market structure, limited to only one type of bond.

Optimization implies a money demand equation:

[3] Home and foreign bonds are treated separately in this adjustment cost to ensure that there exists a determinate allocation between home and foreign currency bonds even in a first-order approximation to the system, as is required by the second-order accurate solution method.

$$\frac{M_t}{P_t} = \frac{c_t^{1/e} C_t^{r/e}}{\left(1-d_t\right)^{1/e}}, \tag{14}$$

a trade-off between consumption and leisure:

$$\frac{W_t}{P_t C_t^r} = H_t^y , \tag{15}$$

a consumption Euler equation:

$$d_t = b E_t \frac{P_t C_t^r}{P_{t+1} C_{t+1}^r}, \tag{16}$$

with the definition of d:

$$d_t = \frac{1}{1+i_t}, \tag{17}$$

an interest parity condition:

$$E_t \left[\frac{P_t C_t^r}{P_{t+1} C_{t+1}^r} \frac{S_{t+1}}{S_t} \left(1+i_t^*\right) \left(1 + \frac{y_B S_t \left(B_{F,t} - \bar{B}_F\right)}{P_{H,t} Y_t}\right)^{-1} \right] = E_t \left[\frac{P_t C_t^r}{P_{t+1} C_{t+1}^r} \left(1+i_t\right) \right], \tag{18}$$

and finally

$$\left(1 + \frac{y_I \left(K_{t+1} - K_t\right)}{K_t}\right) = b E_t \left[\frac{C_t^r}{C_{t+1}^r} \left(r_t + \left(1-d\right) + \left(\frac{1}{2} y_I \frac{K_{t+2}^2 - K_{t+1}^2}{K_{t+1}^2} \right) \right) \right]. \tag{19}$$

equating the benefits and costs of capital accumulation. An analogous problem and first order conditions apply to the foreign household.

2.3 Home firm problem

The benchmark model assumes producer currency pricing, so that firms set prices in their own currency both for sales domestically and sales abroad. They rent capital (*K*) at the rental rate r, and hire labor (*H*) at the nominal rate W. Prices are sticky because there is a quadratic cost to adjusting them. The home firm maximization problem is:

$$\max E_0 \sum_{t=0}^{\infty} x_{t,\,t+n} \Pi_{H,t}\left(i\right), \tag{20}$$

where

$$\Pi_{H,t}\left(i\right) = \left(p_{H,t}\left(i\right) - MC_t\left(i\right) - AC_{P,t}\left(i\right)\right)\left(f_{H,t}\left(i\right) + f_{H,t}^*\left(i\right)\right), \tag{21}$$

with the adjustment and marginal costs defined respectively as:

$$AC_{P,t}(i) = \frac{y_P}{2} \frac{\left(p_{H,t}(i) - p_{H,t-1}(i)\right)^2}{p_{H,t-1}(i)} \quad , \tag{22}$$

$$MC_t = \frac{(r_t P_t)^a W_t^{1-a}}{q_t a^a (1-a)^{1-a}} \, , \tag{23}$$

and subject to the demand function for $f_{H,t}(i)$ from above and the production function specifying output ($y(i)$) as:

$$f_{H,t}(i) + f^*_{H,t}(i) = y_t(i) = q_t K_t^a(i) H_t^{1-a}(i) \, . \tag{24}$$

Here q_t represents technology common to all production firms in the country, and is subject to shocks. Lastly, $x_{t,\,t+n}$ is the pricing kernel used to value random date $t+n$ payoffs. Since firms are owned by the representative household, they are assumed to value future profits according to the household's intertemporal marginal rate of substitution in consumption, so that $x_{t,t+n} = b^n \left(U'_{C,t+n} / P_{t+n}\right) / \left(U'_{C,t} / P_t\right)$. An analogous problem applies to the foreign firm.

