Federal Reserve Bank of Minneapolis
Research Department Staff Report 223

February 1996

Can Sticky Price Models Generate Volatile and Persistent Real Exchange Rates? (December 1998 Version)*

V. V. Chari

University of Minnesota
and Federal Reserve Bank of Minneapolis

Patrick J. Kehoe

University of Pennsylvania,
Federal Reserve Bank of Minneapolis,
and National Bureau of Economic Research

Ellen R. McGrattan

Federal Reserve Bank of Minneapolis

ABSTRACT

The conventional wisdom is that monetary shocks interact with sticky goods prices to generate the observed volatility and persistence in real exchange rates. We investigate this conventional wisdom in a quantitative model with sticky prices. We find that with preferences as in the real business cycle literature, irrespective of the length of price stickiness, the model necessarily produces only a fraction of the volatility in exchange rates seen in the data. With preferences which are separable in leisure, the model can produce the observed volatility in exchange rates. We also show that long stickiness is necessary to generate the observed persistence. In addition, we show that making asset markets incomplete does not measurably increase either the volatility or persistence of real exchange rates.

*Chari thanks the National Science Foundation for support. Kehoe thanks the National Science Foundation and the Ronald S. Lauder Foundation for support. The views expressed herein are those of the authors and not necessarily those of the Federal Reserve Bank of Minneapolis or the Federal Reserve System.

Why are the movements in real exchange rates so large and so persistent? The conventional wisdom is that these movements are the result of monetary shocks, and they can best be understood in a model with sticky prices. In this paper, we develop a general equilibrium monetary model with sticky prices that builds on the work of Svensson and Van Wijnbergen (1989) to investigate the extent to which monetary shocks can account for the observed volatility and persistence of real exchange rates. We find that with the conventional preferences used in the real business cycle literature, irrespective of the length of price stickiness, the model can generate only a small part of the fluctuations of the real exchange rates we see in the data. We show that a version of the model in which preferences over consumption and leisure are separable can account for essentially all of the volatility in real exchange rates. With sufficiently long price stickiness, real exchange rates are about as persistent as they are in the data.

In our model, real exchange rate movements arise from movements in the relative prices of traded goods across countries. Our focus on the relative price of traded goods is guided by recent empirical work. Much of this work begins by recognizing that the evidence on real exchange rates suggests two possibilities: either there are large and persistent changes in the relative prices of nontraded to traded goods across countries or there are large and persistent changes in the relative price of traded goods across countries. Recently, there have been a number of studies documenting that even at a very disaggregated level, there are large and persistent movements in the relative prices of traded goods. (See, for example, Engel (1993) and Knetter (1993).) Following Engel (1995), we present evidence that variations in the relative prices of nontraded to traded goods across countries account for essentially none of the variability in real exchange rates. In our data analysis, we focus on the United States and an aggregate of Europe. Using our admittedly imperfect measure, we find that less than 2% of the variance of real exchange rates is due to variations in the relative price of nontraded to traded goods.

These observations lead us to construct a model with only traded goods. Our model is a version of Svensson and van Wijnbergen's (1989) model modified to allow for price discrimination, staggered price setting, and capital accumulation. We introduce price discriminating monopolists in order to get real exchange rate variations from movements in the relative price of traded goods. (See Dornbusch (1987), Krugman (1987), Knetter (1989), Marston (1990), and Goldberg and Knetter (forthcoming).) We introduce staggered price setting in order to get persistent real exchange rate movements. We introduce capital accumulation in order to have a business cycle model.

We begin with preferences that are standard in the real business cycle literature. In our model, the real exchange rate is the ratio of the marginal utilities of consumption of households in the two countries. With these *benchmark* preferences, we show that given the observed variation in real quantities, the ratio of marginal utilities necessarily fluctuates much less than do real exchange rates so that the model simply cannot produce the observed variability in real exchange rates. This finding is in the spirit of Mehra and Prescott's (1985) work on the equity premium. The intuition is that with the benchmark preferences, increases in consumption lower the marginal utility of consumption, while increases in employment raise this marginal utility. Since consumption and employment are positively correlated, their effects on the marginal utility of consumption offset, and thus the marginal utility does not fluctuate very much.

This finding leads us to consider a class of preferences which are separable in leisure. With these *preferred* preferences, we find that the model can generate the observed volatility in real exchange rates with sufficiently high risk aversion in consumption. We find that prices must be set for at least 12 quarters at a time to generate the kind of persistence observed in the data. We go on to show that if money shocks are correlated across countries, the model is broadly consistent with the comovements in output and consumption across countries as seen in the data. In this sense, monetary shocks operating through a sticky-price/price-discrimination channel can account for most of the movements in real exchange rates.

We have shown that the properties of exchange rates depend crucially on the specification of preferences. A key difference in these preferences is in their implications for balanced growth. If ongoing technological progress occurs only in the market sector, then the benchmark preferences are consistent with balanced growth, while the preferred preferences are not. If, however, technological progress occurs in both the market sector and the production of leisure services, then both types of preferences can be consistent with balanced growth. With this type of technological progress and our preferred preferences, balanced growth imposes a restriction linking risk aversion and the elasticity of labor supply.

Finally, we investigate whether making asset markets incomplete could lead to persistent exchange rate movements with shorter price stickiness. The idea is that with incomplete markets, monetary shocks lead to permanent wealth redistributions and hence to persistent real exchange rate movements. For a simplified version of the model, we find that this channel is quantitatively insignificant.

In terms of the literature, there are a number of papers that investigate the effects of sticky prices. For some early work in a closed economy setting, see Svensson (1986), Blanchard and Kiyotaki (1991), and Ball and Romer (1989). In terms of the international literature on sticky prices, there are three branches. In some of this literature, such as Svensson and van Wijnbergen (1989) and Obstfeld and Rogoff (1995), monopolists do not price discriminate across countries, so there are no deviations from the law of one price. More closely related to our paper are those papers by Betts and Devereux (1996) and Kollman (1996), who consider economies with price discriminating monopolists who set prices as in Calvo (1983). Betts and Devereux are primarily interested in replicating the VAR evidence on monetary policy shocks and exchange rates. Kollman considers a semi-small open economy model without capital in which, in addition to prices, wages are also sticky and shows that the model generates volatile exchange rates. Finally, for some other work on the implications of sticky prices for monetary policy under fixed exchange rates, see Ohanian and Stockman (1993).

1. Data

In this section, we document properties of measures of bilateral exchange rates between the United States and individual European countries and a European aggregate, along with other business cycle statistics. Our aggregate of Europe consists of Austria, Finland, France, West Germany, Italy, Norway, Spain, Switzerland, and the United Kingdom. This choice of countries is dictated by availability of data. Our data are quarterly for the period 1972:1 through 1994:4 and are primarily from DRI's International Monetary Fund database. (See the appendix for details about how we construct the data described here.) We find that real exchange rates are volatile and persistent. We then use disaggregated price data to argue that very little of the variations in real exchange rates arises from variations in the relative price of nontraded to traded goods.

Our measure of the U.S. nominal exchange rate e_t between the United States and Europe is a trade-weighted average of the bilateral nominal exchange rates with each of the nine European countries. (The trade weights are given in Table A1 in the appendix.) We construct a price index for the European countries denoted P_t^* in an analogous fashion using each country's consumer price index (CPI). The U.S. real exchange rate with Europe is $q_t = e_t P_t^* / P_t$, where P_t is the price index in the United States. Our measures of the European nominal and real exchange rates with the United States are the appropriate inverses of the U.S. nominal and real exchange rates. We also construct a time series for output, consumption, investment, and employment for an aggregate of the European countries.

In Figure 1, we plot the U.S. nominal and real exchange rates with Europe and the ratio of the consumer price index for Europe to that in the United States. Clearly, both the nominal and the real exchange rates are highly volatile, especially when compared to the relative price levels. The exchange rates are also highly persistent. In Table 1, we present some statistics for exchange rates and prices, and in Table 2, we present some business cycle statistics. All the data reported in our tables are logged, except for net exports, which are calculated as the ratio of nominal net exports to nominal gross domestic product (GDP). The transformed data are then HP-filtered. The standard deviation of the real exchange rate between the United States and Europe is 7.81. We find it instructive to compare the volatility of real exchange rates to that of a broad aggregate of economic activity measured by real output. By this measure, the real exchange rate is about 4.4 times as volatile as U.S. output, which has a standard deviation of 1.76%. We also see in Table 1 that both nominal and real exchange rates between the United States and Europe are highly persistent, with autocorrelations of 0.86 and 0.83, respectively, and nominal and real exchange rates are very highly correlated with each other, with a cross correlation of 0.99. We also note that there is a modest negative correlation between real exchange rates and both output and net exports. The data on the individual countries show that these patterns are also evident in bilateral comparisons between each European country and the United States.

Our real exchange rate measure is substantially more volatile than a measure of the real exchange rate between the United States and the rest of the world. For example, as reported in the International Financial Statistics, the MERM-weighted effective real exchange rate for the United States has a standard deviation of 5.43. The autocorrelation of the MERM exchange rate is 0.85. The MERM exchange rate is less volatile presumably because shocks affecting bilateral exchange rates are not perfectly correlated across countries and the MERM averages across more countries than our measure does.

In Table 2, we report on standard business cycle statistics. Most of these statistics are standard and are included for completeness. One observation worth pointing out that other authors have also emphasized is that output is more correlated across countries than is consumption. Notice that this holds for each bilateral comparison between a European country and the United States as well as for the European aggregate and the United States.

In the data, movements in real exchange rates arise from two sources: deviations in the law of one price for traded goods across countries and movements in the relative price of nontraded to traded goods across countries. To investigate the quantitative magnitude of these sources, define the price indices for all goods in the two countries as follows: $P = (P_T)^{1-\alpha}(P_N)^{\alpha}$ and $P^* = (P_T^*)^{1-\gamma}(P_N^*)^{\gamma}$, where P_T, P_T^* are traded goods prices, P_N, P_N^* are nontraded goods prices, and α and γ are the consumption shares of nontraded goods. Write the real exchange rate as $q = q_T p$, where $q_T = eP_T^*/P_T$ is the relative price of traded goods and $p = (P_N^*/P_T^*)^{\alpha}/(P_N/P_T)^{\gamma}$ depends on the relative price of nontraded to traded goods in the two countries. If the law of one price holds, then q_T is constant and all the variance in q is attributable to the relative prices of nontraded goods. In what follows, we follow Engel (1995) and use several measures of disaggregated price data to construct this decomposition.

Our first measure uses disaggregated CPI data. The OECD Main Economic Indicators report price index data and disaggregate the price index for all items into indices for food, all goods less food, rent, and services less rent. We construct a price index for traded goods as a weighted average of the price index for food and the price index for all goods less food. Since data on expenditure shares among traded goods by country are not readily available, we used U.S. weights obtained from the Bureau of Labor Statistics (1992) to construct this price index for each country in Europe which has disaggregated price data. These countries are Denmark, France, Italy, Netherlands, Norway, and Switzerland. Our European aggregate uses the trade-weighting procedure described in the appendix. Figure 2 plots the real exchange rate, q, the relative price of traded goods, q_T, and the ratio of q to q_T, p. This figure shows that virtually none of the movement in real exchange rates is due to movements in the relative prices of nontraded to traded goods across countries. The variance of the real exchange rate can be decomposed as $\text{var}(\log q) = \text{var}(\log q_T) + \text{var}(\log p) + 2\text{cov}(\log q_T, \log p)$. In the data, the variance decomposition becomes $(4.29) = (4.89) + (0.08) + (-0.68)$. Since the covariance between the two components is negative, the maximum fraction of the variance of real exchange rates attributable to variability in the relative prices of nontraded to traded goods is 1.86% (0.08/4.29×100%).

Table 3 gives some additional statistics on relative prices, exchange rates, and real exchange rates for individual European countries as well as for the aggregate. Although there is some heterogeneity in the individual countries statistics, the bilateral comparisons have the same basic patterns as the aggregates. For our European aggregate, the correlation between the traded-goods real exchange rate and the all-goods real exchange rate is 0.99. In other respects, the statistics in this table are very similar to those in Table 1.

Our second measure uses disaggregated deflators by type of deflators. The Quarterly National Accounts of the OECD report nominal and real private consumption expenditure by four categories: durable goods, semi-durable goods, nondurable goods, and services. We use these data to construct a price deflator for each category as well as a price deflator for all consumption expenditures. Our traded-goods price index is a weighted average of the deflators for durable goods, semi-durable goods, and nondurable goods; and our nontraded-goods price index is the deflator for services. The weights are the time average of the real expenditure shares for each category. Disaggregated consumption expenditure data are available only for France, Italy, and the United Kingdom. Our European aggregate uses the trade-weighting procedure described in the appendix. In Figure 3, we plot the q, q_T, and p computed using these data. Using these data, we find that the variance decomposition of the real exchange rate becomes $(2.17) = (2.30) + (0.07) + (-0.20)$ so that the maximum fraction of the variance due to variability in the relative price of nontraded to traded goods is 3%. In Table 4 we report additional statistics on relative prices, exchange rates, and real exchange rates for individual European countries as well as for the aggregate. For the European aggregate, the correlation between the all-goods real exchange rate and the traded goods real exchange rate is 0.99. As before there is some heterogeneity in the individual countries statistics, but the bilateral comparisons have the same basic patterns as the aggregates.

These measures provide evidence that the relative price of traded goods varies a great deal across countries. Since our measures of the relative price of traded goods are constructed from broad aggregates, it is possible that the law of one price holds for each traded good and the volatility of the traded goods real exchange rate arises from compositional effects among traded goods. We think it doubtful that composition effects account for much of the volatility of real exchange rates because European countries have similar consumption baskets to the United States and because these consumption baskets do not change a great deal over time.

