Global Monetary Policy under a Dollar Standard[1]

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Abstract For the past four or five decades, the international monetary system has operated on a 'dollar standard'. Popular discussion suggests that this gives the US an advantage in the use of monetary policy. This paper analyzes the determination of monetary policy in a world with a dollar standard, defined here as an environment in which all traded goods prices are set in US dollars. This generates an asymmetry whereby exchange rate pass-through into the US CPI is zero, while pass-through to other countries will be positive. We show that monetary policy in such a setting does seem to accord with popular discussion. In particular, the US is essentially indifferent to exchange rate volatility in setting monetary policy, while the rest of the world places a high weight on exchange rate volatility. More importantly, in a Nash equilibrium of the policy game between the US and the rest of the world, US preferences dominate. The equilibrium is identical to one where the US alone chooses world monetary policy. Despite this, we find surprisingly that the US loses from the dollar's role as an international currency. Even though US preferences dominate world monetary policy, the absence of exchange rate pass-through means that US consumers are worse off than those in the rest of the world, where exchange rate pass-through operates efficiently. Finally, we derive the conditions for a dollar standard to exist.

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1 Introduction

If the dollar were ever displaced by the euro, [the US] .. would lose the enormous freedom it now enjoys in running macro-economic policy.
Ambrose Evans Pritchard, Daily Telegraph, October 10, 2003.

The US dollar occupies a unique role in the world economy. The dollar resembles an international currency, in the sense that it acts as a means of exchange in international goods and asset trade, a store of value in international portfolios and official foreign exchange rate reserves, and a unit of account in international commodity pricing [2]. This predominance of the US dollar has been described by McKinnon (2001, 2002) as a world *dollar standard*.

How does the special role of the US dollar influence monetary policy making in the US and the rest of the world? The quotation above suggests that the US has an advantage in policy making due to the fact that the rest of world holds dollars, and sets prices in dollars. Indeed many commentators argue that there is an enormous welfare gain to the US from having its currency used so widely (e.g. Liu 2002).

This paper examines the determination of optimal monetary policy in an asymmetric world economy, where the currency of one country (e.g. the US dollar) plays a predominant role in trade [3]. While the US dollar has multi-dimensional role as an international currency, we focus on one particular aspect of this role - the importance of the currency in international export good pricing. We define a *reference currency* as one in which the prices of all world exports are pre-set. Many authors have noted (e.g. Campa and Goldberg, 2004) that prices of imported goods sold in the US economy tend to be much less affected by exchange rate fluctuations than do imported good prices in non-US countries [4]. Tavlas (1997) finds that during 1992-1996 98% of US exports and 88.8% of US imports were invoiced in US dollars. In addition, Goldberg and

[2]The dollar is used as one side of about 90 percent of daily foreign exchange rate transactions. According to Eichengreen and Mathieson (2000), 60 percent of world foreign exchange reserves are held in US dollars. Bekx (1998) estimates that over 50 percent of world exports in 1995 were denominated in US dollars, approximately four times the share of the US in total world exports.

[3]In the recent international macroeconomics literature, considerable attention has been devoted to the determination of optimal monetary policy under sticky prices. See Benigno and Benigno (2003), Devereux and Engel (2003), Obstfeld and Rogoff (2002), among many other papers. But most of this literature focuses on symmetric environments.

[4]Bachetta and Van Wincoop (2003) and Kenen (2003) note that the US dollar is used as an invoice currency for the overwhelming majority of US imports, but for other OECD countries, imports are mainly invoiced in foreign currency.

Tille (2005), using a new panel data set on the invoicing of international trade, find that the US dollar is the currency used for most transactions involving the US, and moreover, represents a vehicle currency in many trade flows that do not involve the US.

These findings suggest that prices of a large fraction of exports to the US are pre-set in US dollar terms (which we refer to as local currency pricing, or LCP), and do not react quickly to movements of the exchange rate . However, exports from the US are also likely to have prices pre-set in dollars (producer currency pricing, or PCP). Hence import prices in other countries should be more sensitive to exchange rate movements.

How does this asymmetry in international export good pricing affect optimal monetary policy? We show that at one level the model quite closely accords with popular wisdom about the position of the US dollar in the world economy. In particular, the monetary authority of the reference currency places a very low weight on exchange rate volatility in their monetary policy loss function. By contrast, the monetary authorities of rest of the world will be much more concerned with exchange rate volatility. This seems to well approximate the observed indifference of the US to the exchange rate in monetary policy-making. In addition, the reference currency country follows a more stable monetary policy than the rest of the world.

More importantly, we find that the monetary policy game between the reference currency country and the rest of the world has a key sense in which the reference country is predominant. The Nash equilibrium of the asymmetric game is the same as that which would obtain were the reference currency monetary authority to choose *both* its own and the rest of the world's monetary rules to maximize its own welfare. In this sense, the asymmetry in international pricing gives the reference country a dominant role in international monetary policy determination.

A natural question to ask then is how much the US gains from this predominant role of the dollar in export price setting [5]. The surprising answer is that US residents are not better off, but rather are worse off. Expected utility for residents of the reference currency country, where pass-through from the exchange rate to the CPI is zero, is lower than that of the rest of the world, where there is full pass-through [6].

[5]Our model excludes many factors which would be important in the full accounting of the gains from the dollar standard. In particular, there are no offshore holdings of currency in the model, so there is no seigniorage revenue earned on foreign money holdings. Nevertheless, we can learn from a comparison expected utility in the reference currency country and in the rest of the world, because absent the special role of the reference currency, the model is otherwise symmetric.

[6]While this may seem inconsistent with the result that the US determines world monetary policy, the explanation is that the asymmetric pricing means that the welfare outcomes are asymmetric. Even if monetary

The intuition why the dollar standard hurts the US is that when foreign export prices are set in US dollars, it prevents an efficient response of relative prices to underlying real shocks within the US. An efficient monetary policy will generally want to employ both expenditure level (affecting total aggregate demand) and expenditure switching (affecting the relative demand for one country's goods) effects. When import prices do not respond to the exchange rate, monetary policy cannot be used to generate expenditure switching effects. This has a welfare cost for the residents of the reference currency economy. Hence, in our model, the dollar standard is costly for the US economy.

What explains the special role of the reference currency? There is a considerable literature on the determinants of an 'international currency'. An early contribution by Krugman (1984) argues that there may be multiple equilibria due to network externalities. On the other hand McKinnon (2002) argues that the special role of the U.S. dollar arose partly from the record of low inflation and stable monetary policy that the U.S. economy followed in the Post WWII period. In a later section of the paper, we extend the model to allow exporting firms the choice of currency in which to set prices, and investigate the conditions under which there is an equilibrium where exporters in both countries will use the currency of a single country for price setting [7].

Our results suggest that both the Krugman multiple equilibria explanation and the McKinnon policy-determined explanation are important elements in the selection of a reference currency. In the equilibrium of the monetary policy game, the reference currency country's monetary authority will follow a more stable (lower variance) monetary policy. As a result, this tends to *lock in* an equilibrium where exporters in both countries use this currency in which to set prices. But the reason that the reference currency monetary authorities follow such a rule comes *only* from the fact that the currency is used as a reference in international trade pricing [8].

The paper is structured as follows. The following section develops the main model, which is covered briefly as it is only a slight extension of Devereux and Engel (2003). Section 3 derives the solution of the model for given monetary policy rules. Section 4 derives the optimal rules

policy were determined by a world social planner with equal weights on both regions, welfare of the reference country would differ from that of the rest of the world.

[7] Although many other factors are likely to be important in the acceptability of an international currency, the choice of currency for pricing will remain one important channel.

[8] We also find that there are other equilibria where either another currency will play the role of the reference currency, or no country's currency does.

in Nash equilibrium of a game between monetary authorities. Section 5 extends the model to allow for the endogenous choice of currency in which to set prices. Section 6 concludes.

2 The two-country model

We construct a simple two-country model of trade and exchange rate determination. We label one country the 'home' country, and assume that its currency is the reference currency, while the rest of the world is labelled the 'foreign' country. Firms set prices in advance, by assumption. There is a continuum of home goods (and home population) and foreign goods (foreign population) of measure n and $(1-n)$ respectively. Individual home (or foreign) goods are substitutable in preferences with elasticity λ, but there is unit elasticity of substitution across the home and foreign categories of goods [9]. The expected utility of home agents is: [10]

$$E(\frac{C^{1-\rho}}{1-\rho} + \chi \ln \frac{M}{P} - \eta L) \tag{2.1}$$

where $C = C_h^n C_f^{1-n} n^{-n} (1-n)^{-(1-n)}$ is an aggregate of home and foreign composite goods, $C_h = [n^{-\frac{1}{\lambda}} \int_0^n C_h(i)^{\frac{\lambda-1}{\lambda}} di]^{\frac{\lambda}{\lambda-1}}$ is the composite home goods aggregated over a continuum of home goods indexed by $[0,n]$; C_f, the composite foreign goods, is analogously defined, but over a range of goods indexed by $[n,1]$. $\frac{M}{P}$ denotes real money balances, and L is labor supply. We assume that $\rho \geq 1$, $\lambda > 1$, and η and χ are positive constant parameters [11]. From the consumption structure, the CPI price index is $P = P_h^n P_f^{1-n}$ where P_h and P_f represent the prices for the home and foreign composite goods in the home country respectively.

There is only a single period in which events take place [12]. First, before the period begins,

[9] We assume that all goods are traded. We could incorporate non-traded goods as in Duarte and Obstfeld (2004) without affecting the main results of the paper. See the Technical Appendix - available upon request.

[10] The use of this utility function and the consumption index will give us a closed form solution. It is also used in Obstfeld and Rogoff (2002) and Devereux and Engel (2003). Since our paper represents a direct extension of their results, we follow the literature here in order to make our results comparable to theirs.