The optimization problem implies a trade-off between capital and labor inputs that depends on the relative cost of each:

$$P_t r_t K_t(i) = \frac{a}{1-a} W_t H_t(i) \, , \tag{25}$$

and price setting behavior:

$$\begin{aligned} p_{H,t}(i) &= \frac{l}{l-1}\left(MC_t + AC_{P,t}\right) \\ &+ \frac{y_P}{l-1} p_{H,t}(i) \left(1 - \frac{p_{H,t}(i)}{p_{H,t-1}(i)}\right) \\ &+ \frac{1}{2} \frac{y_P}{l-1} p_{H,t}(i) E_t \left[\frac{x_{t,\,t+i+1}}{x_{t,\,t+i}} \left(1 - \frac{p^2_{H,t+1}(i)}{p^2_{H,t}(i)}\right) \frac{F_{H,t+1}}{F_{H,t}} \right] \end{aligned} \quad , \tag{26}$$

Note that in the special case of no price stickiness ($y_P = 0$), price-setting is set as a simple markup over marginal costs: $p_{H,t}(i) = \frac{l}{l-1} MC_t$. But in the presence of price adjustment costs, price-setting will deviate from this simple markup because of several additional terms. First, the resource cost of setting a price (AC_P) should be included along with the cost of production when computing the overall price of bringing a good to market. The next term in the expression above reflects the backward looking component of price setting: firms are reluctant to make large changes in price due to the marginal adjustment cost.

The final term reflects the forward-looking component of price setting. If a firm expects the need to change prices further in the next period, it will tend to change the price more today, to minimize future adjustment costs. Further, there is an additional reason to raise prices today, because a higher current price means that any future changes will be a smaller percentage change. Here we see one reason for the monopolist to set a higher price on average, as a hedge against future price changes. Finally, note that in the symmetric equilibrium $p_{H,t}(i) = P_{H,t}$.

2.4 Government

Model experiments will consider three alternative policy rules. The first specifies a fixed exogenous money supply:

$$M_t = M_{t-1}. \tag{27}$$

This rule will be used as a benchmark for later comparisons, as it implies no endogenous response of policy to economic shocks or circumstances. The second rule pegs the exchange rate:

$$S_t = \overline{S}. \tag{28}$$

The third rule is a Taylor-type interest rate setting rule

$$i_t = \bar{i} + \Gamma_p p_t + \Gamma_Y \hat{Y}_t + \Gamma_s \Delta s_t \tag{29}$$

where $\bar{i}$ is steady state interest rate, p_t is inflation rate, $\hat{Y}_t = \left(Y_t - \overline{Y}\right)/\overline{Y}$ is the output gap, and Δs_t is the percentage change in the nominal exchange rate.[4] It is assumed that central banks make a commitment to set these parameters at time-invariant values.

The government's budget constraint is:

$$T_t = M_t - M_{t-1}. \tag{30}$$

2.5 Market clearing and equilibrium

Market clearing for the home goods market requires:

$$F_{H,t} + F^*_{H,t} = Y_t, \tag{31}$$

and for the home bond market:

[4] For the foreign country's rule, the response coefficient to the exchange rate is the negative of that for the home country.

$$B_{H,t} + B^*_{H,t} = 0 \,. \tag{32}$$

Total home final goods demand must equal final goods supply:

$$F_t = C_t + \left(K_{t+1} - (1-d)K_t\right) + AC_{I,t} + \frac{AC_{B,t}}{P_t} + Y_t \frac{\int_0^1 \left[AC_{P,t}(i)\,di\right]}{P_t}. \tag{33}$$

The home balance of payments condition may be written:

$$\left(B_{H,t} - B_{H,t-1}\right) + S_t\left(B_{F,t} - B_{F,t-1}\right) = P_{H,t}Y_t + i_{t-1}B_{H,t-1} + S_t i^*_{t-1} B_{F,t-1} - P_t F_t \,. \tag{34}$$

Equilibrium is a set of 37 sequences: $C_t, C_t^*, P_{H,t}, P_{F,t}, P_t, P_t^*, S_t, W_t, W_t^*, H_t, H_t^*$, $Y_t, Y_t^*, F_t, F_t^*, F_{H,t}, F^*_{H,t}, F_{F,t}, F^*_{F,t}, K_t, K_t^*, r_t, r_t^*, d_t, d_t^*, MC_t, MC_t^*, B_{H,t}, B^*_{H,t}, B_{F,t}, B^*_{F,t}, q_t, q_t^*$, M_t, M_t^*, i_t, i_t^*. The 37 equilibrium conditions are comprised of the balance of payments constraint (34) and the following 18 equations combined with their analogous foreign counterparts: the definition of total demand (1), demand conditions for home and foreign goods (8 and 9), the overall price index (5), the price setting rule (26), the money supply rule (27, 28 or 29), labor supply condition (15), capital-labor trade-off (25), money demand condition (14), the interest rate parity condition (18), production function (24), definition of marginal cost (23), definition of total demand (33), definition of *d* (17), consumption Euler equation (16), market clearing conditions for goods (31) and bonds (32), and capital accumulation (19).