Our measures of the prices of traded goods are clearly imperfect in another respect. Our price indices measure the prices paid by the final user of the good. As such, the price incorporates the value of intermediate nontraded services, such as distribution and retailing. Thus, if the value of such nontraded services is volatile, we would expect our traded-goods real exchange rate to be volatile even if the law of one price held for goods net of the value of the nontraded services. Wholesale price indices (WPI's) reflect prices received by producers and thus do not include substantial portions of distribution and retailing costs. One problem with such price indices is they include the prices of exported goods and do not include the prices of imported goods and thus are very imperfect measures of the real exchange rate. In Table 5, we report on relative prices and exchange rates constructed using WPI's. The procedure we use to construct these indices is the same as that underlying the measures in Table 1. For the European aggregate, the standard deviation of the real exchange rate constructed using WPI's is 7.61. For the same set of countries, the standard deviation of the real exchange rate using CPI's is 7.81 as reported in Table 1. These measures are very close, suggesting that volatile distribution costs are unlikely to be a significant source of real exchange rate volatility.

In the next section we develop a model that we use to confront these observations.

2. The World Economy

Consider a two-country world economy consisting of a home country and a foreign country. Each country is populated by a large number of identical, infinitely-lived consumers. In each period t, the economy experiences one of finitely many events s_t. We denote by $s^t = (s_0, \ldots, s_t)$ the history of events up through and including period t. The probability, as of period zero, of any particular history s^t is $\pi(s^t)$. The initial realization s_0 is given.

In each period t, the commodities in this economy are labor, a consumption-capital good, money, a continuum of intermediate goods indexed by $i \in [0, 1]$ produced in the home country, and a continuum of intermediate goods indexed by $i \in [0, 1]$ produced in the foreign country. In this economy the intermediate goods are combined to form final goods which are country specific and cannot be shipped. All trade between the countries is in intermediate goods that are produced by monopolists who can charge different prices in the two countries. We assume that each intermediate goods producer has the exclusive right to sell his own good in the two countries. Thus, there is no possibility for arbitraging away price differences in intermediate goods.

In terms of notation, goods produced in the home country are subscripted with an H, while those produced in the foreign country are subscripted with an F. In the home country, final goods are produced from intermediate goods according to a production function that combines features from the industrial organization literature (Dixit and Stiglitz (1994)) and the trade literature (Armington (1969)):

$$(1) \qquad y(s^t) = \left[\omega_1 \left(\int_0^1 y_H(i, s^t)^\theta di \right)^{\rho/\theta} + \omega_2 \left(\int_0^1 y_F(i, s^t)^\theta di \right)^{\rho/\theta} \right]^{\frac{1}{\rho}},$$

where $y(s^t)$ is the final good and $y_H(i, s^t)$ and $y_F(i, s^t)$ are intermediate goods produced in the home and foreign countries, respectively. This specification of technology will allow our model to be consistent with three features of the data. The parameter θ will determine the markup of price over marginal cost. The parameter ρ, along with θ, will determine the elasticity of substitution between home and foreign goods. Finally, the parameters ω_1 and ω_2, together with ρ and θ, will determine the ratio of imports to GDP.

Final goods producers behave competitively. In the home country in each period t producers choose inputs $y_H(i, s^t)$ for $i \in [0,1]$ and $y_F(i, s^t)$ for $i \in [0,1]$ and output $y(s^t)$ to maximize profits given by

$$(2) \qquad \max \; P(s^t)y(s^t) - \int_0^1 P_H(i, s^{t-1})y_H(i, s^t)\, di - \int_0^1 P_F(i, s^{t-1})y_F(i, s^t)\, di$$

subject to (1), where $P(s^t)$ is the price of the final good in period t, $P_H(i, s^{t-1})$ is the price of the home intermediate good i in period t, and $P_F(i, s^{t-1})$ is the price of foreign intermediate good i in period t. These prices are in units of the domestic currency. The intermediate goods prices do not depend on s_t because period t prices in our economy are set before the realization of the period t shocks. Solving the problem in (2) gives the input demand functions

$$(3) \qquad y_H^d(i, s^t) = \frac{[\omega_1 P(s^t)]^{\frac{1}{1-\rho}} \, P_H(s^{t-1})^{\frac{\rho-\theta}{(1-\rho)(\theta-1)}}}{P_H(i, s^{t-1})^{\frac{1}{1-\theta}}} y(s^t)$$

and

$$(4) \qquad y_F^d(i, s^t) = \frac{[\omega_2 P(s^t)]^{\frac{1}{1-\rho}} \, P_F(s^{t-1})^{\frac{\rho-\theta}{(1-\rho)(\theta-1)}}}{P_F(i, s^{t-1})^{\frac{1}{1-\theta}}} y(s^t),$$

where $P_H(s^{t-1}) = \left(\int_0^1 P_H(i, s^{t-1})^{\frac{\theta}{\theta-1}} di\right)^{\frac{\theta-1}{\theta}}$ and $P_F(s^{t-1}) = \left(\int_0^1 P_F(i, s^{t-1})^{\frac{\theta}{\theta-1}} di\right)^{\frac{\theta-1}{\theta}}$. Using the zero profit condition, we have that in a symmetric equilibrium with $P_H(i, s^{t-1}) = P_H(s^{t-1})$ for all i and $P_F(i, s^{t-1}) = P_F(s^{t-1})$ for all i,

$$P(s^t) = \left(\omega_1^{\frac{1}{1-\rho}} P_H(s^{t-1})^{\frac{\rho}{\rho-1}} + \omega_2^{\frac{1}{1-\rho}} P_F(s^{t-1})^{\frac{\rho}{\rho-1}}\right)^{\frac{\rho-1}{\rho}}.$$

Thus, in equilibrium, the price of the final good in period t does not depend on the period t shock.

The technology for producing each intermediate good i is a standard constant returns to scale production function $y_H(i, s^t) + y_H^*(i, s^t) = F(k(i, s^t), l(i, s^t))$, where $k(i, s^t)$ and $l(i, s^t)$ are the inputs of capital and labor, respectively, and $y_H(i, s^t)$ and $y_H^*(i, s^t)$ are the amounts of this intermediate good used in home and foreign production of the final good, respectively. Intermediate goods producers behave as imperfect competitors. They set prices for one period in local currency units and do so before the realization of event s_t. In particular, in period t, an intermediate goods producer of good i in the home country chooses a price $P_H(i, s^{t-1})$ in units of the home currency for goods sold in the home country and a price $P_H^*(i, s^{t-1})$ in units of the foreign currency for goods sold in the foreign country to maximize

$$\text{(5)} \qquad \max \sum Q(s^t|s^{t-1})\{\left[P_H(i, s^{t-1}) - P(s^t)v(s^t)\right] y_H^d(i, s^t) \\ + \left[e(s^t)P_H^*(i, s^{t-1}) - P(s^t)v(s^t)\right] y_H^{*d}(i, s^t)\},$$

where $Q(s^t|s^{t-1})$ is the price of one unit of local currency at s^t in units of local currency at state s^{t-1} and $e(s^t)$ is the nominal exchange rate. The term $v(s^t)$ is the unit cost of production given by

$$\text{(6)} \qquad v(s^t) = \min_{k,l} \ r(s^t)k + w(s^t)l$$

subject to $F(k, l) \geq 1$, where $r(s^t)$ is the rental rate on capital and $w(s^t)$ is the real wage rate. The solution to the problem stated in (5) is

$$P_H(i, s^{t-1}) = \frac{\sum Q\left(s^t|s^{t-1}\right) P(s^t) y\left(s^t\right) v(s^t)}{\theta \sum Q(s^t|s^{t-1}) y\left(s^t\right)},$$

$$P_H^*(i, s^{t-1}) = \frac{\sum Q(s^t|s^{t-1}) P(s^t) y^*\left(s^t\right) v(s^t)}{\theta \sum Q\left(s^t|s^{t-1}\right) y^*\left(s^t\right) e(s^t)}.$$

Consumer preferences in the home country are given by

$$\text{(7)} \qquad \sum_{t=0}^{\infty} \sum_{s^t} \beta^t \pi(s^t)\, U\left(c(s^t), l(s^t), M(s^t)/P(s^t)\right),$$

where $c(s^t)$, $l(s^t)$, and $M(s^t)$ are consumption, labor, and nominal money balances, respectively. There are complete markets in this economy for state-contingent money claims. We represent the asset structure by having complete contingent one-period nominal bonds denominated in the home currency. We let $B(s^{t+1})$ denote the home consumer's holdings of this bond. One unit of this bond pays one unit of the home currency if state s^{t+1} occurs and 0 otherwise. For notational simplicity, we assume that claims to the capital stock in each country are held by the residents of that country and cannot be traded.

In each period $t = 0, 1, \ldots$, consumers choose their period t allocations after the realization of the event s_t. The problem for consumers is to choose rules for consumption $c(s^t)$, labor $l(s^t)$, investment $x(s^t)$, nominal money balances $M(s^t)$, and one-period nominal bonds $B(s^{t+1})$ to maximize (7) subject to the sequence of budget constraints

$$\begin{aligned} & P(s^t)(c(s^t) + x(s^t)) + M(s^t) + \sum_{s_{t+1}} Q(s^{t+1}|s^t)B(s^{t+1}) \\ & \quad \leq P(s^t)\left[r(s^t)k(s^{t-1}) + w(s^t)l(s^t)\right] + M(s^{t-1}) + B(s^t) + \Pi(s^t) + T(s^t), \end{aligned}$$

the borrowing constraint $B(s^{t+1}) \geq -P(s^t)\bar{b}$, and the law of accumulation for capital

$$k(s^t) = (1-\delta)k(s^{t-1}) + x(s^t) - \phi\left(\frac{x(s^t)}{k(s^{t-1})}\right)k(s^{t-1}).$$

Here $\Pi(s^t)$ is the profits of the home country intermediate goods producers, $T(s^t)$ is transfers of home currency, and the positive constant $\bar{b}$ constrains the amount of real borrowing of the consumer. The function ϕ represents costs of adjusting the capital stock paid for by the consumers. The initial conditions $M(s^{-1})$, $k(s^{-1})$, and $B(s^0)$ are given. The first-order conditions for the consumer can be written as

$$(8) \qquad -\frac{U_l(s^t)}{U_c(s^t)} = w(s^t),$$

$$(9) \qquad \frac{U_m(s^t)}{P(s^t)} - \frac{U_c(s^t)}{P(s^t)} + \beta\sum_{s_{t+1}} \pi(s^{t+1}|s^t)\frac{U_c(s^{t+1})}{P(s^{t+1})} = 0,$$

$$(10) \qquad Q(s^t|s^{t-1}) = \beta\pi(s^t|s^{t-1})\frac{U_c(s^t)}{U_c(s^{t-1})}\frac{P(s^{t-1})}{P(s^t)},$$

$$\begin{aligned} (11) \qquad U_c(s^t) \quad = \quad & \beta\phi'(\frac{x(s^t)}{k(s^{t-1})})\sum \pi(s^{t+1}|s^t)U_c(s^{t+1})\Bigg\{r(s^{t+1}) + \Bigg[1-\delta \\ & +\phi(\frac{x(s^{t+1})}{k(s^t)}) + \phi'(\frac{x(s^{t+1})}{k(s^t)})\frac{x(s^{t+1})}{k(s^t)}\Bigg] / \phi'(\frac{x(s^t)}{k(s^{t-1})})\Bigg\}. \end{aligned}$$

Here $U_c(s^t)$, $U_l(s^t)$, and $U_m(s^t)$ denote the derivatives of the utility function with respect to its arguments, and $\pi(s^{t+1}|s^t) = \pi(s^{t+1})/\pi(s^t)$ is the conditional probability of s^{t+1} given s^t.

The problems of the final goods producers, the intermediate goods producers, and the consumers in the foreign country are analogous to these problems. Allocations and prices in the foreign country are denoted with an asterisk.

We find it useful to develop a relationship between the real exchange rate and marginal utilities of consumption of the consumers in the two countries which is implied by arbitrage. The budget constraint of the consumer in the foreign country is given by

$$P^*(s^t)(c^*(s^t) + x^*(s^t)) + M^*(s^t) + \textstyle\sum_{s_{t+1}} Q(s^{t+1}|s^t)B^*(s^{t+1})/e(s^t)$$
$$\leq P^*(s^t)\left[r^*(s^t)k^*(s^{t-1}) + w^*(s^t)l^*(s^t)\right] + M^*(s^{t-1}) + B^*(s^t)/e(s^t) + \Pi^*(s^t) + T^*(s^t),$$

where $B^*(s^t)$ denotes the foreign consumer's holdings of the home country bonds at s^t. The first-order condition with respect to bond holdings for the foreign consumer is

$$\frac{Q(s^t|s^{t-1})}{e(s^{t-1})} = \beta\pi(s^t|s^{t-1})\frac{1}{e(s^t)}\frac{U_c^*(s^t)}{U_c^*(s^{t-1})}\frac{P^*(s^{t-1})}{P^*(s^t)}.$$

Substituting for the bond price in this equation from the analogous condition for the home consumer and iterating, we obtain

$$\frac{U_c(s^t)}{U_c(s^0)}\frac{P(s^0)}{P(s^t)} = \frac{e(s^0)}{e(s^t)}\frac{U_c^*(s^t)}{U_c^*(s^0)}\frac{P^*(s^0)}{P^*(s^t)}.$$

Defining the real exchange rate as $q(s^t) = e(s^t)P^*(s^t)/P(s^t)$, we obtain

$$(12) \quad q(s^t) = \kappa\frac{U_c^*(s^t)}{U_c(s^t)},$$

where the constant $\kappa = e(s^o)U_c(s^0)P^*(s^0)/U_c^*(s^0)P(s^0)$ We use this relationship between real exchange rates and marginal rates of substitution in evaluating our model specification.