[11] This assumption is important for our welfare results. When $\rho < 1$, the Nash equilibrium does not have the property that the foreign monetary policy maximizes US welfare (see Equations (3.10) and (3.11) below). Also, when $\rho < 1$, it is not necessarily the case that the reference country obtains lower welfare than the rest of the world. For very low values of ρ, we find numerically that welfare rankings may be reversed. Nevertheless, empirical estimates of ρ, and quantitative calibrations of ρ for business cycle and asset pricing literature, are almost always above unity.

[12] The results will carry over to an infinite horizon setting without change because we have assumed a) a full set of nominal state contingent assets, and b) one-period ahead price setting. Extensions to a more general dynamic model with incomplete markets and gradual price adjustment would be less straightforward.

households can trade in a full set of nominal state-contingent bonds [13]. This means that households can offset any risk that is associated with monetary policy uncertainty, as well as risk due to country-specific productivity shocks (see below). The outcome of this stage is that households will enter the period with their revenue stream governed by an optimal risk sharing rule. Then the monetary authorities choose optimal monetary rules, given the optimal risk sharing rule, but taking into account the way in which firms set prices, as well as the distribution of country-specific technology shocks [14]. Following this, firms set prices in advance, contingent on state-contingent discount factors, and the demand and marginal conditions that they anticipate will hold. After the realization of stochastic technology shocks, households choose their optimal consumption baskets, production and consumption takes place, and the exchange rate is determined.

Trade in state-contingent nominal assets across countries will lead to the equalization of the marginal utility of money across countries, up to a state-invariant weighting Γ. If the countries were entirely ex-ante identical, then obviously Γ would equal unity. But given the differences in pricing policies, countries are not necessarily the same, ex-ante. In this case, Γ will be chosen so as to reflect that different positions of the two countries in the initial competitive market in state contingent assets. Given the structure of preferences, we can show that the value of Γ will be: [15]

$$\Gamma = \frac{EC^{(1-\rho)}}{EC^{*(1-\rho)}}. \tag{2.2}$$

[13] We do not explore the questions of currency asymmetry in *assets markets*. The US dollar also plays a large role in foreign exchange trading and as a currency of denomination in international bond markets and bank lending. Strictly speaking, within the context of our model, the assumption of full risk-sharing implies that the currency of denomination of assets is immaterial. Hence a substantive investigation of this issue would require an incomplete markets environment. More generally, the question of the currency asymmetries in financial markets, as explored by Gourinchas and Rey (2005), is beyond the scope of our paper.

[14] Note that this implies that monetary policy is chosen with commitment. If monetary policy were determined after prices are fixed (discretionary monetary policy), monetary authorities have an incentive to generate a surprise inflation, to eliminate the effect of the monopoly pricing distortion on output. In the current model however, there is no cost of surprise inflation. As a result, there would be no finite rational expectations equilibrium monetary rule, since for any anticipated money stock, the monetary authority would find it optimal to set a higher surprise value of the money stock. Thus, relative to the models of Woodford (2003) and others, the present model makes it difficult to investigate discretionary monetary policy making.

[15] For a proof, again see Devereux and Engel (2003), Appendix, and also the Technical Appendix. Qualitatively, the results of the paper would be unchanged if we simply assumed that $\Gamma = 1$. The endogeneity of Γ however does play a role in solving for the optimal monetary rules -see Technical Appendix.

Table 1: **The optimality conditions for firms and home households**[a]

Optimality conditions		Pricing schedules	
Money demand	$M = \chi P C^{\rho}$	Home goods in Home markets	$P_{hh} = \hat{\lambda}\frac{E(\frac{WC^{1-\rho}}{\theta})}{E(C^{1-\rho})}$
Labor supply	$W = \eta P C^{\rho}$	Home Export Goods (PCP)	$P_{hf} = \hat{\lambda}\frac{E(\frac{WC^{*1-\rho}}{\theta})}{E(C^{*1-\rho})}$
Risk Sharing	$\Gamma P C^{\rho} = S P^{*} C^{*\rho}$	Foreign Export Goods (LCP)	$P_{fh} = \hat{\lambda}\frac{E(\frac{W^{*}SC^{1-\rho}}{\theta^{*}})}{E(C^{1-\rho})}$
		Foreign Goods in Foreign	$P^{*}_{ff} = \hat{\lambda}\frac{E(\frac{W^{*}C^{*1-\rho}}{\theta^{*}})}{E(C^{*1-\rho})}$

[a] $\hat{\lambda}$ represents the markup $\frac{\lambda}{\lambda-1}$; subscript h, f represents the price of the home good in the foreign market etc.

Since monetary policy is determined after financial markets have closed, the monetary authorities take Γ as given in their evaluation. We delay the discussion of optimal monetary rules until the next section. The optimal conditions of home households for choosing the state-contingent nominal bond, real balances and labor supply are given in Table 1. These conditions are quite standard in the literature.

Firms face demand for their goods from consumers in both their domestic country and abroad. Output of the home producer i is $Y(i) = \theta L(i)$ where θ is the unpredictable (at the time of price setting) technology shock in production, which follows a log-normal distribution such that $\theta = \exp(u)$ and $u \sim N(0, \sigma_u^2)$ [16]. Firms can price-discriminate across national markets, and households have no ability to re-sell goods across countries. In addition, there is an asymmetric pricing structure. Home firms set prices for both the home market and the foreign market in terms of the home currency. But foreign firms set prices for export in terms of the home country currency. Hence, the foreign firms engage in LCP when selling abroad, whereas the home firms follow PCP. In this sense, the home currency is the 'reference currency' in all international trade, because all traded goods have their prices set in terms of this currency [17].

[16] For the foreign productivity shock, we have $\theta^{*} = \exp(u^{*})$ and $u^{*} \sim N(0, \sigma_u^2)$.

[17] In reality exchange rate pass-through into import prices is higher than pass-through to the CPI (Obstfeld and Rogoff (2000), Burstein *et. al.* (2005)). We could incorporate this feature in the model by following Devereux, Engel and Tille (1999), in allowing for importing firms who purchase at prices set in producer's currency. Then, if we assumed importers in both countries pre-set their sales prices in the reference country, then we would have an environment with full pass-through into import prices, and zero (full) pass-through

The Technical Appendix outlines the details of the optimal pricing policies of firms. Table 1 lists the optimal pricing policies of the representative home and foreign firm for pricing of goods sold in home and foreign markets, respectively. These equations indicate that optimal prices depend on the joint distribution of marginal cost ($\frac{W}{\theta}$), the exchange rate, and consumption.

An asterisk over the price means that the price is denominated in foreign currency. Hence, all home goods prices are denominated in home currency, while only foreign goods sold in foreign markets are denominated in the foreign currency. Given this convention, then the price indices for each country are as follows:

$$P = P_{hh}^{n} P_{fh}^{1-n} \tag{2.3}$$

$$P^{*} = \left[\frac{P_{hf}}{S}\right]^{n} P_{ff}^{*}{}^{1-n}. \tag{2.4}$$

The set of equations given by the risk sharing condition, in combination with the money demand and labor supply equations (with analogous conditions for the foreign economy), the pricing equations, and the price indices (2.3) and (2.4), gives 12 equations that may be solved for the distribution of the variables $C, C^{*}, W, W^{*}, P, P^{*}, P_{hh}, P_{hf}, P_{fh}, P_{ff}^{*}, S$, and Γ.

3 Solving the Model

Because the model is log-linear and the underlying technology shocks are log-normal, we may solve for the exact distribution of all endogenous variables in closed form (the details are in the Technical Appendix). The solution allows a dichotomy between variables that are determined in advance of the realization of technology shocks, i.e. $P_{hh}, P_{hf}, P_{fh}, P_{ff}^{*}$, and Γ, and variables determined after the shocks have occurred; i.e. $C, C^{*}, W, W^{*}, P, P^{*}$ and S.

Using lower case letters for logs, we may write the equations for the exchange rate and consumption as:

$$s - E(s) = [m - E(m)] - [m^{*} - E(m^{*})] \tag{3.1}$$

$$c - E(c) = \frac{1}{\rho}[m - E(m)] \tag{3.2}$$

into consumer prices in the reference country (non-reference country). In fact, because of our assumption of complete asset trade, this specification would leave the results of the paper unchanged (see Devereux, Engel and Tille (1999)). By contrast, in an incomplete markets environment, the degree of pass-through into import goods would have a real effect. Devereux and Engel (2005) discuss how this impacts on the case for exchange rate flexibility as a stabilization policy.

$$c^* - E(c^*) = \frac{1}{\rho}\{n[m - E(m)] + (1-n)[m^* - E(m^*)]\} \tag{3.3}$$

where E denotes the mathematical expectation, and small-case letters denote logarithms.

Since the home country CPI is predetermined, c is independent of the realization of the foreign country money supply. But with full exchange rate pass-through into foreign imported goods, c^* is affected by home country monetary policy.

Equations (3.1)-(3.3) can be solved for the variance of the exchange rate and consumption. But first we need to set out the monetary policy rules. We make the following assumption regarding the determination of monetary policies:

$$m = \bar{m}_0 + a_1 u + a_2 u^* \tag{3.4}$$

$$m^* = \bar{m}_0 + b_1 u + b_2 u^*, \tag{3.5}$$

Thus, the money supply is a log-linear function of the shocks in each country, where the parameters of the rules, a_1, a_2, and b_1, b_2, have yet to be determined [18].