The shocks, to technology and money demand in each country, will be log-normally distributed:

$$\begin{aligned}
\left(\log q_t - \log \overline{q}\right) &= r_1\left(\log q_{t-1} - \log \overline{q}\right) + e_{1t} \\
\left(\log q_t^* - \log \overline{q}^*\right) &= r_1^*\left(\log q^*_{t-1} - \log \overline{q}^*\right) + e^*_{1t} \\
\left(\log c_t - \log \overline{c}\right) &= r_2\left(\log c_{t-1} - \log \overline{c}\right) + e_{2t} \\
\left(\log c_t^* - \log \overline{c}^*\right) &= r_2^*\left(\log c^*_{t-1} - \log \overline{c}^*\right) + e^*_{2t}
\end{aligned} \tag{35}$$

$$\left[e_{1t}, e^*_{1t}, e_{2t}, e^*_{2t}\right] \sim N(0, \Sigma) \,.$$

To deal with the nonstationary nominal variables in this system, they will be transformed by dividing by their respective national price level. The nominal exchange rate will be dealt with in first differences in those cases where it is nonstationary in levels.[5]

[5] The exchange rate is stationary under the fixed exchange rate rule (28) and the exogenous money supply rule with no shocks to money supply (27).

2.6 Solution method and welfare measure

The model is solved numerically to a second order approximation. See Kim et al. (2003) or Schmitt-Grohe and Uribe (2004a) for a detailed explanation of the methodology. This contrasts with the more standard method relying upon log-linear approximations of model equations, which would only capture the direct effects of exchange rate variability on utility through the fact that people dislike variance in consumption and leisure. A second order approximation to the full set of model equations additionally picks up the effects of variability on the means of consumption and leisure and hence utility. For example, firms may hedge against exchange rate variability by setting higher prices and lowering mean output, and households may engage in precautionary saving that affects mean consumption.

Although it is an imperfect measurement of welfare, we follow the literature in using a second order Taylor expansion of the utility function of a representative household around the deterministic steady state, indicated here by overbars.[6] Using unconditional expectations:

$$EU\left(C_t,H_t\right)=\bar{U}+\bar{C}^{1-r}E\left(\hat{C}_t\right)-\frac{1}{2}r\bar{C}^{1-r}\operatorname{var}\left(\hat{C}_t\right)-\bar{H}^{1+y}E\left(\hat{H}_t\right)-\frac{1}{2}y\bar{H}^{1+y}\operatorname{var}\left(\hat{H}_t\right). \quad (36)$$

The unconditional loss is measured in terms of the share (u) of additional deterministic steady state consumption needed to equate the utility level of the unconditional expectation under uncertainty, defined above, with the deterministic steady state:

$$U\left(\left(1+u\right)C,H\right)=EU\left(C_t,H_t\right). \quad (37)$$

This effect can be decomposed into the part due to the variance of uncertain consumption and leisure, and the part due to the effect of uncertainty on the means of these variables:

$$U\left(\left(1+u^{\text{var}}\right)C,H\right)=\bar{U}-\frac{1}{2}r\bar{C}^{1-r}\operatorname{var}\left(\hat{C}_t\right)-\frac{1}{2}y\bar{H}^{1+y}\operatorname{var}\left(\hat{H}_t\right) \quad (38)$$

$$U\left(\left(1+u^{mean}\right)C,H\right)=\bar{U}+\bar{C}^{1-r}E\left(\hat{C}_t\right)-\bar{H}^{1+y}E\left(\hat{H}_t\right). \quad (39)$$

Tables also report conditional utility measures, which have the advantage of taking into consideration the transition dynamics following the implementation of a new policy rule. To compare the implications of adopting the set of alternative policy rules, the utility level is tracked as it starts out from the unconditional expectation implied by the exogenous money supply rule defined above, and evolves over time in response to the alternative rule under consideration. Utility implications are summarized analogously to the unconditional formulas

[6] True welfare analysis is hampered by well-known problems of aggregation. As is standard in this literature, this paper determines optimal policy in a model-consistent manner by maximizing the utility of a representative household.