The money supply processes in the home and foreign countries are given by $M(s^t) = \mu(s^t)M(s^{t-1})$ and $M^*(s^t) = \mu^*(s^t)M^*(s^{t-1})$, where $\mu(s^t)$ and $\mu^*(s^t)$ are stochastic processes and $M(s^{-1})$ and $M^*(s^{-1})$ are given. New money balances of the home currency are distributed to consumers in the home country in a lump-sum fashion by having transfers satisfy $T(s^t) =$

$M(s^t) - M(s^{t-1})$. Likewise, the transfers of foreign currency to foreign consumers satisfy $T^*(s^t) = M^*(s^t) - M^*(s^{t-1})$.

In terms of market-clearing conditions, consider first the factor markets. Notice that the capital stock chosen by consumers in period $t-1$ for rental in period t is $k(s^{t-1})$, while the labor supply in period t is $l(s^t)$. In turn, each intermediate goods producer i chooses his factor demands after the realization of uncertainty s_t in period t, so the demands for capital and labor are $k(i, s^t)$ and $l(i, s^t)$, respectively. Factor market clearing thus requires that $k(s^{t-1}) = \int k(i, s^t)\, di$, and $l(s^t) = \int l(i, s^t)\, di$. The market-clearing condition for the contingent bonds is $B(s^t) + B^*(s^t) = 0$.

An *equilibrium* for this economy is a collection of allocations for home consumers $c(s^t)$, $l(s^t)$, $x(s^t), k(s^t)$, $M(s^t)$, $B(s^{t+1})$; allocations for foreign consumers $c^*(s^t)$, $l^*(s^t)$, $x^*(s^t)$, $k^*(s^t), M^*(s^t)$, $B^*(s^{t+1})$; allocations and prices for home intermediate goods producers $y_H(i, s^t)$, $y_H^*(i, s^t)$ and $P_H(i, s^{t-1})$, $P_H^*(i, s^{t-1})$ for $i \in [0, 1]$; allocations and prices for foreign intermediate goods producers $y_F(i, s^t)$, $y_F^*(i, s^t)$ and $P_F(i, s^{t-1})$, $P_F^*(i, s^{t-1})$ for $i \in [0, 1]$; and allocations for home and foreign final goods producers $y(s^t), y^*(s^t)$, final goods prices $P(s^t)$, $P^*(s^t)$, real wages $w(s^t)$, $w^*(s^t)$, rental rates $r(s^t), r^*(s^t)$, and bond prices $Q(s^{t+1}|s^t)$ that satisfy the following five conditions: (i) consumer allocations solve the consumers' problem; (ii) the prices of each intermediate goods producer solve (5); (iii) the final goods producers' allocations solve the final goods producers' problem; (iv) the market-clearing conditions for capital and bonds hold; and (v) the money supply processes and transfers satisfy the specifications above.

In what follows, we will focus on the symmetric equilibrium in which all the intermediate goods producers in the same country make identical decisions. We are interested in a stationary equilibrium and thus restrict the stochastic processes for the growth rates of the money supplies to be Markovian. To make the economy stationary, all nominal variables are deflated by the level of the relevant money supply. A stationary equilibrium for this economy consists of stationary decision rules and pricing rules which are functions of the state of the economy. The state of the economy at the time monopolists make their pricing decisions (that is, before the event s_t is realized) must record the capital stocks in the two countries, together with the shocks from period $t-1$. The shocks from period $t-1$ are needed because they help forecast the shocks in period t. Thus the aggregate state for the monopolists is $X_{mt} = [k(s^{t-1}), k^*(s^{t-1}), \mu(s^{t-1}), \mu^*(s^{t-1})]$. The state of the economy at the time the rest of the decisions are made (that is, after the event s_t is realized) also includes the current shocks. The aggregate state for the consumers is, therefore, $X_t = [X_{mt}, \mu(s^t), \mu^*(s^t)]$. We compute the equilibrium using standard methods to obtain linear decision rules. For the benchmark preferences with one-quarter price stickiness, we checked the accuracy of the linear decision rules against nonlinear decision rules obtained by the finite element method. (See McGrattan (1996).)

3. Calibration

We consider a benchmark utility function of the form

$$U(c, l, M/P) = \left[(ac^{\nu} + (1-a)(M/P)^{\nu})^{\frac{\gamma}{\nu}} (1-l)^{1-\gamma}\right]^{1-\sigma} /(1-\sigma)$$

and a production function of the form $F(k, l) = Ak^{\alpha}l^{1-\alpha}$. The parameter values that we use are reported in Table 6a. Consider first the preference parameters. The discount factor β was set so as to give an annual real interest rate of 4%. The share parameter γ was set so that the elasticity of labor supply, holding constant the marginal utility, is around 2 and the time devoted to work is about 1/4 of total time. There is a wide range of estimates in the literature for the curvature parameter σ. We set it to 2 and did a variety of sensitivity experiments.

To obtain a and ν, we draw on the money demand literature. Our model can be used to price a variety of assets, including a nominal bond which costs one dollar at s^t and pays $R(s^t)$ dollars in all states s^{t+1}. The first-order condition for this asset can be written as $U_m(s^t) = U_c(s^t)(R(s^t) - 1)/R(s^t)$. When we use our benchmark specification of utility, the first-order condition can be rewritten as

$$(13)\quad \log\frac{M(s^t)}{P(s^t)} = -\frac{1}{1-\nu}\log\frac{a}{1-a} + \log c(s^t) - \frac{1}{1-\nu}\log\left(\frac{R(s^t)-1}{R(s^t)}\right).$$

which has the form of a standard money demand function with consumption and interest rates. To obtain ν we ran a quarterly regression from 1960:1 to 1995:4 in which we used $M1$ for money, the GDP deflator for P, consumption of durables, nondurables and services for c, and the three-month Treasury bill rate for R. We set $-1/(1-\nu)$ equal to our estimate of the interest elasticity of money demand (-0.39) and obtain $\nu = -1.56$. To obtain a, we set $M(s^t)/(P(s^t)c(s^t))$ equal to the average ratio of M1 to quarterly nominal consumption expenditures in the postwar period (1.2), and we set $R(s^t)$ equal to the average quarterly yield on three-month Treasury bills in the postwar period (that is, $R(s^t) = 1.0495^{\frac{1}{4}}$). Substituting these values into (13) yields $a = 0.73$.

Consider next the technology parameters. We set the capital share parameter $\alpha = 1/3$, as is standard in the real business cycle literature. We calibrate θ as follows. Consider a symmetric steady state of our model with $\overline{\mu} = 1$. In such a steady state, $P_H = P_F = P$ and the markup of price to marginal cost is $P_H/Pv = 1/\theta$. Let the real profits of intermediate goods producers in the steady state be denoted by Π. In the steady state, $\Pi = y - vy$, where y is output and v is unit cost. From the pricing equation, it follows that in a steady state, $v = \theta$ so that $\Pi/y = 1-\theta$. To obtain an estimate of Π/y, we use the price-cost margin data of Domowitz, Hubbard, and Petersen (1986). They measure the price-cost margin as (*value added* $-$ *payroll*)/(*value added* + *cost of materials*). The average price-cost margin across a sample of manufacturing industries is approximately 1/4. In the steady state of our model, (*value added* $-$ *payroll*) $= \Pi + (r+\delta)k$, where r and k are the steady-state rental rate on capital and the capital stock, respectively. Jorgenson, Gollop, and Fraumeni (1987) show that the cost of materials is approximately equal to value added in U.S. manufacturing. Using these facts, we obtain $(\Pi + (r+\delta)k)/y = 1/2$. In the steady state of our model, $r + \delta = 0.14$ and $k/y = 2.8$. Using these numbers in the above equations, we obtain $\theta = 0.9$ (that is, a markup of about 11%).

In our model, the elasticity of substitution between home goods and foreign goods is $1/(1-\rho)$. There is a range of estimates for this parameter. The most reliable studies seem to indicate that for the United States the elasticity is between 1 and 2, and values in this range are generally used in empirical trade models (see, for example, the survey by Stern et. al. 1976). For an aggregate of Europe the elasticity seems to be smaller (see, for example, the discussions of Deardoff and Stern 1990, Ch. 3 and Whalley 1985, Ch. 5.) We follow the work of Backus, Kehoe, and Kydland (1994) and use an elasticity of 1.5. To set ω_1 and ω_2, note that in a symmetric steady state, $y_H/y_F = [\omega_1/\omega_2]^{\frac{1}{1-\rho}}$. In U.S. data, imports from Europe are roughly 1.6% of GDP. This implies that $y_H/y_F = 0.984/0.016$. Together with our normalization, this gives the values of ω_1 and ω_2.

We consider an adjustment function of the form $\phi(x/k) = b(x/k-\delta)^2/2$. Notice that with this specification at the steady state, both the costs of adjustment and the marginal costs of adjustment are 0. There is a great deal of uncertainty about the size of these adjustment costs. In all of our experiments, we choose b so that the standard deviation of investment relative to the standard deviation of output is equal to that in the data. One measure of the size of the adjustment costs is the resources used up in adjusting capital relative to the net increment in the capital stock given by $b(x_t/k_t-\delta)^2 k_t/(2[k_{t+1}-(1-\delta)k_t])$. In Table 6b, we report the values of the adjustment cost parameter and the resources used up in adjustment for the four experiments that we report later.

There is extensive debate on the details of the monetary rule followed in the United States and Europe. Here we assume the monetary authority follows a particularly simple rule, namely, that the growth rate of the money stock for both countries follows a process of the form

(14) $$\log \mu_t = \rho_\mu \log \mu_{t-1} + (1-\rho_\mu)\log \overline{\mu} + \epsilon_{\mu t},$$

where ϵ_μ is a normally distributed mean zero shock with a standard deviation σ_μ. The stochastic process for money in the foreign country is the same. In all but one set of experiments, we assume that the two processes for money are independent. We assume this because there is essentially no correlation between the growth rates of money in the United States and Europe. The parameters governing the stochastic process for money growth are obtained from running a regression of the form (14) on quarterly data on U.S. data for M1 from 1973 through 1995 and are obtained from Citibase. We obtain $\overline{\mu} = (1.06)^{1/4}$, $\rho_\mu = 0.57$, and $\sigma_\mu = 0.0092$.

4. Findings

In Tables 7 and 8, we report on the Hodrick-Prescott filtered statistics for the data and the benchmark economy. From these statistics, it is clear that this model does not generate the kind of persistence and variability of exchange rates that we see in the data. In our model, real exchange rates show little persistence because prices are set for only one quarter at a time. One way to increase persistence is to have prices set for many periods at a time. With simultaneous price setting, the price level moves infrequently but by large amounts. This is contrary to the data. One way to have slow movement of the price level is to have prices set for many periods at a time but in a staggered fashion. (See Taylor (1980); Blanchard (1983); and Chari, Kehoe, and McGrattan (1996) for models with staggered price setting.)

Consider a version of our model in which the intermediate goods producers set prices for N periods and do so in a staggered fashion. In particular, in each period t, a fraction $1/N$ of the home country producers choose a home currency price $P_H(i, s^{t-1})$ for the home market and a foreign currency price $P_H^*(i, s^{t-1})$ for the foreign market before the realization of the event s_t. These prices are set for N periods, so for this group of intermediate goods producers, $P_H(i, s^{t+\tau-1}) = P_H(i, s^{t-1})$ and $P_H^*(i, s^{t+\tau-1}) = P_H^*(i, s^{t-1})$ for $\tau = 0, \ldots, N-1$. The intermediate goods producers are indexed so that producers indexed $i \in [0, 1/N]$ set new prices in 0, N, $2N$, and so on, while producers indexed $i \in [1/N, 2/N]$ set new prices in 1, $N+1$, $2N+1$, and so on, for the N cohorts of intermediate goods producers. In period t, each producer in a cohort chooses prices $P_H(i, s^{t-1})$ and $P_H^*(i, s^{t-1})$ to maximize discounted profits from periods t to $t+N-1$. That is, each intermediate goods producer solves

$$(15) \qquad \max_{\substack{P_H(i,s^{t-1}) \\ P_H^*(i,s^{t-1})}} \sum_{\tau=t}^{t+N-1} \sum_{s^\tau} Q(s^\tau | s^{t-1}) \{ \left[P_H(i, s^{t-1}) - P(s^\tau) v(s^\tau) \right] y_H(i, s^\tau) + \left[e(s^\tau) P_H^*(i, s^{t-1}) - P(s^\tau) v(s^\tau) \right] y_H^*(i, s^\tau) \},$$

where $Q(s^\tau | s^{t-1})$ is the price of one unit of home currency in s^τ in units of the home currency at s^{t-1}, $y_H(i, s^t)$ and $y_H^*(i, s^t)$ are given in (3) and (4), and $v(s^t)$ is the unit cost of production given in (6). In what follows, we focus on the symmetric equilibrium in which all the intermediate goods producers of the same cohort make identical decisions. Thus $P_H(i, s^{t-1}) = P_H(j, s^{t-1})$, $P_H^*(i, s^{t-1}) = P_H^*(j, s^{t-1})$, $y_H(i, s^t) = y_H(j, s^t)$, and $y_H^*(i, s^t) = y_H^*(j, s^t)$ for all $i, j \in [0, 1/N]$, and so on, for the N cohorts.

We consider a version of the model in which prices are set for six quarters in a staggered fashion. In Table 7, we report on the statistics for an economy with the benchmark preferences and six-quarter price stickiness. We see that introducing staggered price setting raises the serial correlation of the real exchange rate but raises its variability only slightly.