Monetary policy will be chosen to maximize expected utility for each country. In order to evaluate expected utility, it is necessary to determine expected consumption and employment. These will be affected by the stochastic structure of the model, given ex-ante optimal price setting. Using the pricing conditions, the labor supply equations, the risk sharing condition, and the properties of the log-normal distribution, we may solve for Ec and Ec^* as:

$$E(c) = -\frac{1}{\rho}\ln(\Gamma^{1-n}\hat{\lambda}\eta) - \frac{2-\rho}{2}\sigma_c^2 - \frac{n\sigma_u^2 + (1-n)\sigma_{u^*}^2}{2\rho} + \frac{n\sigma_{cu} + (1-n)\sigma_{cu^*}}{\rho} \tag{3.6}$$

$$\begin{aligned} E(c^*) \quad &= \quad -\frac{1}{\rho}\ln(\Gamma^{-n}\hat{\lambda}\eta) - \frac{2-\rho}{2}\sigma_{c^*}^2 - \frac{n(1-n)}{2\rho}\sigma_s^2 - \frac{n\sigma_u^2 + (1-n)\sigma_{u^*}^2}{2\rho} \\ &\quad + \frac{n\sigma_{c^*u} + (1-n)\sigma_{c^*u^*}}{\rho} + \frac{n(1-n)(\sigma_{su} - \sigma_{su^*})}{\rho} \end{aligned} \tag{3.7}$$

Equations (3.2) and (3.6) imply that both the mean and variance of home consumption are independent of foreign monetary policy and exchange rate volatility. On the other hand, mean consumption of the foreign country depends the distribution of the exchange rate. Why is it that exchange rate volatility affects expected foreign consumption, but not home consumption? This is because exchange rate volatility affects foreign import prices, and through this, the

[18] These rules are perfectly general, because given that the model is log-linear, and the shocks log-normal, the optimal form of monetary rules must be log-linear.

average level of pre-set prices. It will therefore affect mean consumption in the foreign country. Note that from (3.1), (3.3) and (3.7), foreign consumption will clearly be influenced by *both* home and foreign monetary policy rules.

Assume that monetary authorities in each country are concerned with the expected utility of consumption and dis-utility of labor supply, but ignore the utility of real money balances [19]. Thus, the home country monetary authority chooses its monetary rules to maximize

$$E(\frac{C^{1-\rho}}{1-\rho} - \eta L). \tag{3.8}$$

From the properties of the price setting equations in the home and foreign countries, and the labor market clearing condition, we can establish that:

$$EL = \frac{n}{\hat{\lambda}\eta} E(C^{1-\rho}) + \frac{1-n}{\hat{\lambda}\eta} E(C^{*1-\rho})\Gamma \tag{3.9}$$

Combining (3.8) and (3.9), we may write expected home country utility as

$$EU = \frac{\lambda - n(\lambda-1)(1-\rho)}{(1-\rho)\lambda} E(C^{1-\rho}) - \frac{(1-n)(\lambda-1)}{\lambda} \Gamma E(C^{*1-\rho}) \tag{3.10}$$

Given log-normality, (3.10) ultimately depends only on the second moments and cross moments of consumption, the exchange rate and technology shocks, which in turn depend on the monetary rules (3.4)-(3.5). Similarly, we get the expected utility of the foreign country:

$$EU^* = \frac{\lambda - (1-n)(\lambda-1)(1-\rho)}{(1-\rho)\lambda} E(C^{*1-\rho}) - \frac{n(\lambda-1)}{\lambda} \Gamma^{-1} E(C^{1-\rho}) \tag{3.11}$$

Flexible Price Equilibrium

It is useful to show the allocation that would obtain in an economy with fully flexible prices. In this case, the asymmetry in pricing would be irrelevant, because with ex-post price setting, the law of one price would hold across markets. Consumption and employment would be equalized across countries. The expressions for consumption and employment in the flexible price equilibrium are:

$$C = C^* = (\hat{\lambda}\eta)^{-\frac{1}{\rho}} (\theta^n \theta^{*1-n})^{\frac{1}{\rho}}. \tag{3.12}$$

$$L = L^* = (\hat{\lambda}\eta)^{-\frac{1}{\rho}} (\theta^n \theta^{*1-n})^{\frac{1-\rho}{\rho}}. \tag{3.13}$$

Productivity shocks affect consumption in each country in proportion to country size, and reduce employment in each country as $\rho > 1$.

[19] Obstfeld and Rogoff (2000) give a justification for this assumption.

4 Optimal Monetary Policy

Monetary policy is chosen with commitment, in the sense that monetary authorities choose the parameters of a monetary rule to maximize expected utility of the domestic agent, taking into account the way in which prices are set.

A natural objective of policy would be to design monetary rules so that the economy replicates the flexible price allocation. But given the way in which prices are set, this is not possible. The reason is that there is no expenditure switching mechanism in the home country. A monetary policy which guaranteed that consumption in both countries achieved the flexible price response to technology shocks would require that $a_1 = n, \quad a_2 = 1 - n$ and $b_1 = n, \quad b_2 = 1 - n$. But from Equation (3.1), this would imply a fixed exchange rate. In this case, the employment response in the home and foreign countries could not achieve the flexible price equilibrium level.

Monetary authorities take as given the coefficient of optimal risk-sharing Γ. In order to define an equilibrium of the monetary policy game between countries, it is convenient to reformulate the objective functions (3.10) in the following way. Define expected utility in the home country as: [20]:

$$\widetilde{EU(a,b)} = \Gamma^{n\frac{\rho-1}{\rho}} EU = \phi_n \Gamma^{\frac{\rho-1}{\rho}} X - \frac{(1-n)}{\hat{\lambda}} \Gamma X^* \tag{4.1}$$

Likewise, expected utility for the foreign country monetary authority can be rewritten as:

$$\widetilde{EU^*(a,b)} = \Gamma^{n\frac{\rho-1}{\rho}} EU^* = \phi_{1-n} X^* - \frac{n}{\hat{\lambda}} \Gamma^{-1} \Gamma^{\frac{\rho-1}{\rho}} X \tag{4.2}$$

where X and X^* are defined as:

$$X = \Theta \exp[(1-\rho)(-\frac{1}{2}\sigma_c^2 - \frac{\tilde{\sigma_u^2}}{2\rho} + \frac{\tilde{\sigma_{cu}}}{\rho})] \tag{4.3}$$

$$X^* = \Theta \exp[(1-\rho)(-\frac{1}{2}\sigma_{c^*}^2 - \frac{n(1-n)}{2\rho}\sigma_s^2 - \frac{\tilde{\sigma_u^2}}{2\rho} + \frac{\tilde{\sigma_{c^*u}}}{\rho} + n(1-n)\frac{(\sigma_{su} - \sigma_{su^*})}{\rho}], \tag{4.4}$$

ϕ_n, ϕ_{1-n}, and Θ are constant functions of parameters [21], and $\tilde{\sigma_u^2} = n\sigma_u^2 + (1-n)\sigma_{u^*}^2$, $\tilde{\sigma_{cu}} = n\sigma_{cu} + (1-n)\sigma_{cu^*}$, $\tilde{\sigma_{c^*u}} = n\sigma_{c^*u} + (1-n)\sigma_{c^*u^*}$.

[20] The first equality in the following equations follows from the fact that $E(C^{1-\rho}) = \Gamma^{(1-n)\frac{\rho-1}{\rho}} X$ and $E({C^*}^{1-\rho}) = \Gamma^{-n\frac{\rho-1}{\rho}} X^*$.

[21] In particular, $\phi_n = \frac{1}{1-\rho} - \frac{n}{\hat{\lambda}}$, $\phi_{1-n} = \frac{1}{1-\rho} - \frac{1-n}{\hat{\lambda}}$, and $\Theta = \exp\left[\frac{(\rho-1)}{\rho}\ln(\hat{\lambda}\eta)\right]$.

Although home consumption is independent of the foreign monetary rule (shown above), its *welfare* does depend on the foreign monetary rule, because expected home country employment is affected by foreign monetary policy. Thus, the home country is not indifferent to the rule followed by the foreign monetary authority.

Case $\rho = 1$

A special case of (4.1) and (4.2) arises when $\rho = 1$. Then expected employment is constant in both countries (see Equation (3.9)). Therefore, the monetary authorities are concerned solely with maximizing expected utility of their own consumption. For the home country, this is equivalent to using monetary rules to maximize:

$$-\frac{1}{2}\sigma_c^2 - \frac{\tilde{\sigma_u^2}}{2} + \sigma_{c\tilde{u}}. \tag{4.5}$$

By contrast in this case the foreign country maximizes:

$$-\frac{1}{2}\sigma_{c^*}^2 - \frac{n(1-n)}{2}\sigma_s^2 - \frac{\tilde{\sigma_u^2}}{2} + \sigma_{c^*\tilde{u}} + n(1-n)(\sigma_{su} - \sigma_{su^*}). \tag{4.6}$$

Home utility is reduced by consumption variance, but is increasing in the covariance of consumption and productivity shocks. An optimal monetary rule trades off these costs and benefits, making consumption positively co-vary with u and u^*. Note that the home monetary authority is indifferent to exchange rate variance.

For the foreign country, exchange rate variance does have welfare consequences. Exchange rate variance reduces foreign utility. But positive covariance of the exchange rate and home productivity shocks, or a negative covariance with foreign productivity, raises foreign utility [22]. An optimal monetary rule for the foreign country therefore has to take account of effects on both consumption and the exchange rate.

In the more general case with $\rho > 1$, the home country is no longer completely indifferent to exchange rate variability. But for reasonable parameter values and shock distributions, the home country places less weight on exchange rate variability than does the foreign country. Table 2 illustrates the impact of exchange rate volatility on expected utility, for each country, for various values of ρ, and a given calibration of other parameters. In all cases, the home country is less affected by movements in exchange rate variance.

[22] Exchange rate variance raises the mean foreign price level, for any expected value of the money stock, and hence reduces expected foreign consumption. But since exchange rate generates an expenditure switching effect in the foreign economy, a positive home (foreign) technology shock requires a depreciation (appreciation) in order to increase foreign demand for home (foreign) goods. This channel does not work in the home country, because there is no expenditure switching at the consumer level.