above, except that it is the discounted sum of expected utilities over time rather than the unconditional expectation that is reported. For example, the overall effect is computed:

$$U\left(\left(1+u^{conditional}\right)C,H\right)=\left(1-b\right)\sum_{t=0}^{\infty}b^{t}E_{0}U\left(C_{t},H_{t}\right). \qquad (40)$$

To solve for the reaction parameters in the policy rule (29) that are optimal, the sum of home and foreign unconditional utility levels is maximized. Since the benchmark case is symmetric, this is a fairly simple matter of choosing three policy parameters, Γ_p, Γ_Y, and Γ_S, which we accomplish by grid search.[7]

2.7 Calibration

Regarding behavioral parameters, the labor supply elasticity is set at unity ($y = 1$), following Christiano at. al. (1997). Following Bergin and Feenstra (2001), we set $e = r = 4$, implying an interest elasticity of real money balances of 0.25 and an income elasticity of unity. Following estimates of the elasticity of substitution between home and foreign goods in Harrigan (1993) and Trefler and Lai (1999), m is set at 5. A value of $l = 7$ implies an average price mark-up of 16%. The share of home goods in the home final goods aggregator, a, is set at 0.80, reflecting the 20% share of imports in GDP on average for the G7 countries in the 1990:1-1998:4 period. $b = 0.99$, where a period in the model is one quarter. For the depreciation rate, $d = 0.025$, and for the capital share in production $a = 0.36$.

Regarding adjustment costs, $y_P = 50$, which implies that 95% of the price has adjusted 4 periods after a monetary shock. Investment adjustment cost, $y_I = 4$, is calibrated such that investment is about three times more volatile than output. A small bond adjustment cost ($y_B = 4x10^{-6}$) is necessary to avoid a unit root associated with the incompleteness of the asset markets.

Regarding shocks, the variance and persistence of the technology shock is calibrated at standard values: $\mathrm{var}(e_1) = \mathrm{var}(e_1^*) = 0.01^2$ and $r_1 = r_1^* = 0.90$, common values in the real business cycle literature. Money demand shocks are calibrated to replicate the variability and serial correlation of data on the bilateral exchange rate between the U.S. and remaining G7,

[7] Search grids ranged from 1 to 5 for Γ_p, and from 0 to 5 for Γ_Y and Γ_S, with step size 0.25.

HP filtered, for the period 1973:1 - 2000:4.[8] To replicate these moments in the benchmark model for the exchange rate in levels form requires the calibration $\text{var}(e_2) = \text{var}(e_2^*) = 0.03^2$ and $r_1 = r_1^* = 0.99$. For simplicity the shocks are specified as uncorrelated across countries.

3 Results

3.1 Benchmark model

Table 1 reports the results for the three types of policy rules. The optimized Taylor rule stresses inflation targeting, with inflation response $\Gamma_p = 5.0$, and with no effort to stabilize output or the exchange rate ($\Gamma_Y = 0.0$, $\Gamma_S = 0.0$).[9] This policy neutralizes the effects of money demand shocks, calling for shifts in money supply that accommodate shifts in money demand. And it responds procyclically to technology shocks, calling for a lower interest rate and higher money growth rate in the periods shortly following a productivity increase. This result corresponds to previous findings in the literature using simpler models (Devereux and Engel, 2003; Gali and Monacelli, 2005). Sticky prices prevent output and employment from rising fully in response to a rise in productivity, and a monetary expansion helps remedy this shortcoming.

Of special interest here is the implication of the optimal rule for exchange rate variability. Table 1 shows that while a large portion of exchange rate variance is offset, it is not optimal to eliminate all exchange rate variability. Impulse responses show that while the conditional variability following money demand shocks is fully eliminated, the monetary policy response to productivity shocks induces exchange rate fluctuations. This reflects the finding in preceding literature using simpler models, where exchange rate movements can help compensate for price stickiness, by promoting adjustment in international relative prices to productivity shocks. Figure 1 plots the dynamic response of the exchange rate to a 1% rise in home country productivity. The story above is reflected in a substantial home currency depreciation in the initial periods after the shock. But the dynamics also indicate there is a

[8] While the search for an adequate theoretical explanation for exchange rate variability is itself the subject of ongoing research, the approach taken here follows on the example of the literature discussed in the introduction; Devereux and Engel (2003) and Bacchetta and van Wincoop (2000) each use money demand or money supply shocks to generate exchange rate variability. Bergin (2003) offers some empirical support for this approach.