In order to understand why real exchange rates show such little variability relative to output, it is helpful to log-linearize (12) to obtain

$$(16) \quad \hat{q} = A(\hat{c} - \hat{c}^*) + B(\hat{m} - \hat{m}^*) + D(\hat{l} - \hat{l}^*),$$

where a caret denotes the deviation from the steady state of the log of the variable and m, m^* denote real balances. The coefficients are given by

$$A = -\frac{cU_{cc}}{U_c}, \; B = -\frac{mU_{cm}}{U_c}, \; D = -\frac{lU_{cl}}{U_c},$$

evaluated at the steady state. For our benchmark preferences, these coefficients are $A = 1.4$, $B = -0.1$, and $D = -0.2$. From (16), we see that there are two factors which make the impact effect on real exchange rates small. The first factor is that the coefficient on consumption is small so that by itself, a 1% rise in consumption is associated with only a 1.4% depreciation in the real exchange rate. The second factor is that D is negative so that the increase in employment upon impact mitigates the depreciation of the real exchange rate. We ignore the coefficient on money since it plays a quantitatively minor role.

Intuitively, one might think that raising σ would raise A and therefore the variability of the real exchange rate. While raising σ does indeed raise A, it does not raise the variability of the real exchange rate because it increases the magnitude of D. To see this, note that for our benchmark preferences, $A = 1-\nu+[\nu+\gamma(\sigma-1)]/[1+\frac{1-a}{a}\frac{m^{\nu}}{c^{\nu}}]$, $D = -(1-\gamma)(\sigma-1)l/(1-l)$. We experimented with increasing σ and found that it had little effect on the volatility of real exchange rates.

There is another sense in which the model with the benchmark preferences cannot reproduce the variability of real exchange rates seen in the data. Suppose that the model produces the same variances and covariances for consumption, real balances, and employment as in the data. Then the standard deviation of the real exchange rate implied by the model is the standard deviation of the right-hand side of (16). Using the model's values for the A, B and D and the data for the various variance and covariance terms, we find that the standard deviation implied by (16) is 1.81, which is roughly a quarter of the standard deviation of the real exchange rate in the data. (In addition to the data previously described, this calculation uses money data. See the appendix for details on these data.)

These considerations suggest a modification of our preferences which has the effect of raising the coefficient on consumption and reducing that on employment. Consider the following preferences, referred to as our *preferred* preferences:

$$U(c,l,M/P) = \left[(ac^{\nu} + (1-a)(M/P)^{\nu})^{\frac{1}{\nu}}\right]^{1-\sigma}/(1-\sigma) + \psi(1-l)^{(1-\xi)}/(1-\xi).$$

With these preferences, $D = 0$ and A is increasing in σ. We set ψ so that the fraction of time allocated to the market is 1/4. We set ξ so that the labor supply elasticity is 2. In Figure 4, we plot the volatility and persistence of real exchange rates against σ for these preferences. This figure shows that the variability of real exchange rates rises with σ and the persistence of real exchange rates does not change. With $\sigma = 6$, the variability of real exchange rates in the model is similar to that in the data. In Tables 7 and 8, we report statistics for our preferred preferences model with $\sigma = 6$ and with $N = 6$, that is, six-quarter price stickiness.

From these tables, we see that the nominal exchange rate is about 4 times as variable as output and the real exchange rate is 4.1 times as variable as output. These values are close to the corresponding ones in the data (4.7 and 4.4). However, the persistence of nominal and real exchange rates in the model (0.69 and 0.67) is still less than in the data (0.86 and 0.83). One reason why the persistence of real exchange rates is too low is that the persistence of consumption is too low, as can be seen from Table 8. This table also shows that foreign and domestic macroeconomic aggregates are not correlated in the model, while they are in the data.

To get some intuition for these results, consider the impulse responses to a 1% money shock given in Figures 5–9. Figures 5-8 graph the percent deviations of the relevant variables from their steady state values, while Figure 9 graphs the level of the nominal and real interest rates. In these figures, we see that on impact, consumption rises by 1/2%, real balances rise by 1%, and foreign aggregates hardly change. Since for our preferred preferences $A = 5.8$, $B = 0.2$, and $D = 0$, from (16), we would expect that the real exchange rate would depreciate by 2.5%, as indeed it does. Since output only rises by 1.1% on impact, it should be clear that this model can generate substantial volatility in real exchange rates relative to output.

The model also implies substantial volatility in nominal exchange rates. Since prices are sticky in the short run, nominal and real exchange rates must move together so if real exchange rates are volatile relative to output, then the nominal rates are volatile relative to output as well. We can also think about the volatility of nominal exchange rates relative to the money shocks. In the data, nominal exchange rates move much more than do money supplies. Thus, if money shocks are to account for most of the movements in exchange rates, the effects of money shocks on exchange rates must be magnified. (In Dornbusch's (1976) terminology, exchange rates must overshoot.) Figure 8 shows that on impact the nominal exchange rate overshoots its long-run value. One way to think about this magnification effect is to use the consumers' first-order conditions to obtain

$$e_1 = \left[\frac{Q_1 Q_2 \cdots Q_{t-1}}{Q_1^* Q_2^* \cdots Q_{t-1}^*}\right] e_t,$$

where Q_t is the price of a one-period bond in units of the home currency issued at t and Q_t^* is the price of a one-period bond in units of the foreign currency issued at t, where, for simplicity, we have dropped uncertainty. In this model in the long run, the nominal exchange rate, e_t, moves as much as the money supply, about 2.3% for large t. In response to domestic monetary shocks, foreign interest rates typically do not change very much. The only way to obtain a magnification effect is for money shocks to lead to large or persistent decreases in nominal interest rates (increases in bond prices). That is, we need a liquidity effect in our model. Figure 9 shows that there is indeed a liquidity effect in our model. Even though this liquidity effect is small it persists long enough so that the exchange rate on impact changes much more than the long run exchange rate.

The two main shortcomings of the model are that the serial correlation of real exchange rates is lower than in the data and the cross correlation of standard aggregates, like output and investment, are lower than in the data. We experiment with changing the parameter values both to see how the model's predictions for these statistics change and to check on the sensitivity of our results. We focus on changing the length of price stickiness and changing the specification of the money shock process because these changes seem the most likely candidates to affect these statistics. Moreover, we have very little prior information on these two features of the model.

Consider first increasing the length of price stickiness. In the last columns of Tables 7 and 8, we report on an experiment with 12 quarters of price stickiness and with our preferred preferences. In the tables, we see that increasing the price stickiness from 6 to 12 quarters increases the serial correlation of real exchange rates from 0.67 to 0.77 with little effect on other statistics.

As we mentioned above, there is extensive debate on the details of the money supply process followed by monetary authorities. To get a better feel for the workings of our model, we experiment with alternative money supply processes. We are interested in determining if increasing the serial correlation of money growth shocks will increase the serial correlation of real exchange rates. To do so, we increase the serial correlation of the money growth rates by increasing ρ_μ from 0.57 to 0.8. In unreported work, we find that this change raises the serial correlation of real exchange rates a small amount from 0.67 to 0.70, increases the volatility of real exchange rates relative to output from 4.1 to 4.3, and has little effect on other variables.

With the specifications of the money supply process we have considered so far, there is little correlation between domestic and foreign aggregates. Under these specifications, the only reason why we would expect comovement between aggregates is that monetary shocks in one country had a large transmission effect abroad. With our calibrated trade shares, this transmission effect is small and the resulting comovements are small. Allowing money shocks to be positively correlated across countries introduces another channel for generating positive comovements across countries. We increase the correlation between the money growth rates by increasing the correlation between the home and foreign money supply innovations. We do so in order to get a feel for how comovements in monetary aggregates affect comovements in macroeconomic aggregates.

In Figure 10, we plot some statistics from the resulting economies. (None of the other statistics changes very much.) We see that increasing the correlation of the money shocks increases the cross-country correlation of both output and consumption. Interestingly, the cross-country correlation of consumption is smaller than that of output as in the data. Thus this model does not yield the quantity anomaly problems that arise in standard real business cycle models. (See Backus, Kehoe, and Kydland (1992).) We think of these experiments as suggesting that the details of the comovements of monetary policy across countries is important for the comovements of aggregates.

5. Incomplete Markets

In this section, we investigate whether making asset markets incomplete can lead to volatile and persistent exchange rate movements. In terms of volatility, the idea is that with incomplete markets, the simple static relationship between the real exchange rate and the ratio of the marginal utilities given in (12) no longer holds so that even with our benchmark preferences, the real exchange rate could potentially be volatile. In terms of persistence, the idea is that with incomplete markets, monetary shocks lead to permanent wealth redistributions and hence to persistent real exchange rate movements. These permanent wealth redistributions could lead to persistence even with short stickiness.

It turns out that it is very difficult to compute equilibria for incomplete market models with capital and other assets. (See Rios-Rull (1997).) Therefore, we consider a version of our benchmark model with no capital in which the only asset is a state uncontingent nominal bond denominated in home country currency units. (It seems likely that adding more assets, such as foreign currency denominated debt or capital, would move the economy closer to complete markets.) In Tables 9 and 10, we present statistics for both the complete market and the incomplete market version of our model with benchmark preferences and with one-quarter price stickiness. As is evident, there is almost no difference between the two versions.

It turns out that the wealth effects in our models are very small. To see why consider starting in a steady state in which net claims on foreigners are zero. For the home country to increase its wealth, it must increase its net exports. The home country's net exports are given by

$$(17) \quad NX_t = e_t P^*_{Ht} c^*_{Ht} - P_{Ft} c_{Ft},$$

where c^*_{Ht} are the exports of home produced goods and c_{Ft} are the imports of foreign produced goods. With sticky prices, a positive money shock in the home country leads to a depreciation of the exchange rate e_t, a rise in domestic consumption of all goods, including c_{Ft}, and essentially no change in foreign consumption, including c^*_{Ht}. Since the prices foreigners pay for home exports is fixed in the foreign currency the depreciation of the home currency leads to a rise in export earnings. This rise in export earnings helps pay for the rise in imports that comes from increased home demand for foreign goods. Indeed, for a version of our model, it turns out that the rise in export earnings exactly pays for the rise in imports so that money shocks lead to no wealth redistributions at all. We find it instructive to work through the details of such a version.

Consider a deterministic version of our model with a utility function of the form

$$U(c, l, M/P) = \log c + \gamma \log(1 - l) + \phi \log M/P.$$

Starting from a steady state with zero debt, we suppose that a one-time unanticipated monetary shock of 1% in the home country occurs in period 1 and is constant thereafter. We show that such a shock leads to the following outcomes. In period 1, net exports are zero, home consumption of both home and foreign goods rises by 1%, foreign consumption is unaffected, and the real and nominal exchange rates depreciate by 1%. In the following period, the economy returns to a new steady state with the same real allocations as in the old steady state. The domestic price level rises by 1% and the nominal exchange rate stays at its depreciated level, while the real exchange rate returns to its old steady-state level. In order for these outcomes to constitute an equilibrium, debt at the end of period 1 should be zero or, equivalently, net exports in period 1 must be zero.

Suppose, by way of contradiction, that net exports are positive in period 1 so that the home country's wealth rises. Since there are no state variables besides debt, the economy returns to a new steady state in period 2 with the home country richer. We will show that since the home country is richer, then in period 1 the exchange rate depreciates by less than 1%, domestic consumption rises by 1%, and foreign consumption is unaffected. From (17), it follows that net exports in period 1 must actually be negative, which implies that in the new steady state, the home country is poorer. This is a contradiction. (A similar argument shows that in the new steady state, the home country cannot be poorer.)

First note that if net exports in period 1 are positive, the home country's wealth in the new steady state is greater than in the old steady state, and hence the home country's consumption and final goods production is higher in the new steady state and the foreign country's consumption and final goods production is lower.

We next show that the nominal exchange rate in period 1 depreciates by less than 1%. We do this by working backward from the new steady state. Since home final goods use home produced intermediate goods disproportionately, market clearing requires that the price of home produced intermediate goods rise relative to the price of foreign-produced intermediate goods, and thus the real exchange rate appreciates. To see what happens to the nominal exchange rate in the new steady state, substitute the money demand equation evaluated at the new steady state $M_{ss}/P_{ss} = \phi c_{ss}/(1 - Q_{ss})$ and its foreign analogue into the relationship $q_{ss} = e_{ss}P^*_{ss}/P_{ss}$ to obtain

$$e_{ss} = q_{ss}\frac{c^*_{ss}}{c_{ss}}\frac{M_{ss}}{M^*_{ss}},$$

where the subscript ss denotes steady-state values. Relative to the old steady state, the nominal exchange rate must depreciate by less than the money supply increase (1%) because $q_{ss}c^*_{ss}/c_{ss}$ falls. Working backwards we show that $e_1 = e_{ss}$ so that the impact effect on the exchange rate is the same as the steady-state effect. We begin by considering the money demand equation and the bond price equation in the home country given by

$$(18) \quad \frac{M_t}{P_t} = \frac{\phi c_t}{1 - Q_t}$$

and

$$(19) \quad Q_t = \beta \frac{P_t c_t}{P_{t+1} c_{t+1}}.$$

Substituting for c_t from (18) into (19) and using $M_{t+1} = M_t$ for $t \geq 1$, we obtain $Q_t = \beta(1 - Q_t)/(1 - Q_{t+1})$. This difference equation has a unique, unstable steady state β. Since $Q_0 = \beta$, it follows that $Q_1 = Q_2 = Q_0 = \beta$. Likewise, $Q_1^* = Q_2^* = Q_0^* = \beta$. Next, in a deterministic model, interest rate parity holds from period 1 onward, $Q_t = Q_t^* e_t / e_{t+1}$. Since $Q_1 = Q_1^*$, it follows that $e_1 = e_2 = e_{ss}$, and thus, on impact the exchange rate depreciates by less than the money supply increase.