Table 2: **The weight on exchange rate volatility in monetary policy decision**[b]
($\rho > 1$, $n = 0.5$, $\sigma_u^2 = \sigma_{u^*}^2 = 0.0004$, $\hat{\lambda} = 1.1$)

Weight	$\rho = 1.5$	$\rho = 2$	$\rho = 3$	$\rho = 4$	$\rho = 6$	$\rho = 8$	$\rho = 15$
Home	-0.0144	-0.0188	-0.0219	-0.023	-0.0239	-0.0242	-0.0247
Foreign	-0.0778	-0.0603	-0.046	-0.0399	-0.0344	-0.0319	-0.0285
Ratio	0.1850	0.3118	0.4761	0.5764	0.6948	0.7586	0.8667

b. The weight on exchange rate volatility in monetary policy decision for home and foreign monetary authorities are measured by:

$$\frac{\partial EU}{\partial \sigma_s^2} = -\frac{(1-n)}{\hat{\lambda}}\Gamma^{(1-n\frac{\rho-1}{\rho})}\frac{\partial X^*}{\partial \sigma_s^2} < 0, \qquad \frac{\partial EU^*}{\partial \sigma_s^2} = [\frac{1}{1-\rho} - \frac{(1-n)}{\hat{\lambda}}]\Gamma^{-n\frac{\rho-1}{\rho}}\frac{\partial X^*}{\partial \sigma_s^2} < 0$$

where $\frac{\partial X^*}{\partial \sigma_s^2} > 0$, and Γ is endogenously determined by equation 2.2.

General Solution

A Nash equilibrium in the monetary game between countries (when $\rho \geq 1$) is defined in the standard way, as the pair a^n, b^n which solves:

$$\max_a \widetilde{EU(a, b^n)} \qquad \max_b \widetilde{EU^*(a^n, b)} \tag{4.7}$$

The first order conditions characterizing the Nash equilibrium can be written as (for both a_1, a_2 and b_1, b_2 respectively):

$$\phi_n \Gamma^{-\frac{1}{\rho}} \frac{\partial X}{\partial a} = \frac{(1-n)}{\hat{\lambda}} \frac{\partial X^*}{\partial a} \tag{4.8}$$

$$\frac{\partial X^*}{\partial b} = 0 \tag{4.9}$$

Using the property of optimal risk sharing from equation, we may establish that:

$$\Gamma = \frac{EC^{1-\rho}}{EC^{*(1-\rho)}} = \Gamma^{\frac{\rho-1}{\rho}} \frac{X}{X^*} = (\frac{X}{X^*})^{\rho}. \tag{4.10}$$

where the second equality follows from the definition of X and X^*. Now substituting into the first order conditions (4.8) and (4.9), we can derive the solutions to the Nash equilibrium (4.7).

Table 3 describes the solution. From the table, we may establish that a) $n \leq a_1 < 1$, $0 < a_2 \leq (1-n)$, b) $b_1 \leq 0$, $b_2 \geq 1$, and c) $a_1 + a_2 = 1$, $b_1 + b_2 = 1$.

In the special case with $\rho = 1$, we have $a_1 = n, a_2 = 1-n$, and $b_1 = 0, b_2 = 1$. In this case, the home country adjusts monetary policy to both the home and foreign shocks according to their weight in world GDP, and the foreign country focuses only on its own domestic shock. Given our assumption that u and u^* are i.i.d., it follows the home country monetary variance is lower than that of the foreign country. In addition the variance of the exchange rate is lower than would occur were there to be no world reference currency. Under the Nash equilibrium, exchange rate variance is $2n^2\sigma_u^2$. If exchange rate pass-through into both countries was complete, then the Nash equilibrium would give $a_1 = 1, a_2 = 0$, and $b_1 = 0, b_2 = 1$, and exchange rate variance would be $2\sigma_u^2$.

Table 3 also gives the solution for a_1, a_2 and b_1, b_2 in the more general case where $\rho > 1$. The same general properties of the solution described above still apply.

Using the solutions of Table 3, and the description of the Nash equilibrium, we now state the following proposition:

Proposition 1 *A Nash equilibrium is identical to an outcome where the home economy determines world monetary policy rules.*

The Nash equilibrium is asymmetric, in the sense that it gives the same allocation as if the home economy was choosing both its own *and* the foreign economy's monetary rules. Equivalently, in the Nash equilibrium, the foreign economy indirectly maximizes home country expected utility.

The proof of the proposition is straightforward. From the objective function (4.1), note that X is independent of b_1 and b_2, and home expected utility is linear in X^*. Since, in a Nash equilibrium, the foreign monetary authority chooses b_1 and b_2 to maximize a linear function of X^*, it's choice is also the optimal choice of b_1 and b_2 for the home economy, when $\rho \geq 1$.

The proposition does not hold in the reverse direction. The Nash allocations for a_1 and a_2 do not maximize foreign country welfare. Hence, the foreign country experiences negative welfare externalities in a Nash equilibrium.

The key ingredient in this asymmetry is that home consumption is independent of foreign monetary rules. As a result, the foreign monetary policy influences home utility only to the extent that it influences expected employment in the home country. Since the monetary rules b_1 and b_2 that maximize foreign utility are identical to those which minimize expected home employment, these rules are then the optimal rules from both the home and foreign country perspective [23].

[23] A corollary of the proposition is that there is no gain from international monetary policy coordination,

This equilibrium has features that seem to resemble the description of US monetary policy under the de facto world 'dollar standard'. It is widely acknowledged that the US pays little attention to the exchange rate in its monetary policy. But compared to many other countries, the US follows a more stable path of monetary policy[24]. More importantly, the US does have an advantage over the rest of the world in setting monetary policy, due to the special role of the dollar. In our model, this advantage is quite extreme in the sense that world monetary policy completely reflects US preferences.

Welfare Comparison

It is frequently asserted that US residents gain from the role of the US dollar as the international reference currency. Although there is a wide range of popular explanations for how these gains might come about, most economists (e.g. Krugman 1999) estimate that the gains to the US from the dominance of the dollar are modest, mainly accounted for by seigniorage revenue on offshore dollar holdings, and are a very small percentage of total US fiscal revenue.

We now address the question of the welfare gains to a reference currency. In our model, there are no offshore currency holdings, so the primary source of benefit is not present. Hence our welfare comparison is only partial. But the fact that the pricing structure and outcome of the monetary policy game are asymmetric means that welfare levels are different for the home and foreign countries. Since the country labels are irrelevant, the experiment is essentially a comparison of welfare of a country in an equilibrium where its currency is the reference currency and welfare in an equilibrium where it is not. Since the rest of the model is perfectly symmetric, the difference in welfare gives an exact measure of the gains from having an international currency (at least along the particular dimension we focus on).

It might be thought that this question has already been answered by Proposition 1. The role of the reference currency leads the home country to be placed on one end of the utility contract curve. It would then seem that the reference currency country is always better off. But this conclusion is incorrect. Since the game itself is asymmetric, welfare levels would differ even if each country's preference was given equal weight in world monetary policy making. In order to assess the gains to having a dominant currency, we must compare levels of expected

except in the trivial case where the social welfare function used for coordination places all weight on the home economy welfare. The Nash equilibrium is therefore efficient.

[24]Note that since we assume $\sigma_u^2 = \sigma_{u^*}^2$, $\sigma_m^2 = (a_1^2 + a_2^2)\sigma_u^2$, $\sigma_{m^*}^2 = (b_1^2 + b_2^2)\sigma_u^2$. Using the general properties of the solutions, we have $a_1^2 + a_2^2 = (a_1 + a_2)^2 - 2a_1a_2 < 1$ and $b_1^2 + b_2^2 = (b_1 + b_2)^2 - 2b_1b_2 > 1$. So $\sigma_m^2 < \sigma_{m^*}^2$.

utility to a country with and without a reference country. This comparison gives a surprising result.

Proposition 2 *In a Nash equilibrium, expected utility for the home country is always lower than that of the foreign country.*

Proof: See Appendix A.

Although the home country's preferences dominate world monetary policy making, as holders of the reference currency, home country residents are actually worse off than those of the foreign country, in the equilibrium of the monetary policy game. The explanation is quite intuitive. The absence of exchange rate pass-through into the home economy inhibits the usefulness of monetary policy. An ideal monetary policy rule is one which achieves both expenditure *level* effects and *expenditure switching* effects. The foreign country can use both channels. But the home country can't do this - since monetary policy can affect only the level of home spending, not the composition. Without pass-through into the home economy, home output is not adjusted efficiently to home and foreign technology shocks. Expected utility is lower than that of the foreign country, where relative prices can be affected by the exchange rate.

To show how big this welfare difference is, Table 4 gives a measure of the numerical welfare of the home and foreign country for plausible parameter values. Using the same measure, we also make a welfare comparison between the asymmetric pricing (PCP-LCP) and the symmetric pricing cases (both PCP and LCP). We define ϵ as the fraction of consumption that a consumer in an economy with pricing structure r would be willing to give up in order to make her indifferent between this and an economy with pricing structure s.

In Table 4, we reported the value of ϵ in each case. As might be anticipated, the welfare difference across different pricing structures is small [25]. As shown by Proposition 2, the welfare of the reference currency (home) country is always lower than that of the foreign country, but the welfare difference is lower than 0.01% of consumption under the PCP case.

From Table 4, we can also see that aggregate world welfare (with equal weights) under the PCP-LCP case is always higher than that under the symmetric LCP case, but always lower than that under the symmetric PCP structure [26]. This is because the terms of trade can be adjusted under the asymmetric pricing structure, which is better than the pure LCP case,

[25] We use the symmetric PCP case as the benchmark of comparison as it replicates the flexible price equilibrium.