[9] As in Schmitt-Grohe and Uribe (2004b) we found that the inflation parameter is at the upper bound of the range considered in the grid search. Allowing yet higher values of this parameter appears to have negligible effects on the equilibrium.

long-run currency appreciation implied by this rule following productivity gains.[10] As this implies a significant nonstationary component to the exchange rate movement, the table reports the variability for exchange rate depreciations rather than for the exchange rate level.

The table shows that the optimized policy rule eliminates any extra price markup ratio present under exogenous money supply and under the fixed exchange rate rules. This helps explain why the mean levels of output and consumption are higher under the optimized rule relative to the exogenous money rule (by 0.06% and 0.05%, respectively). This rule also raises unconditional utility of the representative household, by the equivalent of 0.07% of steady state consumption. The fixed exchange rate case is also inferior to the optimized rule, with lower output, consumption and utility. In particular, if this economy fixes the exchange rate, it lowers utility by 0.04% relative to the optimal policy.

While the optimal policy does generate positive gains relative to both alternatives here, it is worth noting that these gains are small in magnitude. As a useful comparison, Lucas (1987) measured the costs of business cycle fluctuations at 0.04% of annual consumption, concluding that this was trivial. Lastly, we note that results based on conditional rather than unconditional measures are similar to those presented above.

The analysis of the benchmark model above indicates that some of the basic conclusions drawn in preceding literature in the context of simpler models continue to hold in the context of a more richly specified and more realistically calibrated model. However, a second lesson is that the gains in terms of utility remain quite small. The following two sections will consider further extensions to the basic model.

3.2 Habits

Past research on household consumption and asset choices has found that habits may be an essential part of household preferences.[11] Given that this literature has found households to be quite sensitive to variability in domestic equity markets, one might also expect them to be sensitive to variability in international asset markets. Yet research analyzing optimal monetary policy and exchange rate stabilization to date has not been able to consider this potentially important feature because it precludes the usual analytical solution.

[10] Gali and Monacelli (2005) find a very similar permanent appreciation is implied by the various Taylor rules they consider.

[11] See for example Constantinides (1990) and Campbell and Cochrane (1999) regarding the equity premium puzzle, and see Deaton (1987) and Fuhrer (2000) for a discussion in the context of consumption behavior.

To include habits in the model, we consider the utility function:

$$U_t = \frac{(C_t - g\,C_{t-1})^{1-r}}{1-r} + \frac{c_t}{1-e}\left(\frac{M_t}{P_t}\right)^{1-e} - \frac{H_t^{1+y}}{1+y}, \quad (41)$$

which implies an intertemporal Euler equation:[12]

$$d_t = b\,E_t\left[\left(\frac{P_t}{P_{t+1}}\right)\frac{(C_{t+1} - g\,C_t)^{-r} - bg\,E_{t+1}(C_{t+2} - g\,C_{t+1})^{-r}}{(C_t - g\,C_{t-1})^{-r} - bg\,E_t(C_{t+1} - g\,C_t)^{-r}}\right]. \quad (42)$$

As g goes to unity, households act to smooth changes in consumption rather than the level of consumption. We calibrate the habit persistence parameter at g = 0.8, which is approximately what Deaton (1987) and Constantinides (1990) require in order to explain aggregate consumption smoothness and the equity premium puzzle.

While it is common in calibrating habit persistence models to impose a large investment adjustment cost to keep the standard deviation of consumption from falling to implausibly low levels, this device does not work in an open economy where international borrowing breaks the link between domestic investment and saving. Instead we augment the bond adjustment cost in the household budget constraint to penalize large changes in asset holding as well as large levels:

$$AC_{B,t} = \frac{y_B}{2}\frac{\left(S_t\left(B_{F,t} - \overline{B}_F\right)\right)^2}{P_{H,t}Y_t} + \frac{y_{B2}}{2}\frac{\left(S_t\left(B_{F,t} - B_{F,t-1}\right)\right)^2}{P_{H,t}Y_t} \quad (43)$$

Where y_{B2} is calibrated at $9\text{x}10^{-4}$.