Finally, we show that domestic consumption rises by 1% and that foreign consumption is unaffected. To see this note that since in period 1 prices have already been set, it follows from (18) that c_1 rises by 1% and by a similar argument that c_1^* is unchanged. Since the relative price of home to foreign goods has not changed in the impact period, it follows from (4) that c_{F1} rises by 1% and c_{H1}^* is unchanged.

In sum, if in the new steady state the home country is richer, then in period 1 the exchange rate depreciates by less than 1%, domestic consumption rises by 1%, and foreign consumption is unaffected. From (17), it follows that net exports in period 1 must actually be negative, which implies that in the new steady state, the home country is poorer. This is the contradiction. A similar argument shows that in the new steady state, the home country cannot be poorer.

6. Preference Specification and Balanced Growth

Our two specifications of preferences have very different implications for the volatility of real exchange rates. In this section, we show that these specifications have very different implications for the type of growth paths the models generate.

To study these implications for growth paths, we suppress uncertainty and add labor-augmenting technical change z_t so that the technology for each intermediate goods producer is given by $F(k_t, z_t l_t)$, where z_t grows at a constant rate g. We say that our economies are on a balanced growth path if output, consumption, real balances, the capital stock, and wages all grow at rate g, while labor and interest rates are constant. Inspecting (8)–(11), we show that in order for there to be a balanced growth path, three key conditions must be satisfied: U_{lt}/U_{ct} must be homogeneous of degree 1 in c_t and m_t when l_t is held fixed; U_{mt}/U_{ct} must be homogeneous of degree 0 in c_t and m_t when l_t is held fixed; and U_{ct+1}/U_{ct} must be homogeneous of degree 0 in c_t and m_t when $c_{t+1} = (1+g)c_t$ and $m_{t+1} = (1+g)m_t$ when labor is held fixed. For our benchmark preferences, it is easy to verify that a balanced growth path exists.

Our preferred preferences violate the condition that U_{lt}/U_{ct} is homogeneous of degree 1 (except when $\sigma = 1$). Thus a balanced growth path does not exist. To get some intuitive feel for the extent to which the economy is far from a balanced growth path, suppose that consumption, real balances, and wages grow at 2% a year. Then with our preferred parameter values, it is easy to show that leisure grows at 7.5% per year so that if leisure is initially 3/4 of the time endowment, within four years, leisure uses up the entire time endowment and labor supply is zero.

On the face of it, this violation is very troublesome. An important feature of the model that leads to this violation is that technical progress raises the productivity of time allocated in the market sector but does not raise the productivity of time allocated to nonmarket activities. In the spirit of Becker (1976), suppose that technical progress raises the productivity of time allocated to nonmarket activities so that an input of $(1 - l_t)$ units of time outside the market produces $z_t(1 - l_t)$ units of leisure services. With this formulation, it is easy to show that

$$-\frac{U_{lt}}{U_{ct}} = \frac{\psi(1+g)^{(1-\xi)t}(1-l_t)^{-\xi}}{ac_t^{\nu-1}\left[ac_t^{\nu} + (1-a)m_t^{\nu}\right]^{\frac{1-\sigma}{\nu}-1}}.$$

If c_t and m_t grow at the same rate as z_t and l_t is a constant, then

$$-\frac{U_{lt}}{U_{ct}} = \kappa \frac{(1+g)^{(1-\xi)t}}{(1+g)^{-\sigma t}},$$

where κ is a constant. Along a balanced growth path, wages grow at the same rate as z_t so that in order for there to be a balanced growth path, we need $\sigma = \xi$.

The parameter ξ, together with the fraction of time allocated to the market, determines the Frisch elasticity of labor supply. If the fraction of time allocated to the market is 1/4, then this labor supply elasticity is $3/\xi$. The balanced growth restriction $\sigma = \xi$ thus connects the labor supply elasticity to the intertemporal elasticity of substitution in consumption. In our earlier experiments when we varied σ, we left ξ unchanged. We conducted experiments in which as we varied σ we changed ξ so that the balanced growth restriction held. We found that imposing this balanced growth restriction made little difference for our results. It is worth noting that with $\sigma = \xi = 6$, the implied labor supply elasticity is 1/2, which is within the wide range of estimates of the labor supply elasticity.

7. Conclusion

The central puzzle in international fluctuations is the evidence of large and persistent deviations of exchange rates from purchasing power parity. In this paper, we have found that we need separable preferences, high risk aversion, and long price stickiness in order for monetary shocks to generate large and persistent fluctuations in exchange rates. We also showed that if monetary shocks are correlated across countries, then the comovements in aggregates across countries are broadly consistent with those in the data.

Data Appendix

Our measures of exchange rates between the United States and Europe are constructed as follows. We obtain nominal exchange rate data measured as dollars per unit of foreign currency for each of the nine European countries. Our constructed index e_t between Europe and the United States is a trade-weighted average of the bilateral exchange rates, $e_t = \sum_{i=1}^{7} \omega_i e_{it}/e_{i0}$, where e_{it} is the exchange rate for country i in period t, e_{i0} is the exchange rate for country i in the first quarter of 1972, and the weight ω_i is the time series average of the ratio of the dollar value of exports plus imports between country i and the United States to the total dollar value of all exports plus imports between the eight European countries and the United States. We construct a price index for the European countries denoted P_t^* in an analogous fashion using each country's CPI. The real exchange rate index is defined to be $q_t = e_t P_t^*/P_t$, where P_t is the price index in the United States with the first quarter of 1972 normalized to be 1. All of our data are obtained from DRI's International Monetary Fund database. Details are available upon request.

We also construct a time series for output, consumption, investment, and employment for Europe. For each country, we obtain output, consumption, and investment in 1990 local currency units. We convert these series into dollars using the 1990 PPP exchange rate from the OECD Main Economic Indicators and add them to obtain our aggregates for Europe. Since employment data for Spain are not available, employment for Europe is the sum of the employment in the eight remaining countries.

We construct a time series for a European monetary aggregate using the trade-weighting procedure described above. Data availability limits us to using M1 data (series 34) for France, Germany, and Italy. For the United States, we also use M1 data (series 59).

All the data reported in our tables and figures are logged, except for net exports, which are calculated as the ratio of nominal net exports to nominal GDP. The transformed data are then HP-filtered.