[26] In Table 4, for all the parameter values, $\epsilon + \epsilon^* > 0$ under the PCP-LCP case.

but the adjustment is still not as efficient as that under the PCP case. For the individual countries, compared to the symmetric PCP or LCP cases, the home country is worse off as an international reference currency country [27]. Foreign country households however are better off in the asymmetric pricing structure than in the symmetric LCP case. Under some parameter values, the foreign country's welfare is even higher than that under the pure PCP case. Intuitively, the global welfare loss from inefficient terms of trade adjustment is combined with a welfare gain for the foreign country given that it can achieve exchange rate pass-through. For ρ quite large, the second effect may dominate.

5 Endogenous Currency Pricing

So far it has just been assumed that the home currency is used as a reference for international pricing. In principle, this decision should be endogenous. The set of forces leading to the adoption of an international 'vehicle' currency have been discussed extensively in the literature on international monetary economics (see Matsuyama *et al.* (1991), McKinnon (2002), Krugman (1984), Rey (2001)). Many factors, such as economic size, history, capital flows, and economic policy may be part of the explanation. Moreover, the presence of 'network externalities' in the choice of standard may give rise to multiple equilibria. Krugman (1984) notes that while economic size is likely to be an important factor, there may also be 'snowballing' effect, whereby even if countries are of similar size, if one currency becomes acceptable in exchange then all countries will have an incentive to support this outcome [28]. This suggests that the US dollar standard may be due to historical accident as much as current fundamentals. By contrast, McKinnon (2002) stresses the importance of US monetary policy, arguing that the US dollar's role as a world currency resulted from low and stable US inflation rates in the post-WWII international system.

In this section, we present a brief analysis of the determination of the reference currency for international trade pricing by allowing the currency of pricing to be endogenous [29].

[27] When $\rho = 1$, welfare of the reference currency country will be the same as that under the symmetric LCP case, while welfare of the foreign country equals its welfare under the pure symmetric PCP case.

[28] Economic size does not play any significant role in our model, because a) there are no non-traded goods, so all countries are fully open, and b) each country produces a measure of goods equal to its population, so the terms of trade is independent of size.

[29] Our analysis doubtless omits many important factors that determine the role of an international currency, but highlights one potentially important factor, within the context of this model.

We assume that firms can choose which currency they would like to set their price in. They realize that whatever their choice, they will then choose a nominal price to maximize expected discounted profits. In addition to this however, the firm incurs a cost of adjusting prices, ex-post. Assume that these costs arise only when the price facing consumers is adjusted. We might think of these as menu-changing costs, or customer resistance costs, that require management services on the part of the firm. If the firm sets the price in the local currency of the buyer, it will never face these costs, as the price to the buyer will be independent of the state of the world. But if the price is set in the exporting firms' own currency, prices facing the foreign consumer will be dependent upon the exchange rate.

Therefore, if the firm sets prices in its own currency, then it faces a fixed nominal cost given by δ. This is thought of as a cost of ex-post adjustment that comes from the exchange rate pass-through into the importing countries CPI. The presence of this fixed cost per se will therefore encourage the firm to set prices in the currency of the consumer (LCP).

On the other hand, the level of expected (discounted) profits, gross of fixed costs, will depend upon whether prices are pre-set in the producers currency or consumers currency. Using the same demand and cost structure from the model set out above, we may define the expected discounted profits on foreign sales for a home firm that sets its export price in terms of its own currency (PCP) as:

$$E[d\pi(i)^{PCP}] = E[d(P_{hf}(i) - \frac{W}{\theta})X_h^{*PCP}(i))] \tag{5.1}$$

where $X_h^{*PCP}(i) = (\frac{P_{hf}(i)}{SP_{hf}^*})^{-\lambda}\frac{P^*}{P_{hf}^*}C^*$ is the foreign demand under PCP, $d = \frac{1}{PC^\rho}$ is the stochastic discount factor.

If the firm chooses alternatively to set its price in terms of foreign currency (LCP), it faces expected discounted profits given by:

$$E[d\pi(i)^{LCP}] = E[d(SP_{hf}^*(i) - \frac{W}{\theta})X_h^{*LCP}(i))] \tag{5.2}$$

where $X_h^{*LCP}(i) = (\frac{P_{hf}^*(i)}{P_{hf}^*})^{-\lambda}\frac{P^*}{P_{hf}^*}C^*$ is the foreign demand under LCP.

The home country firm will set its price in its own currency if the expected profit differential from doing so exceeds the expected menu cost. Thus it follows PCP whenever:

$$E[d\pi(i)^{PCP}] - E[d\pi(i)^{LCP}] > \delta \tag{5.3}$$

The sequence of actions within a period is now described as follows. First, firms choose the currency in which prices are set. Following this, the monetary authorities in each country choose their optimal rules. Then firms choose the actual prices of goods. Finally, the technology shocks are realized, and consumption, output and exchange rates are determined.

In Devereux, Engel and Storgaard (2003), it is shown that the left hand side of (5.3) may be approximated by the following:

$$\bar{d}\bar{\pi}\lambda(\lambda-1)\left[\frac{Var(\ln S)}{2}-Cov(\ln\frac{W}{\theta},\ln S)\right] \tag{5.4}$$

where $\bar{d}$ and $\bar{\pi}$ denote the discount factor and profits in a deterministic economy. The intuition behind this condition is straightforward. Since profits are convex (linear) in the exchange rate when the firm following PCP (LCP), a higher exchange rate variance will encourage the firm to follow PCP. But if the covariance of the exchange rate and marginal cost $\frac{W}{\theta}$ is positive, expected costs will be higher under PCP. If the right hand side of (5.4) is positive, the firm would wish to set prices in its own currency (PCP), in the absence of menu costs of price change. Thus, the condition (5.3) becomes:

$$\lambda(\lambda-1)\left[\frac{Var(\ln S)}{2}-Cov(\ln\frac{W}{\theta},\ln S)\right]>\frac{\delta}{\bar{d}\bar{\pi}} \tag{5.5}$$

The equivalent condition for the foreign firm is:

$$\lambda(\lambda-1)\left[\frac{Var(\ln S)}{2}+Cov(\ln\frac{W^*}{\theta^*},\ln S)\right]>\frac{\delta}{\bar{d}\bar{\pi}}, \tag{5.6}$$

where, to maintain symmetry, we assume that the fixed cost facing the foreign firm is identical to that of the home firm.

If condition (5.5) (condition (5.6)) is not satisfied, then the home firm (foreign firm) will instead set prices according to LCP. From these conditions, we can establish the following proposition.

Proposition 3 *There exists threshold values for menu cost δ_H, δ_L, where $\delta_H > \delta_L$, such that if $\delta_L \leq \delta \leq \delta_H$, then all home firms follow PCP, and all foreign firms follow LCP.*

Proof: See Appendix B.

The proposition says that there exists an interval for δ such that the asymmetric pricing structure outlined in the previous section is an equilibrium. The home firm will choose PCP, while the foreign firm will choose LCP. Following this, the monetary authorities choose their optimal rules in the way described in the previous section. The key intuition is that the way in which the monetary rules are set acts so as to *lock in* the asymmetric pricing policies of home and foreign firms. The home (reference) country's monetary policy rule tends to target both home and foreign productivity shocks. Since these are independent of each other, the home country's money supply is less volatile than that of the foreign country. As a result, $Cov(\ln \frac{W}{\theta}, \ln S)$ is less than $-Cov(\ln \frac{W^*}{\theta^*}, \ln S)$, because the variability of the wage rate is completely determined by the variance of the domestic money stock. Thus, for relatively small menu costs of price change, it is more likely that the home firm will wish to set its price in its own currency, while the foreign firm will wish to set its price in the home currency.

These results suggest that both the Krugman (1984) multiple equilibria hypothesis, and the McKinnon (2002) fundamentals hypothesis, may be part of the explanation for the dollar standard. Given asymmetric pricing, the endogenous decisions of monetary authorities respond in a certain way so as to confirm the pricing decisions of firms, and this involves the reference currency monetary policy being more stable. Nevertheless, there are clearly other equilibria. Since the underlying structure is symmetric, if foreign firms followed PCP and home firms LCP, then the foreign country would be the reference currency [30].

6 Conclusions

In the decades since floating exchange rates, the US dollar has remained a pre-eminent currency in international trade and finance - leading to a de facto dollar standard. This paper has extended the recent literature on monetary policy in sticky-price general equilibrium models to allow for a US dollar standard. We found that the equilibrium has many of the attributes of popular discussion of the predominance of US monetary policy in the world economy. In particular, a decentralized world of floating exchange rates acts so as to maximize the welfare of the US. But, in sharp contrast to popular discussion, we found that this situation brings no net benefits to the US, when compared to welfare of the rest of the world. US residents are worse off in the situation of having a dollar standard, compared to residents of the rest of the world.

[30] There are other equilibria also. If all firms choose LCP, then from the results of Corsetti and Pesenti (2002), Devereux and Engel (2003), and Devereux, Engel and Storgaard (2003), the optimal monetary rules chosen by home and foreign countries will in fact support global LCP as an outcome.

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APPENDIX

A Proof of Proposition 2

When $\rho = 1$, using equation (4.5) and (4.6), given the optimal monetary rules that $a_1 = n$, $a_2 = 1-n$, $b_1 = 0$ and $b_2 = 1$, we can derive the expected utility for home country and foreign country.

$$EU = -\ln(\hat{\lambda}\eta\Gamma^{1-n}) - \frac{n(1-n)}{2}[\sigma_u^2 + \sigma_{u^*}^2] - (\frac{n}{\hat{\lambda}\eta} + \frac{1-n}{\hat{\lambda}\eta}\Gamma) \tag{A.1}$$

$$EU^* = -\ln(\hat{\lambda}\eta\Gamma^{-n}) - \frac{n(1-n)^2}{2}[\sigma_u^2 + \sigma_{u^*}^2] - (\Gamma^{-1}\frac{n}{\hat{\lambda}\eta} + \frac{1-n}{\hat{\lambda}\eta}) \tag{A.2}$$

Note that $\Gamma = 1$ when $\rho = 1$. Thus, $EU < EU^*$.