Results are reported in Table 2. The optimal policy parameters are the same as in the benchmark model above. It remains optimal to respond aggressively to stabilize the inflation rate, with no response to the exchange rate. Further the optimal degree of variability of the exchange rate remains essentially the same as above, both in terms of unconditional variance, and in terms of the conditional response to shocks, as depicted in Figure 1.

The welfare gains from optimal stabilization policy are increased slightly relative to the benchmark model. The optimized rule raises unconditional utility by the consumption equivalent of 0.13% relative to the exogenous money rule, which is around double the gain in the context of the benchmark economy. In contrast, the representative household in this habits economy would be willing to trade a more sizeable 0.66% of steady state consumption if it were possible to eliminate all shocks from the economy, an amount which is more than

[12] The welfare formula is of course updated with the second order expansion of the new utility function.

four times that in the benchmark economy. So even if habits indicate that households are more concerned about certain types of variability, it appears that monetary policy has a limited ability to influence this impact on utility.

3.3 “original sin” in asset markets

The implications of exchange rate variability can be shaped also by the structure of a country's asset market. Eichengreen et al. (2005) has noted that perceptions in the international capital market make it impossible for many countries to issue international debt denominated in their own national currency. Given that such perceptions of untrustworthiness may well be beyond the control of the country to change, but simply are a feature of the international capital market, the authors have termed this condition “original sin.”

To study this feature, consider a version of the model where there is only one nominal bond that is traded internationally, denominated in the currency of the home country. This returns to the benchmark model above, except that B_{Ft} is set to zero in all periods. The home country in this model certainly is relevant for those countries whose currencies have the status of reserve currencies, such as the U.S., Japan, and EMU countries. And the foreign country in the model is relevant to some degree for any of the remaining countries, and most especially for developing countries.

Table 3 indicates that the equilibrium in the “original sin” model under the exogenous money supply policy is quite different from that in the benchmark model. The stochastic steady state deviations for endogenous variables are often a full order of magnitude larger. Further, they are asymmetric across countries, with consumption higher in the home country but lower abroad, and vice versa for production levels. Some intuition for this effect can be found by noting the large asymmetry in asset holdings, with net bond holdings by the home country rising 60% relative to the benchmark case, and hence that of the foreign country falling by 60%. This finding is precisely the inverse of that found by Kollmann (2002) in a small open economy model with a similar asset structure. That model indicated that the presence of uncertainty raised the desire for precautionary saving, which raised wealth and hence consumption. We show that moving from a small open economy to a two country general equilibrium model reverses this result. The distinction is that a small open economy model assumes only agents in the small economy respond to the presence of shocks, while assuming the saving behavior of agents in the rest of the world and the equilibrium world interest rate are exogenous and remain unaffected.

In contrast, a two-country environment makes clear that if uncertainty encourages saving behavior of all households in the world, the world interest rate on bonds must fall to balance an excess demand for bonds. The presence of this effect in our model is confirmed by the fall in the interest rate in column 1 of Table 3. In equilibrium the demand and supply of bonds are held equal by having the home (non sin) country save more while the foreign (sin) country saves less. This appears to be due to an asymmetry in the saving options facing the two countries. Recall that the foreign country cannot accumulate a net positive asset position in its own currency. It may be that accumulating assets is a less attractive hedge against uncertainty, when the accumulation of foreign currency assets itself may increase exposure to the uncertainty of exchange rate fluctuations. As a result, the interest rate falls enough to more than compensate for the desired increase in precautionary saving in the sin country, and in equilibrium it holds fewer bonds.

A fixed exchange rate policy substantially offsets the asymmetries above. As column 2 indicates, the asymmetry in asset holdings is reduced by over two-thirds. Further, an optimized Taylor rule policy comes close to replicating the fixed exchange rate regime. When policy parameters are chosen to maximize the sum of home and foreign utility, as shown in column 3, the optimal exchange rate response is at the upper bound of the search grid and the response to inflation is reduced compared to previous cases ($\Gamma_p = 2.0, \Gamma_S = 5.0$).[13] As a result, the unconditional standard deviation of the exchange rate is reduced to only 0.02%, and the conditional response of the exchange rate to productivity shocks is nearly completed dampened, as shown in Figure 1. Further, if one chooses policy parameters to maximize just the utility of the sin country alone, the response to inflation is reduced yet a bit further ($\Gamma_p = 1.25, \Gamma_S = 5.0$), leading to even greater exchange rate stabilization (as shown in column 4).[14] Each country still offsets its own money demand shocks under these rules, even more so, as policy works to dampen the currency appreciation proceeding from a rise in money demand. Policy continues to respond procyclically to a productivity shock by lowering interest rates, but the degree of inflation stabilization is smaller under these policy rules.