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Figure 1

Exchange Rates and Price Ratio
Between the United States and Europe

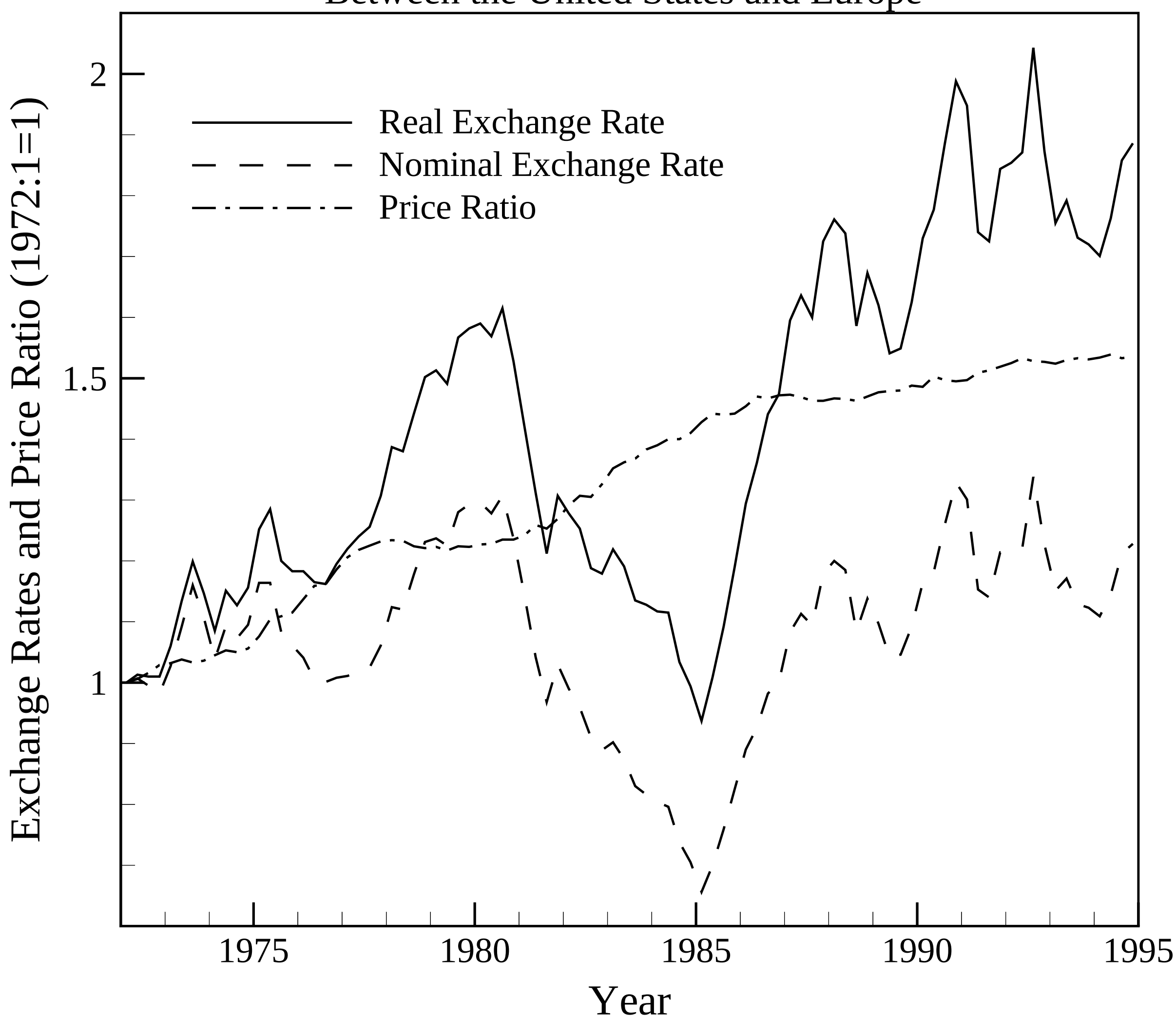

Figure 2
Real Exchange Rate Components Using CPI's

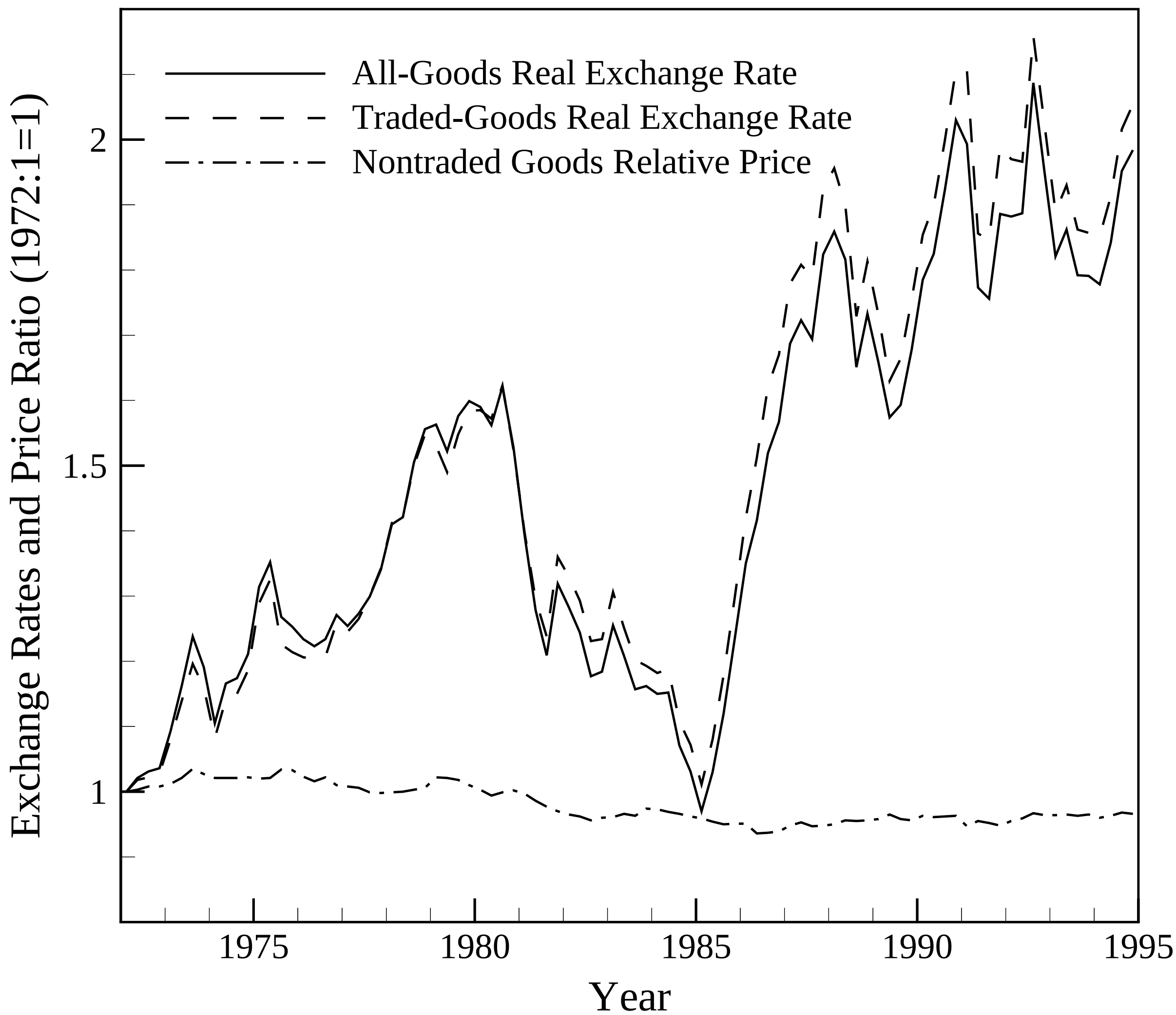

Figure 3

Real Exchange Rate Components Using Deflators

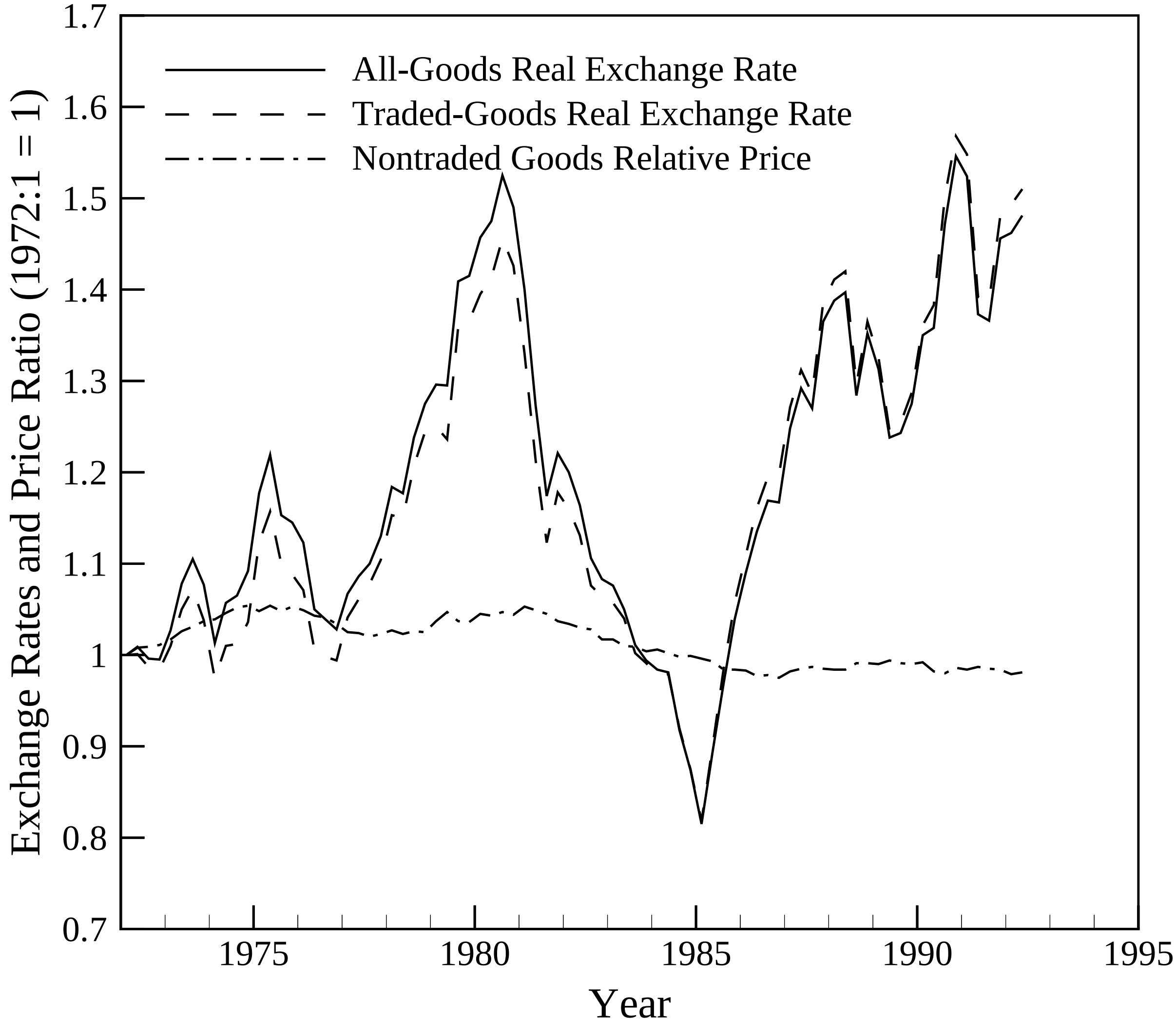

Figure 4

Real Exchange Rate Properties vs. Utility Parameter

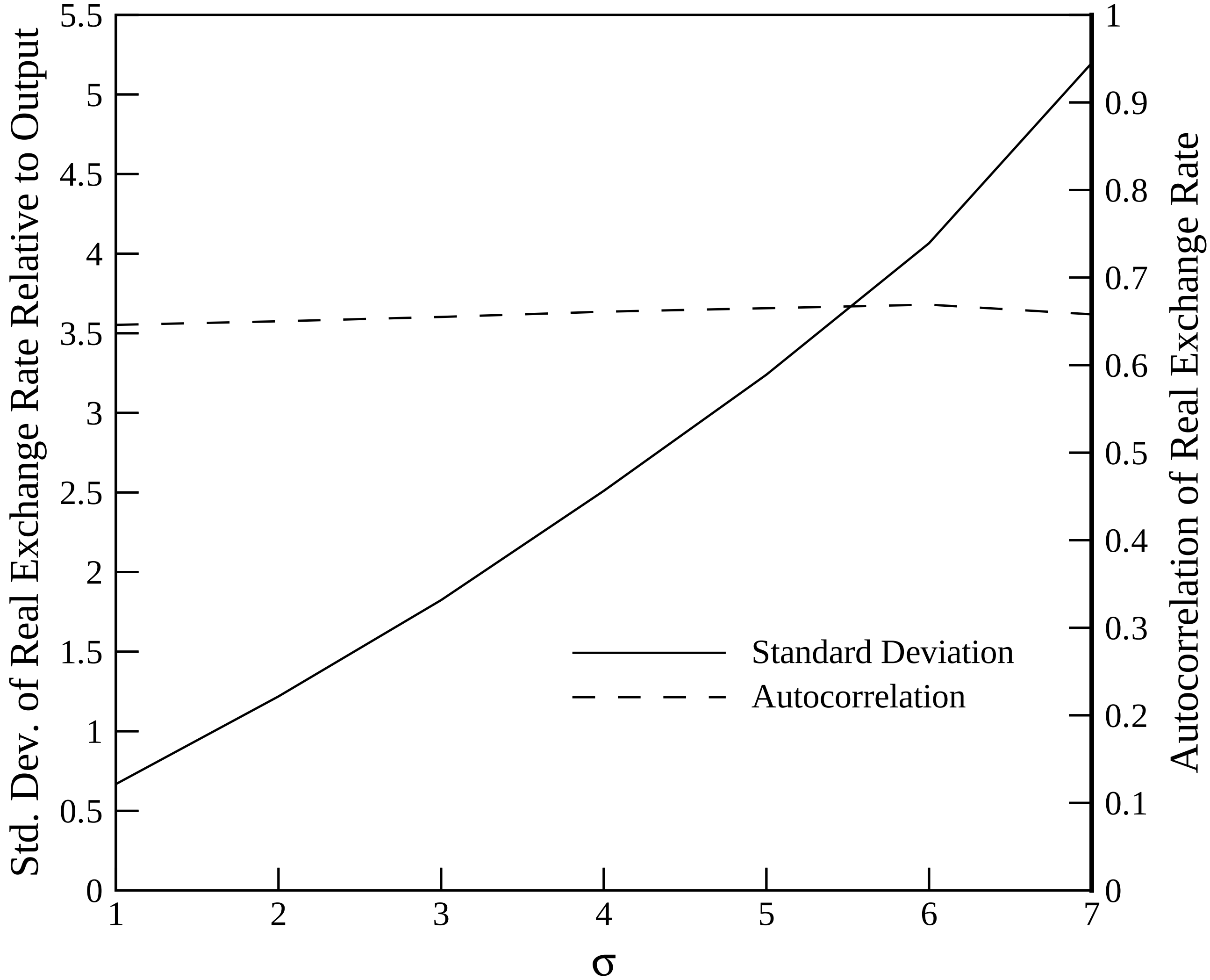

Figure 5

Preferred: Home Country Impulse Responses