When $\rho > 1$, from equations (4.1) and (4.2), we have $EU = \Gamma^{-n\frac{\rho-1}{\rho}}\widetilde{EU}$ and $EU^* = \Gamma^{-n\frac{\rho-1}{\rho}}\widetilde{EU^*}$. Since $\Gamma > 0$, to show that $EU < EU^*$ is equivalent to show $\widetilde{EU} < \widetilde{EU^*}$. Using the fact that $\Gamma = (\frac{X}{X^*})^\rho$, we can simplify $\widetilde{EU}$ and $\widetilde{EU^*}$ as :

$$\widetilde{EU} = \frac{\lambda - (\lambda-1)(1-\rho)}{(1-\rho)\lambda}\Gamma X^* \tag{A.3}$$

$$\widetilde{EU^*} = \frac{\lambda - (\lambda-1)(1-\rho)}{(1-\rho)\lambda}X^* \tag{A.4}$$

Since $\frac{\lambda-(\lambda-1)(1-\rho)}{(1-\rho)\lambda}$ is negative, to prove $\widetilde{EU} < \widetilde{EU^*}$ is equivalent to prove $\Gamma > 1$. We denote

$$\tilde{X} = -\frac{1}{2}\sigma_c^2 - \frac{1}{2}\tilde{\sigma_u^2} + \tilde{\sigma_{cu}} \tag{A.5}$$

$$\tilde{X^*} = -\frac{1}{2}\sigma_{c^*}^2 - \frac{n(1-n)}{2}\sigma_s^2 - \frac{1}{2}\tilde{\sigma_u^2} + \tilde{\sigma_{c^*u}} + n(1-n)(\sigma_{su} - \sigma_{su^*}) \tag{A.6}$$

That is,

$$X = \Theta\exp[(1-\rho)\tilde{X}] \tag{A.7}$$

$$X^* = \Theta\exp[(1-\rho)\tilde{X}^*], \tag{A.8}$$

Since $\rho > 1$, to prove $\Gamma > 1$ is equivalent to prove $\tilde{X} < \tilde{X^*}$. Substituting the optimal monetary rules for the general case listed in Table 3 into equation (A.5) and (A.6), we may have

$$\tilde{X^*} - \tilde{X} = A\sigma_u^2 + A^*\sigma_{u^*}^2 \tag{A.9}$$

Where

$$A = \frac{(1-n)(a_1-b_1)}{2\rho^2(n(\rho-1)+1)}[a_1 + n^2(\rho-1)^3 + n(\rho-1)(\rho+(\rho-1)(1-a_1))] \tag{A.10}$$

$$A^* = \frac{(1-n)(a_2-b_2)}{2\rho^2(n(\rho-1)+1)}[a_2-(1-n)(n(\rho-1)^2+2\rho-1)-a_2n(\rho-1)^2-\rho n(n(\rho-1)^2+2\rho-1)] \tag{A.11}$$

Given the properties of the optimal policy coefficients ($n \leq a_1 < 1$, $b_1 < 0$, $a_1 - b_1 > 0$, $0 < a_2 \leq 1-n$ and $a_2 - b_2 < 0$), we can show

$$A > 0, \qquad A^* > 0 \tag{A.12}$$

That is, $\tilde{X} < \tilde{X^*}$ and $X > X^*$. Therefore,

$$\Gamma = (\frac{X}{X^*})^\rho > 1 \tag{A.13}$$

Thus, $\widetilde{EU} < \widetilde{EU^*}$, or $EU < EU^*$ when $\rho > 1$. Q.E.D.

B Proof of Proposition 3

To prove Proposition 3 , we need to show that there exist threshold values for menu cost δ_H, δ_L, $\delta_H > \delta_L$, such that if $\delta_L \leq \delta \leq \delta_H$, then all home firms follow PCP and the foreign firms follow LCP. That is:

$$\frac{1}{2}\sigma_s^2 - Cov(\ln\frac{W}{\theta}, s) > Z \tag{B.14}$$

$$\frac{1}{2}\sigma_s^2 + Cov(\ln\frac{W^*}{\theta^*}, s) < Z \tag{B.15}$$

where $Z = \frac{\delta}{d\bar{\pi}}\frac{1}{\lambda(\lambda-1)}$, $s = \ln S$.

Step 1 To prove that both (B.14) and (B.15) hold is equivalent to prove the following inequality:

$$Cov(s, \ln\frac{W}{\theta}) < -Cov(s, \ln\frac{W^*}{\theta^*}) \tag{B.16}$$

Using the labor supply function $W = \eta PC^\rho$ and money demand function $M = \chi PC^\rho$, we can write inequality (B.16) as

$$Cov(s, m-u) < -Cov(s, m^* - u^*) \tag{B.17}$$

Given the monetary policy rules (3.4) and (3.5), (B.17) becomes:

$$Cov[(a_1-b_1)u+(a_2-b_2)u^*,(a_1-1)u+a_2u^*] < -Cov[(a_1-b_1)u+(a_2-b_2)u^*,b_1u+(b_2-1)u^*] \tag{B.18}$$

Using the property that u and u^* are i.i.d, (B.18) could be rewritten as:

$$(a_1-b_1)(a_1+b_1-1)\sigma_u^2+(a_2-b_2)(a_2+b_2-1)\sigma_{u^*}^2 < 0 \tag{B.19}$$

From the optimal monetary rules listed in Table 3, we have $a_1+a_2=1$, $b_1+b_2=1$, $n \leq a_1 < 1$, $b_1 \leq 0$, $0 < a_2 \leq (1-n)$ and $b_2 \geq 1$, this implies

$$(a_1-b_1)(a_1+b_1-1) = (a_2-b_2)(a_2+b_2-1) < 0 \tag{B.20}$$

Thus, we show that the two conditions (B.14) and (B.15) hold.

Step 2 We need to show there exist threshold value δ_H, δ_L, and $\delta_H > \delta_L > 0$ (or Z_H, Z_L, and $Z_H > Z_L > 0$). Defining the left side term in equation (B.14) and (B.15) as Z_1 and Z_2, respectively, and using equation (B.14) and the properties of optimal policy parameters (a's and b's), we have

$$\begin{aligned} Z_1 &= \frac{1}{2}[(a_1-b_1)^2\sigma_u^2+(a_2-b_2)^2\sigma_{u^*}^2]-[(a_1-b_1)(a_1-1)\sigma_u^2+(a_2-b_2)a_2\sigma_{u^*}^2] \\ &= \underbrace{(a_1-b_1)}_{+}\underbrace{(\frac{a_1-b_1}{2}+1-a_1)}_{+}\sigma_u^2+\underbrace{(a_2-b_2)}_{-}\underbrace{(\frac{a_2-b_2}{2}-a_2)}_{-}\sigma_{u^*}^2 > 0 \end{aligned} \tag{B.21}$$

From equation (B.16), we have $Z_2 < Z_1$. Therefore, there must exist an interval Z_H and Z_L such that $Z_1 \geq Z_H > Z_L > Z_2$ such that (B.14) and (B.15) hold. Q.E.D.

Table 3: **The optimal monetary rules in Nash game**

Parameters	$\rho > 1$	$\rho = 1$
a_1	$\frac{[\rho n+(1-n)]\delta_1 - n(\rho-1)\delta_2}{[\rho n+(1-n)]\delta - n(\rho-1)\delta_2}$	n
a_2	$\frac{[\rho n+(1-n)]\delta_3}{[\rho n+(1-n)]\delta - n(\rho-1)\delta_2}$	$1-n$
b_1	$\frac{-n(\rho-1)\delta_3}{[\rho n+(1-n)]\delta - n(\rho-1)\delta_2}$	0
b_2	$\frac{[\rho n+(1-n)]\delta - n(\rho-1)\delta_2 + n(\rho-1)\delta_3}{[\rho n+(1-n)]\delta - n(\rho-1)\delta_2}$	1
Where	$\delta = \hat{\lambda} - n(1-\rho)\{1+(1-n)[\rho(1-n)+n]\}$	
	$\delta_1 = n\left\{\hat{\lambda} - (1-\rho)[n+(1-n)[\rho(1-n)+n]]\right\}$	
	$\delta_2 = n[(1-n)(1-\rho)]^2$	
	$\delta_3 = (1-n)[\hat{\lambda} - n(1-\rho)]$	
and	$\delta_1 + \delta_3 = \delta$	

Table 4: **Welfare comparison**[c]
($\rho > 1$, $\eta = 0.4$, $n = 0.5$, $\sigma_u^2 = \sigma_{u^*}^2 = 0.0004$, $\hat{\lambda} = 1.1$)

	$\rho = 1.5$			$\rho = 2$		
	PCP	LCP	PCP-LCP	PCP	LCP	PCP-LCP
ϵ	0	0.0067%	0.0078%	0	0.0050%	0.0070%
ϵ^*	0	0.0067%	0.0010%	0	0.0050%	−0.0008%
	$\rho = 4$			$\rho = 6$		
	PCP	LCP	PCP-LCP	PCP	LCP	PCP-LCP
ϵ	0	0.0025%	0.0061%	0	0.0017%	0.0057%
ϵ^*	0	0.0025%	−0.0033%	0	0.0017%	−0.0039%

[c] ϵ, ϵ^* represents the percentage decrease in the permanent consumption for the reference currency country (home) and the non-reference currency country (foreign), compared to the PCP case, respectively. If $\epsilon_x > 0 (< 0)$, it implies that the welfare of case x is lower(higher) than that of the PCP case.