[13] The grid search above is restricted to policy parameters symmetric across countries, implying that both countries work jointly to stabilize their bilateral exchange rate. Nonetheless, some ancillary experiments here with unilateral pegs indicated that the welfare of the foreign country can fall if it alone has $\Gamma_S > 0$.
[14] Figure 1 does not plot the response for the policy rule optimized for foreign welfare, as this is nearly identical to that for joint welfare discussed above.

The gains from stabilization policy for the sin country are somewhat larger than in the previous cases studied. The second of the optimized policies discussed above raises unconditional foreign utility by 0.29% over the exogenous policy, more than four times the gain from policy observed under the benchmark model. [15] The gains occur entirely in the mean component of utility, reflecting the effect of variability on the means of endogenous variables, rather than in the variance component itself. The gain is even a bit larger under the fixed exchange rate rule (0.33%), suggesting that the gains from the optimized policy rule observed here are due to stabilizing the exchange rate and moderating the resulting asymmetries. We think this experiment is informative, indicating that economies of this type warrant further investigation in the theoretical literature.

4 Conclusions

This paper performs a quantitative model-consistent evaluation of optimal policy rules in a two-country sticky-price model. The experiments focus on the important question of what degree of exchange rate variability is optimal for various types of open economies. The utility benefits of pursuing an optimized policy appear to be small for the types of simple economies typically studied in this literature. Developments in solving second-order approximations to dynamic stochastic models in principle open up the door to study much more varied and realistic economic environments.

The paper finds that extending the environment to consider consumer habits has only minor effects on the conclusions standard in the literature. It remains optimal to aggressively stabilize inflation, while allowing the exchange rate to fluctuate in response to productivity shocks. Further, the utility benefits of pursuing optimized stabilization rules remain quite small. In contrast, an extension of the environment to consider asset markets exhibiting ”original sin”, does alter these conclusions. Since ”original sin” appears to impose significant constraints on a country's precautionary saving, it becomes optimal, both from the perspective of the two-country world as well as from the sin country in particular, to actively suppress exchange rate fluctuations. These results would seem to indicate that it is alternative economic environments such as this one, which most warrant further investigation in the theoretical literature.

[15] Note also that the conditional welfare effect is small despite the large unconditional effect. Adopting a new policy does not change the fact that the foreign economy is starting off with a low share of wealth. After the adoption of the new policy, the foreign country begins saving more, but this entails a lower consumption level during the lengthy transition period where it is building up its capital stock and assets.

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Table 1: Benchmark Model

	Exogenous money supply	Fixed exchange rate	Optimized flexible exch. rate rule[3]
Standard deviations:			
consumption	1.24	1.21	1.20
output	2.41	2.36	1.86
investment	5.09	5.09	4.93
inflation	0.70	0.48	0.02
exchange rate depr.	1.44	0.00	0.20
Stochastic steady state deviations[1]:			
consumption	-0.036	-0.018	0.016
leisure	0.012	0.017	0.026
output	-0.015	0.007	0.046
capital stock	-0.034	0.023	0.108
interest rate	-1.481	-1.082	-0.324
markup ratio	0.341	0.215	0.001
home net assets	0.000	0.000	0.000
trade volume	0.299	0.256	0.277
Unconditional welfare effects (as percentage of steady state consumption)[2]:			
u-overall	-0.144	-0.113	-0.070
u-variance	-0.099	-0.082	-0.067
u-mean	-0.046	-0.031	-0.003
Conditional welfare effects (as percentage of steady state consumption)[2]:			
u-overall	-0.144	-0.129	-0.109
u-variance	-0.099	-0.087	-0.070
u-mean	-0.046	-0.042	-0.039

[1] Percent difference between stochastic steady state and deterministic steady state.

[2] Difference between stochastic steady state and deterministic steady state, shown as a share of deterministic steady state consumption.

Foreign variables are identical to home in the cases shown here.