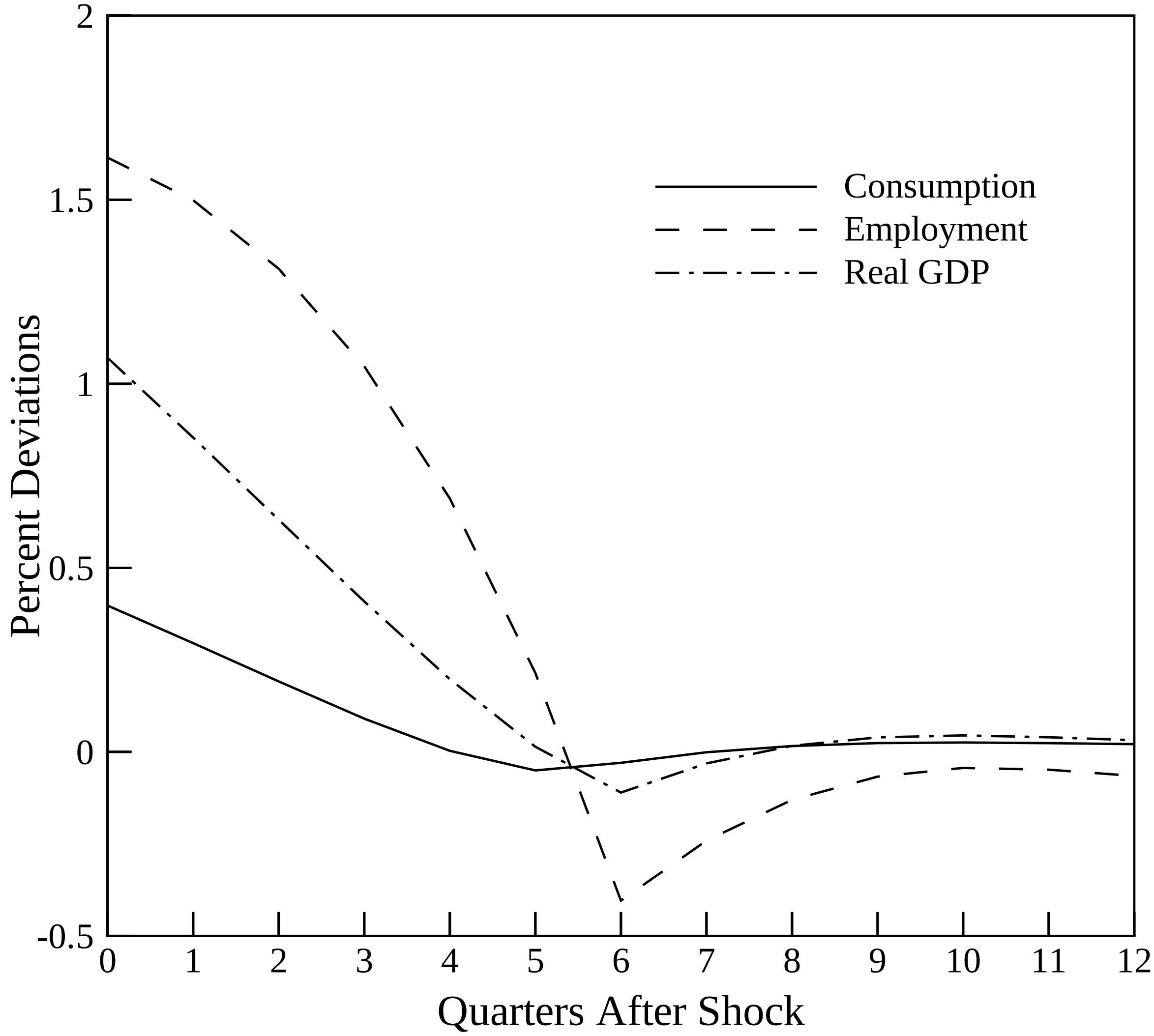

Figure 6

Preferred: Foreign Country Impulse Responses

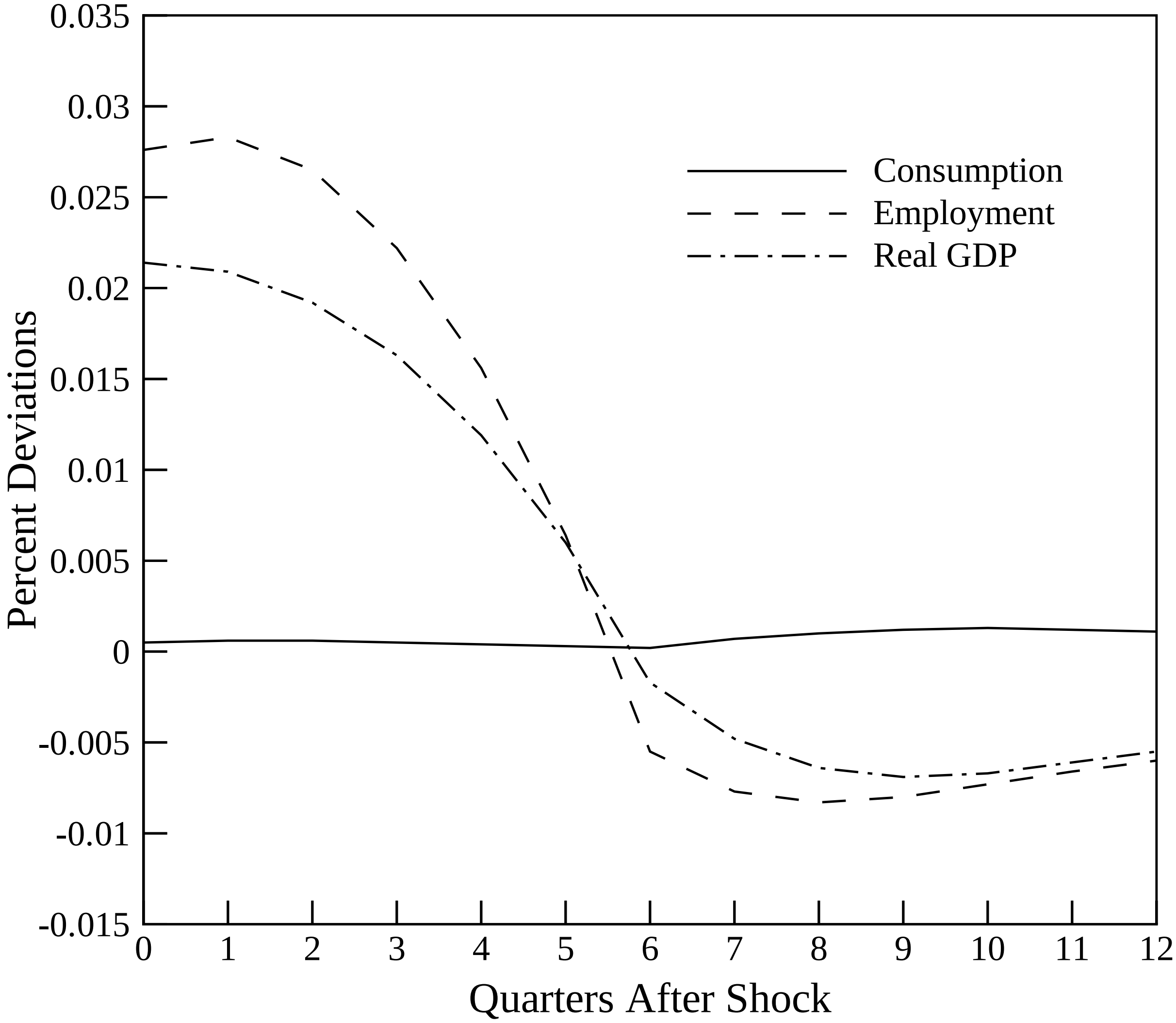

Figure 7
Preferred: Home Country Impulse Responses

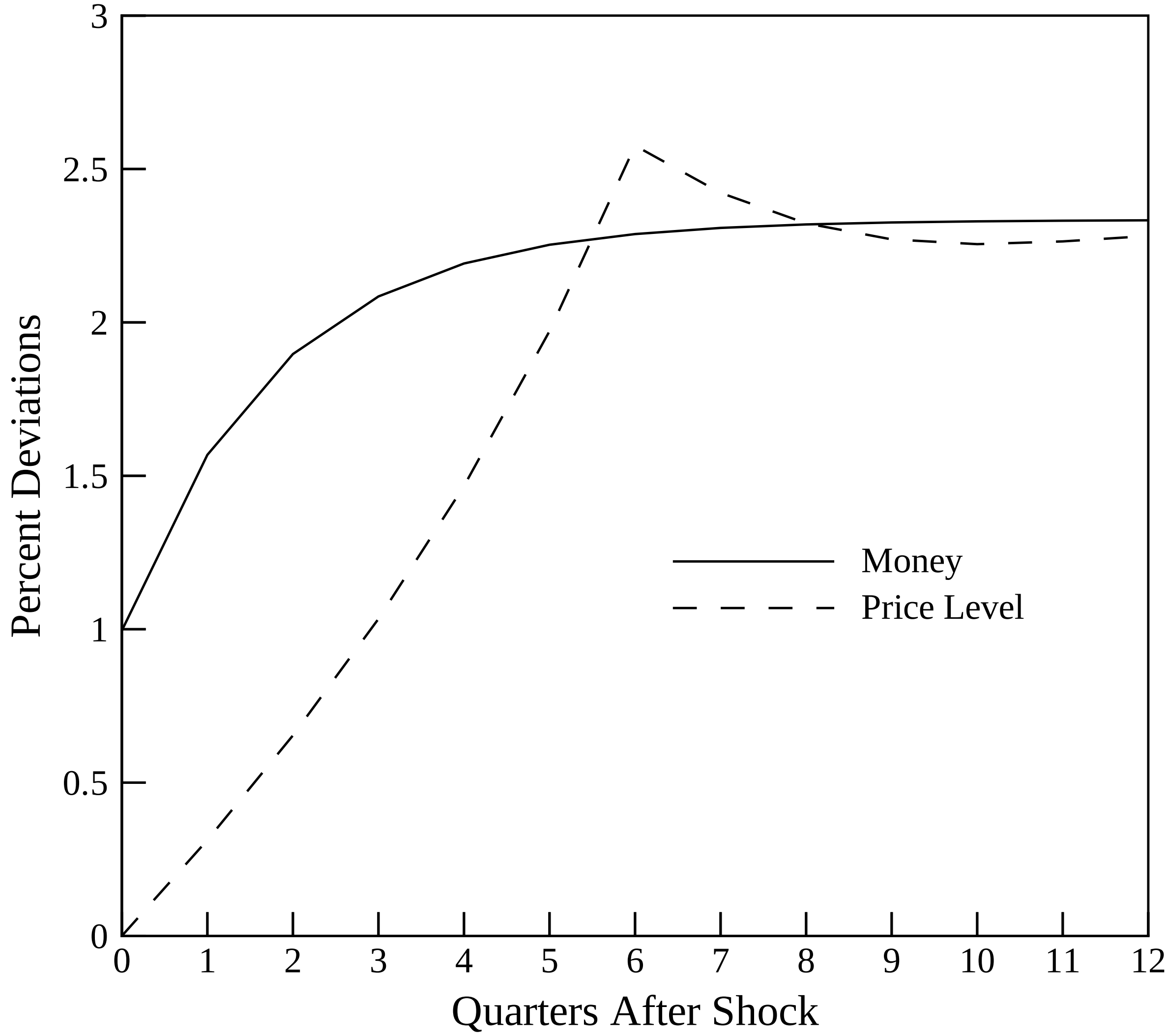

Figure 8

Preferred: Exchange Rate Impulse Responses

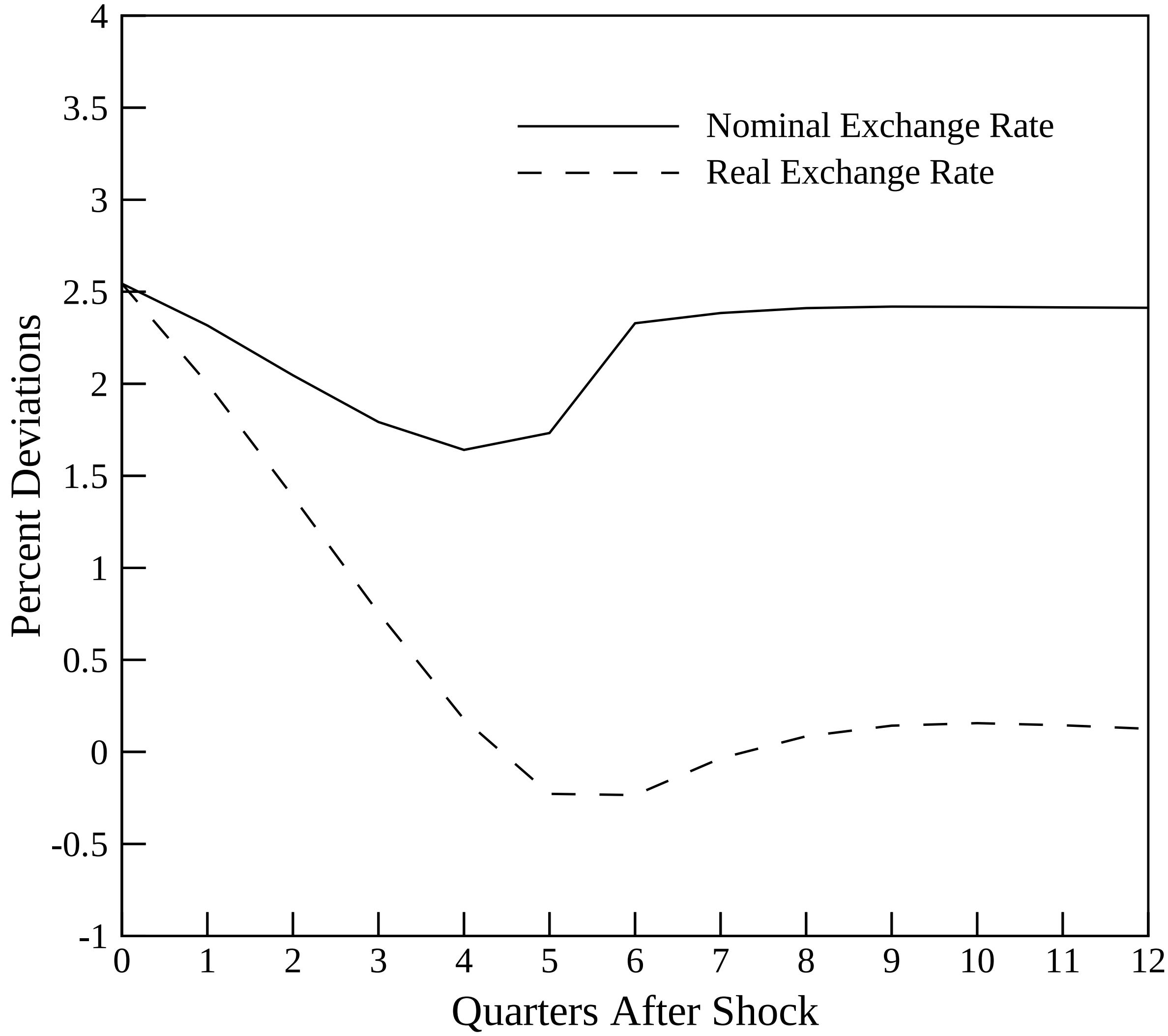

Figure 9
Preferred: Interest Rate Impulse Responses

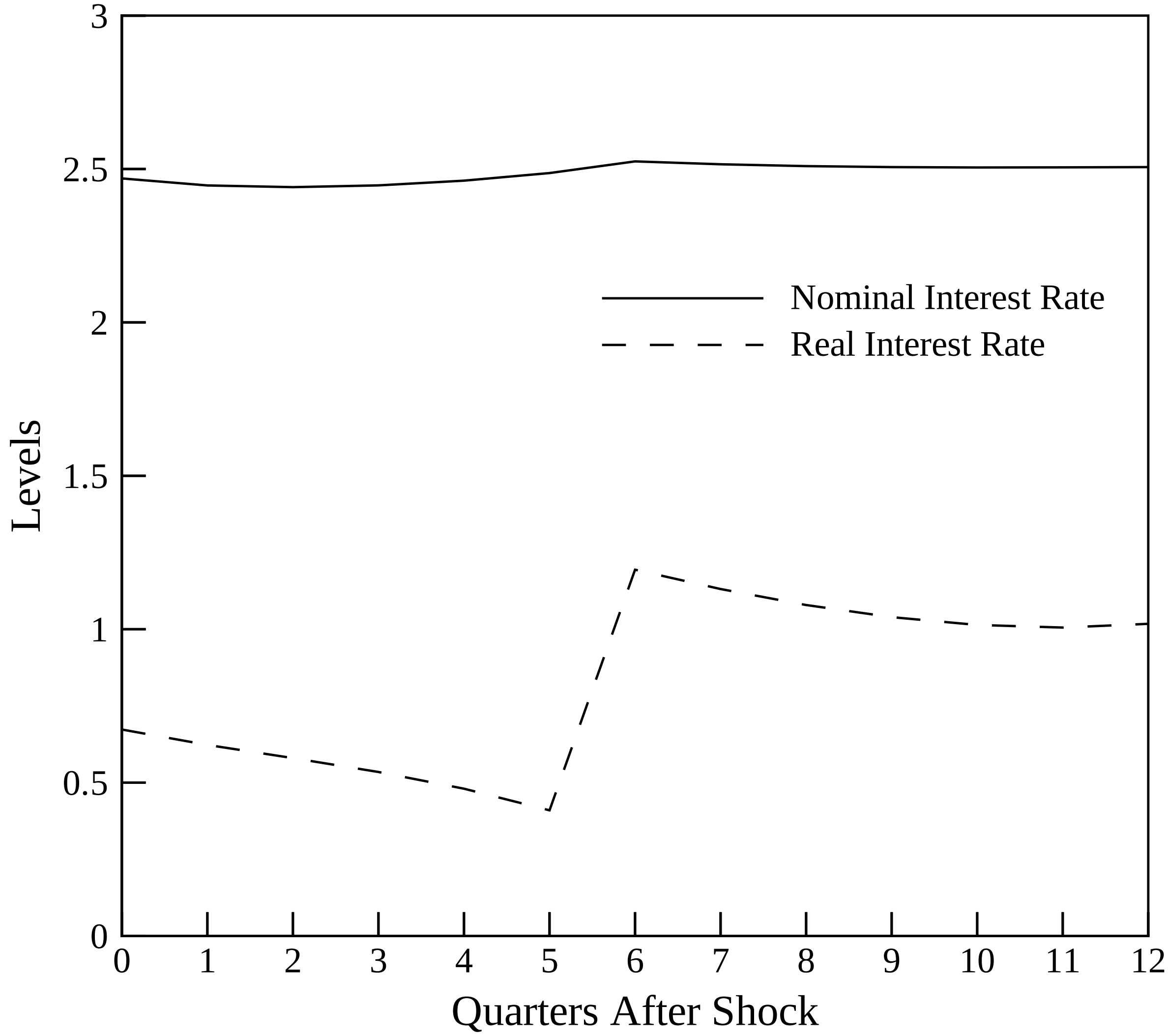

Figure 10

Cross-country Correlations of GDP and Consumption and
Exchange Rate Volatility vs. Money Growth Correlation