Technical Appendix

Not to be published

A Optimal pricing setting

The optimization problem of each firm is to maximize the discounted expected profits, taking the individual demand function as given. Home firms set both the domestic price and export price in the currency of the producer (PCP). The home firm i's problem is then:

$$\max_{P_{hh},P_{hf}} E[d\pi(i)] = \max_{P_{hh},P_{hf}} E[d((P_{hh}(i) - \frac{W}{\theta})X_h(i) + (P_{hf}(i) - \frac{W}{\theta})X_h^*(i))] \tag{A.1}$$

Where $d = P^{-1}C^{-\rho}$ is the stochastic discount factor, $X_h(i) = nC_h(i)$ is the total sales of firm i to home residents and $X_h^*(i) = (1-n)C_h^*(i)$ is the total sales to foreign residents.

Foreign firms set both the domestic and the export price in the currency of the consumer (LCP). The foreign firm i's problems is:

$$\max_{P_{fh},P_{ff}^*} E[d^*\pi^*(i)] = \max_{P_{fh},P_{ff}^*} E[d^*((\frac{P_{fh}(i)}{S} - \frac{W^*}{\theta^*})X_f(i) + (P_{ff}^*(i) - \frac{W^*}{\theta^*})X_f^*(i))] \tag{A.2}$$

Substitute the risk-sharing condition into the first order conditions derived from home and foreign firms' optimization problem, we can derive the optimal pricing policies of firms listed in Table 1.

B Model solution

The risk-sharing condition, in combination with the money demand equation and the analogous condition for the foreign country implies a solution for the exchange rate:

$$S = \Gamma\frac{M}{M^*}. \tag{B.3}$$

Substituting this solution back into the money market clearing conditions then implies that

$$C = [\frac{1}{\chi}\frac{M}{P_{hh}^n P_{fh}^{1-n}}]^{\frac{1}{\rho}}, \qquad C^* = [\frac{1}{\chi}\frac{M^n M^{*(1-n)}}{P_{hf}^n P_{ff}^{*\,1-n}}]^{\frac{1}{\rho}}. \tag{B.4}$$

Taking logs of these conditions, and expectations, gives equations (3.1) - (3.3).

Solving for Ec From the price index (2.3) and pricing equations P_{hh} and P_{fh} in Table 1, we have

$$P_{hh}^{n}P_{fh}^{1-n} = \hat{\lambda}\frac{[E(\frac{WC^{1-\rho}}{\theta})]^{n}[E(\frac{W^{*}SC^{1-\rho}}{\theta^{*}})]^{1-n}}{E(C^{1-\rho})}$$

Using the risk-sharing condition, the labor supply equation and its foreign equivalent, taking out the predetermined terms, we have

$$1 = \hat{\lambda}\eta\Gamma^{1-n}\frac{[E(\frac{C}{\theta})]^{n}[E(\frac{C}{\theta^{*}})]^{1-n}}{E(C^{1-\rho})} \tag{B.5}$$

Now using the fact that the solution for consumption and exchange rate will be log-normal, and taking logs, we may get the expected consumption (3.6):

$$Ec = -\frac{1}{\rho}\ln[\hat{\lambda}\eta\Gamma^{1-n}] - \frac{2-\rho}{2}\sigma_{c}^{2} - \frac{n\sigma_{u}^{2} + (1-n)\sigma_{u^{*}}^{2}}{2\rho} + \frac{n\sigma_{cu} + (1-n)\sigma_{cu^{*}}}{\rho}$$

Similarly, we can use the foreign price index (2.4), P_{ff}^{*} and P_{hf} to derive the following equation

$$1 = \hat{\lambda}\eta\Gamma^{-n}\frac{[E(\frac{S^{1-n}C^{*}}{\theta})]^{n}[E(\frac{S^{-n}{*}C^{*}}{\theta^{*}})]^{1-n}}{E(C^{*1-\rho})} \tag{B.6}$$

which could be used to solve for Ec^{*}

$$\begin{aligned} Ec^{*} \quad = \quad & -\frac{1}{\rho}\ln(\Gamma^{-n}\hat{\lambda}\eta) - \frac{2-\rho}{2}\sigma_{c^{*}}^{2} - \frac{n(1-n)}{2\rho}\sigma_{s}^{2} - \frac{n\sigma_{u}^{2} + (1-n)\sigma_{u^{*}}^{2}}{2\rho} \\ & + \frac{n\sigma_{c^{*}u} + (1-n)\sigma_{c^{*}u^{*}}}{\rho} + \frac{n(1-n)(\sigma_{su} - \sigma_{su^{*}})}{\rho} \end{aligned} \tag{B.7}$$

Solving for EL and EU Home goods market clearing condition implies

$$\theta L = n\frac{PC}{P_{hh}} + (1-n)\frac{P^{*}C^{*}}{\frac{P_{hf}}{S}} \tag{B.8}$$

Substituting the pricing equations P_{hh} and P_{hf} into (B.8), we get

$$L = n\frac{PC}{\theta}\frac{E(C^{1-\rho})}{\hat{\lambda}E(\frac{WC^{1-\rho}}{\theta})} + (1-n)\frac{SP^{*}C^{*}}{\theta}\frac{E(C^{*1-\rho})}{\hat{\lambda}E(\frac{WC^{*1-\rho}}{\theta})} \tag{B.9}$$

Using the labor supply equation and risk-sharing condition in Table 1, and taking expectation, we can get (3.9) of the paper:

$$EL = \frac{n}{\hat{\lambda}\eta}EC^{1-\rho} + \frac{1-n}{\hat{\lambda}\eta}EC^{*(1-\rho)}\Gamma$$

Analogously, we can get:

$$EL^{*} = \Gamma^{-1}\frac{n}{\hat{\lambda}\eta}E(C^{1-\rho}) + \frac{1-n}{\hat{\lambda}\eta}E(C^{*1-\rho}) \tag{B.10}$$

Then we can get the expected home country utility (3.10) and its foreign equivalent (3.11).

Calculating the variances and covariances From the equations (3.1)-(3.3) and monetary policy rule (3.4) and (3.5), we can solve for the variances and covariances terms in Equation (3.6) and (3.7).

$$\sigma_s^2 = (a_1 - b_1)^2\sigma_u^2 + (a_2 - b_2)^2\sigma_{u^*}^2 \tag{B.11}$$

$$\sigma_c^2 = \frac{1}{\rho^2}[a_1^2\sigma_u^2 + a_2^2\sigma_{u^*}^2] \tag{B.12}$$

$$\sigma_{c^*}^2 = \frac{1}{\rho^2}[(na_1 + (1-n)b_1)^2\sigma_u^2 + (na_2 + (1-n)b_2)^2\sigma_{u^*}^2] \tag{B.13}$$

$$\sigma_{cu} = \frac{1}{\rho}a_1\sigma_u^2, \qquad \sigma_{cu^*} = \frac{1}{\rho}a_2\sigma_{u^*}^2 \tag{B.14}$$

$$\sigma_{c^*u} = \frac{1}{\rho}[na_1 + (1-n)b_1]\sigma_u^2, \qquad \sigma_{c^*u^*} = \frac{1}{\rho}[na_2 + (1-n)b_2]\sigma_{u^*}^2 \tag{B.15}$$

$$\sigma_{su} = (a_1 - b_1)\sigma_u^2, \qquad \sigma_{su^*} = (a_2 - b_2)\sigma_{u^*}^2 \tag{B.16}$$

Using the relationship

$$EC^{1-\rho} = \exp\left\{(1-\rho)[E(c) + \frac{1-\rho}{2}\sigma_c^2]\right\}, \tag{B.17}$$

we can express the expected home and foreign country utility as an function of monetary policy parameters (a_1, a_2, b_1, b_2).

The Nash Equilibrium The Nash equilibrium of the monetary game between countries is characterized by (4.7). Substituting the determination of Γ (4.10) into the first order conditions (4.8) and (4.9), we arrive at the characterization of the optimal monetary reaction functions for each country

$$\delta a_1 = n\left\{\hat{\lambda} - (1-\rho)\left[n + (1-n)[n + \rho(1-n)]\right]\right\} + n[(1-n)(1-\rho)]^2 b_1 \tag{B.18}$$

$$\delta a_2 = (1-n)[\hat{\lambda} - n(1-\rho)] + n[(1-n)(1-\rho)]^2(b_2 - 1) \tag{B.19}$$

$$b_1 = \frac{n(\rho-1)}{\rho n + (1-n)}(a_1 - 1) \tag{B.20}$$

$$b_2 = \frac{n(\rho-1)(a_2+1)+1}{\rho n + (1-n)} \tag{B.21}$$

where

$$\delta = \hat{\lambda} - n(1-\rho)\{1 + (1-n)[\rho(1-n) + n]\} \tag{B.22}$$

Equations (B.18) and (B.19) describe the home country's first order conditions, while (B.20) and (B.21) describe the foreign country's conditions. The solution to (B.18)-(B.21) is the Nash equilibrium in the monetary rules.

C Extension to an Economy with Non-traded goods.

Following Duarte and Obstfeld (2004), assume that in each country a fraction $1-\gamma$ of all consumer goods are non-traded. In addition, assume that non-traded goods are produced using the same technology as the domestic traded goods. The aggregate consumption index for the home country is now replaced by

$$C = AC_N^{1-\gamma} C_h^{\frac{1}{2}\gamma} C_f^{\frac{1}{2}\gamma} \tag{C.23}$$

where $A = [(1-\gamma)^{1-\gamma}(\frac{1}{2}\gamma)^{\frac{1}{2}\gamma}(\frac{1}{2}\gamma)^{\frac{1}{2}\gamma}]^{-1}$. Here, we simplify the notation by assuming $n = \frac{1}{2}$ (as in Duarte and Obstfeld (2004)). The price index may then be written as $P = P_N^{1-\gamma} P_{hh}^{\frac{1}{2}\gamma} P_{fh}^{\frac{1}{2}\gamma}$, where P_N is the price of the non-traded good.