[3] The policy rule is $i_t = \bar{i} + 5.0 p_t + 0.0 \hat{Y}_t + 0.0 \Delta s_t$.

Table 2: Habit Persistence Model

	Exogenous money supply	Fixed exchange rate	Optimized flexible exch. rate rule[3]
Standard deviations:			
consumption	1.25	1.24	1.25
output	1.41	1.41	1.39
investment	7.35	7.32	7.35
inflation rate	0.73	0.50	0.14
exchange rate depr.	1.20	0.00	0.23
Stochastic steady state deviations[1]:			
consumption	0.018	0.023	0.030
leisure	-0.003	-0.013	-0.020
output	0.113	0.123	0.140
capital stock	0.513	0.571	0.630
interest rate	-8.235	-7.833	-8.560
markup ratio	0.360	0.186	0.020
home net assets	0.000	0.000	0.000
trade volume	0.576	0.561	0.570
Unconditional welfare effects (as percentage of steady state consumption)[2]:			
u-overall	-0.659	-0.580	-0.530
u-variance	-0.692	-0.674	-0.680
u-mean	0.033	0.095	0.150
Conditional welfare effects (as percentage of steady state consumption)[2]:			
u-overall	-0.659	-0.655	-0.636
u-variance	-0.692	-0.688	-0.683
u-mean	0.033	0.032	0.047

[1] Percent difference between stochastic steady state and deterministic steady state.
[2] Difference between stochastic steady state and deterministic steady state, shown as a share of deterministic steady state consumption.
Foreign variables are identical to home in the cases shown here.
[3] The policy rule is $i_t = \bar{i} + 5.0p_t + 0.0\hat{Y}_t + 0.0\Delta s_t$.

Table 3: Asymmetric Asset Market Model

	Exogenous money supply	Fixed exchange rate	Optimized rule: Joint welfare[3]	Optimized rule: Foreign welfare[4]
Standard deviations:				
consumption	1.31	1.28	1.36	1.34
output	1.67	1.69	1.71	1.71
investment	5.89	6.56	6.56	6.56
inflation rate	0.57	0.39	0.08	0.26
exchange rate depr.	1.04	0.00	0.02	0.01
Stochastic steady state deviations[1]:				
consumption (home)	0.157	0.079	0.122	0.109
consumption (foreign)	-0.137	-0.031	-0.041	-0.036
leisure (home)	-0.403	-0.088	-0.176	-0.148
leisure (foreign)	0.595	0.287	0.376	0.345
output (home)	-0.410	-0.094	-0.152	-0.130
output (foreign)	0.534	0.261	0.371	0.336
capital stock (home)	-0.389	-0.081	-0.086	-0.081
capital stock (foreign)	0.431	0.227	0.369	0.324
interest rate	-0.440	-0.218	-0.255	-0.477
markup ratio	0.139	0.070	0.003	0.015
home net assets	60.169	17.954	29.902	25.838
trade volume	1.051	0.861	0.924	0.903
Unconditional welfare effects (as percentage of steady state consumption)[2]:				
u-overall (home)	0.278	-0.030	0.079	0.046
u-overall (foreign)	-0.751	-0.416	-0.491	-0.462
u-variance	-0.177	-0.174	-0.173	-0.172
u-mean (home)	0.454	0.144	0.252	0.218
u-mean (foreign)	-0.575	-0.242	-0.318	-0.290
Conditional welfare effects (as percentage of steady state consumption)[2]:				
u-overall (home)	0.278	0.288	0.298	0.299
u-overall (foreign)	-0.751	-0.736	-0.733	-0.731
u-variance	-0.177	-0.171	-0.168	-0.168
u-mean (home)	0.454	0.458	0.466	0.466
u-mean (foreign)	-0.575	-0.565	-0.565	-0.564

[1] Percent difference between stochastic steady state and deterministic steady state.

[2] Difference between stochastic steady state and deterministic steady state, shown as a share of deterministic steady state consumption.

[3] The policy rule is $i_t = \bar{i} + 2.0p_t + 0.0\hat{Y}_t + 5.0\Delta s_t$.

[4] The policy rule is $i_t = \bar{i} + 1.25p_t + 0.0\hat{Y}_t + 5.0\Delta s_t$.

Figure 1: Exchange rate impulse responses following home productivity shock under optimized Taylor policy rules