Given that production costs and the scale of total demand are the same for non-traded goods firms and firms selling traded goods to their domestic market, the prices set by these two groups will be identical. Thus, $P_N = P_{hh}$, and similarly for the rest of the world, we have $P_N^* = P_{ff}^*$. The equations of Table 1 now hold exactly as before (with $n = \frac{1}{2}$), save for the fact that the price index incorporating non-traded goods has different weights as described in the previous paragraph. This gives us the new condition which determines Ec as:

$$1 = \hat{\lambda}\eta\Gamma^{\frac{\gamma}{2}} \frac{[E(\frac{C}{\theta})]^{1-\frac{\gamma}{2}}[E(\frac{C}{\theta^*})]^{\frac{\gamma}{2}}}{E(C^{1-\rho})} \tag{C.24}$$

In like manner, we may use the following condition to derive Ec^*:

$$1 = \hat{\lambda}\eta\Gamma^{-\frac{\gamma}{2}} \frac{[E(\frac{S^{1-\frac{\gamma}{2}}C^*}{\theta})]^{\frac{\gamma}{2}}[E(\frac{S^{-\frac{\gamma}{2}}C^*}{\theta^*})]^{1-\frac{\gamma}{2}}}{E(C^{*1-\rho})} \tag{C.25}$$

From (C.24) and (C.25), it is apparent that the solution for Ec and Ec^* dichotomizes in the same way as in the model without non-traded goods. In particular, the value of Ec can be solved as a function of $\ln\Gamma$ and the variance of c and $\ln\theta$, $\ln\theta^*$, and their covariances, just as before. The value of Ec^* will then, as before, depend on the variance of c^*, $\ln\theta$, $\ln\theta^*$, and the variance of the exchange rate.

To determine the objective function for the monetary authority in the economy with non-traded goods, we may amend (B.8) to get:

$$\theta L = (1-\frac{\gamma}{2})\frac{PC}{P_{hh}} + \frac{\gamma}{2}\frac{P^*C^*}{\frac{P_{hf}}{S}}, \tag{C.26}$$

which in combination with the optimal pricing equations, and upon taking expectations gives:

$$EL = \frac{(1-\frac{\gamma}{2})}{\hat{\lambda}\eta} EC^{1-\rho} + \frac{\frac{\gamma}{2}}{\hat{\lambda}\eta} EC^{*(1-\rho)}\Gamma \tag{C.27}$$

$$EL^* = \frac{(1-\frac{\gamma}{2})}{\hat{\lambda}\eta} EC^{*(1-\rho)} + \frac{\frac{\gamma}{2}}{\hat{\lambda}\eta} EC^{(1-\rho)}\Gamma^{-1} \tag{C.28}$$

From (C.27) and (C.28) we can obtain the analogous monetary policy objective functions as (3.10) and (3.11), differing only by the weights attached to each term. It follows immediately then that Proposition 1 holds as before, since as before, the term $EC^{1-\rho}$ is independent of foreign monetary policy rules, and in choosing to maximize $EC^{*(1-\rho)}$ the foreign monetary authority chooses the same monetary rule that would be chosen by the home authority to maximize home utility. In particular, it is straightforward to show that when $\rho = 1$, we obtain the following equilibrium monetary rules:

$$\{a_1, \quad a_2\} = \{1 - \frac{\gamma}{2}, \quad \frac{\gamma}{2}\} \qquad \{b_1, \quad b_2\} = \{0, \quad 1\}$$

Likewise, Proposition 2 holds as before, since following the approach of the proof of this proposition we can derive the expected utility terms in Proposition 2 as functions of Γ and X^* in exactly the same form as before. Finally, the conditions for Proposition 3 will not be affected by the presence of non-traded goods, since these depend only on expected profits in the export sector in each country.

D Deriving the Endogenous Value of Γ

Here we explain the derivation of the endogenous Γ function given in (2.2). The proof is a direct application of that in Devereux and Engel (2003). Without loss of generality, assume a finite set of possible states of the world Ω. Let the current state of the world be $\omega \in \Omega$. Countries participate in trading in state-contingent bonds with a home currency price $q(\omega)$ in the securities trading market. The home country budget constraint is:

$$\sum_{\omega \in \Omega} q(\omega)[P(\omega)C(\omega) + M(\omega) - M_{-1} + W(\omega)L(\omega) - \Pi(\omega) - T(\omega)] = 0 \tag{D.29}$$

where the price index, consumption, employment, money balances, wages, profits $\Pi(\omega)$, and transfers from the central bank $T(\omega)$ are all contingent on the current state. This budget constraint makes it clear that the household can choose consumption, employment on a state by state basis, given the current securities prices $q(\omega)$. Notice that we do not need here to specify the currency of goods prices in our definition of $P(\omega)$ and $\Pi(\omega)$. This makes the proof of Devereux and Engel immediately applicable to this amended model.

To show how Γ is determined, we can derive the first order condition for the choice of $C(\omega)$ for the home country as

$$\pi(\omega)C(\omega)^{-\rho} = \Lambda q(\omega)P(\omega), \tag{D.30}$$

where Λ is a state-invariant Lagrange multiplier on the budget constraint (D.29), and $\pi(\omega)$ is the probability of state ω. Now use the analogous procedure for the foreign country's budget constraint and derive the foreign first order condition as:

$$\pi(\omega)C(\omega)^{*-\rho} = \Lambda^* q(\omega)S(\omega)P^*(\omega). \tag{D.31}$$

Note that combining (D.30) and (D.31) gives the risk sharing condition:

$$\frac{\Lambda}{\Lambda^*} = \frac{S(\omega)P^*(\omega)}{P(\omega)}\frac{C^{*\rho}}{C^\rho}. \tag{D.32}$$

Thus, $\frac{\Lambda}{\Lambda^*}$ is equivalent to Γ of the text. An equilibrium in securities markets, given the form of preferences, must imply that

$$\sum_{\omega\in\Omega} q(\omega)[P(\omega)C(\omega) - S(\omega)P^*(\omega)C^*(\omega)] = 0. \tag{D.33}$$

Then, combining (D.30), (D.31), and (D.33), we obtain

$$\Gamma = \frac{\Lambda}{\Lambda^*} = \frac{\sum_{\omega\in\Omega} C^{1-\rho}}{\sum_{\omega\in\Omega} C^{*(1-\rho)}}, \tag{D.34}$$

which is the solution for (2.2) (in the simpler notation) of the text. Moreover, this solution also extends to the model with non-traded goods, since due to unit elasticity of substitution between traded and non-traded goods, the condition (D.33) still applies in this case.

E The Model without Securities Markets

Here we sketch out the implications of shutting down all ex ante securities markets, so that trade must balance on a state by state basis in every state of the world. In this case, the description of the model in Table 1 is amended only insofar as the risk sharing condition is replaced by the following condition:

$$PC = SP^*C^* \tag{E.35}$$

Without securities markets, and with unit elasticity of substitution between home and foreign goods, balanced trade must imply that the value of aggregate consumption is equalized across countries. It follows immediately that the results of the text will continue to apply without change when $\rho = 1$, since in this case, the trade balance condition is equivalent to the risk sharing condition when $\Gamma = 1$.

In the more general case where $\rho > 1$, the determination of Ec and Ec^* does not dichotomize in the same way as before. The conditions analogous to (B.5) and (B.6) are now written as:

$$1 = \hat{\lambda}\eta\Gamma^{1-n} \frac{[E(\frac{C}{\theta})]^n [E(\frac{C}{\theta^*})(\frac{C}{C^*})^{1-\rho}]^{1-n}}{E(C^{1-\rho})} \tag{E.36}$$

$$1 = \hat{\lambda}\eta\Gamma^{-n} \frac{[E(\frac{S^{1-n}C^*}{\theta})(\frac{C^*}{C})^{1-\rho}]^n [E(\frac{S^{-n}*C^*}{\theta^*})]^{1-n}}{E({C^*}^{1-\rho})} \tag{E.37}$$

In addition, the conditions determining expected employment in each country are written as:

$$EL = \frac{n}{\hat{\lambda}\eta} EC^{1-\rho} + \frac{1-n}{\hat{\lambda}\eta} EC^{*(1-\rho)} \frac{E(\frac{SP^*C^*}{\theta})}{E(\frac{SP^*C^*}{\theta}(\frac{C^*}{C})^{1-\rho})} \tag{E.38}$$

Analogously, we can get:

$$EL^* = \frac{n}{\hat{\lambda}\eta} E(C^{1-\rho}) \frac{E(\frac{PC}{\theta^*})}{E(\frac{PC}{\theta^*}(\frac{C}{C^*})^{1-\rho})} + \frac{1-n}{\hat{\lambda}\eta} E({C^*}^{1-\rho}) \tag{E.39}$$

From (E.36) and (E.37) it is apparent that Ec and Ec^* are determined simultaneously by the variance and covariances of c, c^*, θ and θ^*, and S. Thus, in determining its monetary rules, the foreign country will take account of their effect on the mean of home country consumption. From (E.38) and (E.39) we may use (3.8) (and its foreign analogue) to construct the objective functions for the home and foreign monetary authorities. Given the form of (E.38) and (E.39) it is clear that the property implied by Proposition 2 no longer applies; in choosing monetary rules to maximize foreign utility, the foreign monetary authority no longer maximizes home country utility by default.

An additional complication raised by this version of the model is that the solutions cannot be obtained analytically. Although it is possible to use (E.36) and (E.37) to derive Ec and Ec^*, the derivation of the optimal policy rules in a Nash equilibrium must be done numerically.

This implies that when trade must be balanced on a state by state basis, and in the $\rho > 1$ case, the clean analytical results of the paper no longer apply. A Nash equilibrium is not in general equivalent to an outcome where the reference currency country chooses world monetary policy. But since the results of the text do apply exactly when $\rho = 1$, our conjecture is that for values of ρ close to unity, the qualitative implications of the paper will remain.