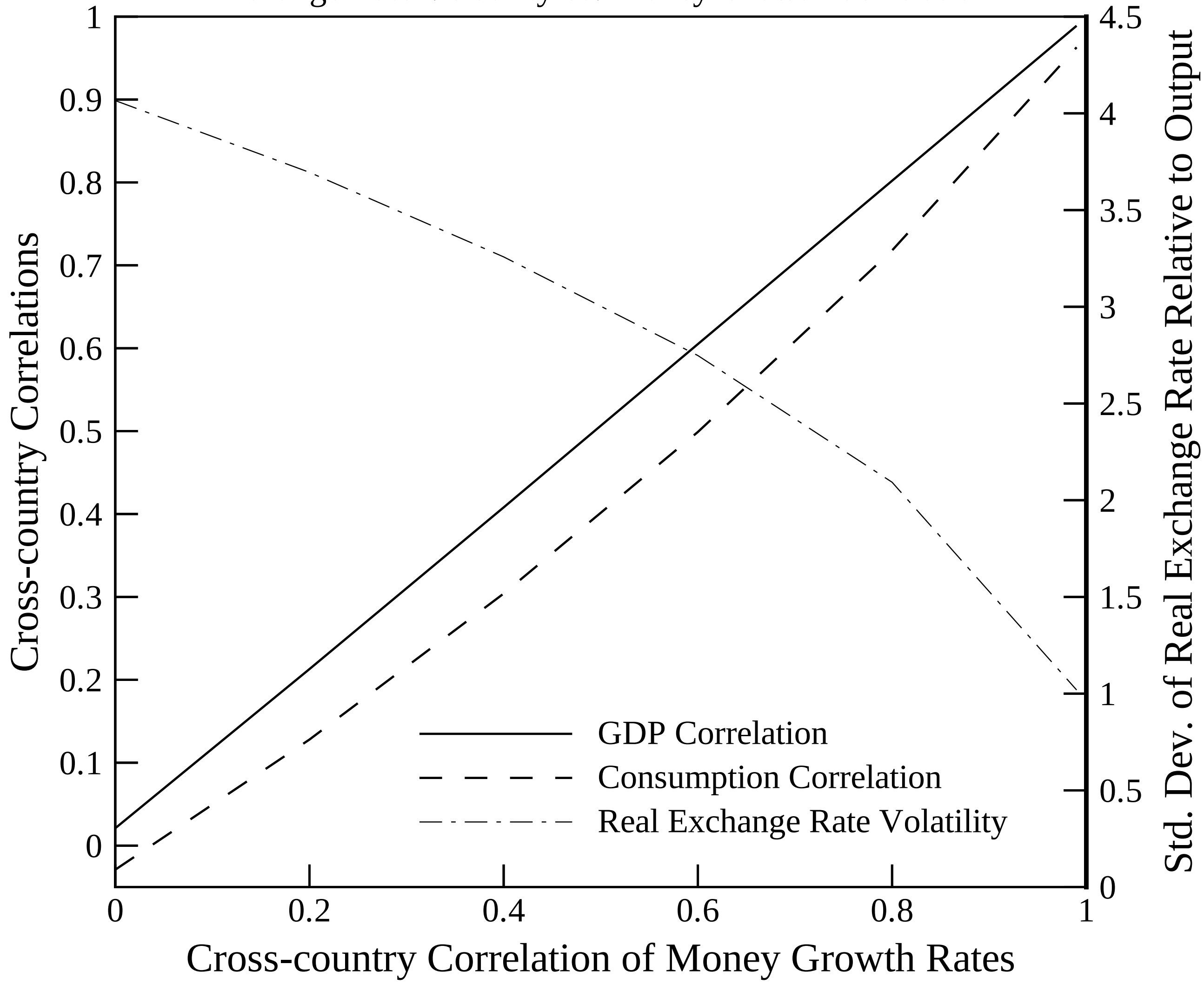

Table A1. Country Trade Weights

Country	Trade Weight
Austria	1.02
Belgium	7.49
Denmark	1.74
Finland	1.01
France	12.40
Germany	23.26
Italy	10.64
Netherlands	9.70
Norway	1.99
Spain	4.71
Switzerland	5.13
United Kingdom	20.91

Table 1. Properties of Exchange Rates and Consumer Price Indices, 1972:1-1994:4

Statistics	Austria	Finland	France	Germany	Italy	Norway	Spain	Switzerland	UK	Europe
Standard Deviations										
Price ratio	1.70	1.95	1.29	1.54	1.86	1.94	2.58	1.69	2.08	1.30
Nominal exchange rate	8.52	7.87	8.97	8.75	8.97	6.40	9.43	9.24	8.81	8.34
Real exchange rate	8.18	7.21	8.28	8.44	8.08	6.21	8.79	8.98	8.41	7.81
Autocorrelations										
Price ratio	0.88	0.92	0.92	0.90	0.87	0.90	0.90	0.91	0.83	0.90
Nominal exchange rate	0.83	0.83	0.86	0.84	0.86	0.78	0.88	0.82	0.83	0.86
Real exchange rate	0.82	0.80	0.84	0.83	0.83	0.76	0.87	0.82	0.80	0.83
Cross correlations										
Real, nominal exchange rate	0.98	0.97	0.99	0.98	0.98	0.95	0.96	0.98	0.97	0.99
Real exchange rate, GDP	−0.10	−0.44	−0.18	−0.29	−0.27	−0.20	−0.29	0.07	−0.06	−0.38
Real exchange rate, net exports	−0.19	−0.50	−0.29	−0.14	−0.35	−0.04	−0.20	−0.10	−0.20	−0.28

NOTE: The statistics are based on logged and Hodrick-Prescott filtered data. The statistics for Europe are trade-weighted aggregates of countries in the table. (See the appendix for details.)

Table 2. Business Cycle Statistics, 1972:1-1994:4

Statistics	Austria	Finland	France	Germany	Italy	Norway	Spain	Switzerland	UK	Europe
Standard Deviations										
GDP	1.11	2.52	1.17	1.56	1.55	1.71	1.20	1.99	1.90	1.11
Net Exports/GDP	0.27	0.44	0.30	0.51	0.43	1.03	0.47	0.83	0.49	0.38
Standard Deviations Relative to GDP										
Consumption	1.02	0.51	1.12	0.72	0.85	2.04	1.33	0.74	1.08	0.73
Investment	2.79	3.22	2.73	3.92	2.66	5.43	4.17	3.03	2.91	3.05
Employment	0.63	0.61	0.50	0.67	0.58	0.68		0.70	0.77	0.65
Autocorrelations										
GDP	0.91	0.94	0.84	0.93	0.86	0.91	0.93	0.82	0.83	0.90
Consumption	0.82	0.82	0.68	0.91	0.82	0.95	0.59	0.60	0.80	0.80
Investment	0.90	0.94	0.86	0.93	0.88	0.87	0.90	0.85	0.86	0.92
Employment	0.94	0.94	0.95	0.96	0.92	0.95		0.96	0.95	0.96
Net Exports/GDP	0.75	0.77	0.82	0.94	0.86	0.76	0.72	0.63	0.70	0.90
Cross correlations										
Foreign and domestic GDP	0.11	−0.02	0.33	0.24	0.42	0.36	0.14	0.27	0.68	0.52
Foreign and domestic consumption	0.05	−0.08	−0.25	0.07	0.14	0.41	−0.03	−0.05	0.56	0.27
Foreign and domestic investment	0.16	−0.40	−0.03	0.33	−0.01	0.21	−0.26	0.18	0.48	0.22
Foreign and domestic employment	0.22	−0.06	0.23	0.31	−0.22	0.25		0.29	0.77	0.51
GDP and net exports/GDP	−0.11	0.42	0.34	0.14	0.22	−0.10	0.23	0.08	0.16	0.23

NOTE: The statistics are based on Hodrick-Prescott filtered data. All variables except net exports to GDP are logged. The statistics for Europe are trade-weighted aggregates of countries in the table. (See the appendix for details.)

Table 3. Properties of Exchange Rates and Disaggregated Consumer Price Indices, 1972:1-1994:4

Statistics	Denmark	France	Italy	Netherlands	Norway	Switzerland	Europe
Standard Deviations							
All-goods price ratio	1.33	1.07	1.62	1.48	1.91	1.69	1.26
Traded-goods price ratio	1.58	1.57	2.12	2.04	2.24	1.56	1.65
Nominal exchange rate	8.37	8.97	8.97	8.60	6.40	9.24	8.50
All-goods real exchange rate	8.05	8.41	8.27	8.26	6.15	9.01	7.95
Traded-goods real exchange rate	8.24	8.18	8.17	8.05	6.31	8.85	7.86
Autocorrelations							
All-goods price ratio	0.87	0.88	0.83	0.94	0.90	0.91	0.92
Traded-goods price ratio	0.71	0.87	0.81	0.88	0.89	0.73	0.88
Nominal exchange rate	0.84	0.86	0.86	0.84	0.78	0.82	0.85
All-goods real exchange rate	0.83	0.84	0.83	0.83	0.75	0.81	0.83
Traded-goods real exchange rate	0.83	0.84	0.83	0.82	0.77	0.82	0.83
Cross Correlations of Exchange Rates							
All-goods real and nominal	0.99	0.99	0.99	0.99	0.95	0.98	0.99
Traded-goods real and nominal	0.98	0.99	0.97	0.97	0.94	0.99	0.98
All- and traded-goods real	0.99	1.00	0.99	0.99	0.99	0.99	0.99

NOTE: The statistics are based on logged and Hodrick-Prescott filtered data. The statistics for Europe are trade-weighted aggregates of countries in the table. (See appendix for details.)

Table 4. Properties of Exchange Rates and Disaggregated Price Deflators, 1972:1-1992:2

Statistics	France	Italy	UK	Europe
Standard Deviations				
All-goods price ratio	1.03	1.53	1.87	1.24
Traded-goods price ratio	1.55	2.03	2.54	1.87
Nominal exchange rate	9.36	8.83	8.94	8.62
All-goods real exchange rate	8.65	7.85	8.52	7.94
Traded-goods real exchange rate	8.41	7.71	8.24	7.72
Autocorrelations				
All-goods price ratio	0.90	0.91	0.79	0.87
Traded-goods price ratio	0.91	0.91	0.78	0.88
Nominal exchange rate	0.87	0.88	0.85	0.88
All-goods real exchange rate	0.86	0.86	0.83	0.86
Traded-goods real exchange rate	0.85	0.86	0.80	0.85
Cross Correlations of Exchange Rates				
All-goods real and nominal	1.00	0.99	0.98	0.99
Traded-goods real and nominal	0.99	0.98	0.96	0.98
All- and traded-goods real	1.00	1.00	0.99	0.99

NOTE: The statistics are based on logged and Hodrick-Prescott filtered data. The statistics for Europe are trade-weighted aggregates of countries in the table. (See appendix for details.)

Table 5. Properties of Exchange Rates and Wholesale Price Indices, 1972:1-1993:3

Statistics	Austria	Belgium	Denmark	Finland	Germany	Italy	Netherlands	Norway	Spain	Switzerland	UK	Europe
Standard Deviations												
Price ratio	2.62	4.30	2.49	1.93	2.18	3.23	2.84	1.75	3.24	2.07	3.36	2.42
Nominal exchange rate	8.71	9.47	8.55	7.75	8.95	9.16	8.80	6.48	9.57	9.43	9.04	8.57
Real exchange rate	7.80	6.65	6.80	6.78	8.24	7.79	8.03	6.13	8.13	9.10	8.03	7.61
Autocorrelations												
Price ratio	0.74	0.92	0.86	0.81	0.88	0.84	0.91	0.79	0.87	0.84	0.89	0.90
Nominal exchange rate	0.83	0.87	0.84	0.84	0.84	0.86	0.84	0.78	0.87	0.82	0.83	0.85
Real exchange rate	0.79	0.78	0.80	0.80	0.82	0.82	0.82	0.77	0.84	0.81	0.79	0.82
Cross Correlations of Exchange Rates												
Real and nominal	0.96	0.92	0.97	0.97	0.97	0.94	0.95	0.96	0.95	0.98	0.93	0.96

NOTE: The statistics are based on logged and Hodrick-Prescott filtered data. The statistics for Europe are trade-weighted aggregates of countries in the table. (See appendix for details.)

Table 6a. Parameter Values

Preferences	$\beta = 0.99$, $a = 0.73$, $\nu = -1.56$
Benchmark, 1 Qtr.	$\gamma = 0.32$, $\sigma = 2$
Benchmark, 6 Qtr.	$\gamma = 0.32$, $\sigma = 2$
Preferred, 6 Qtr.	$\psi = 45$, $\xi = -1/2$, $\sigma = 6$
Preferred, 12 Qtr.	$\psi = 50$, $\xi = -1/2$, $\sigma = 6$
Final goods technology	$\rho = 1/3$, $\omega_1/\omega_2 = 15.58$
Intermediate goods technology	$\alpha = 1/3$, $\delta = 0.026$, $\theta = 0.9$
Money growth process	$\bar{\mu} = 1.015$, $\rho_\mu = 0.57$, $\sigma_\mu = 0.0092$

Table 6b. Adjustment Costs

Economy	Value of b	Average Costs (%)
Benchmark, 1 Qtr.	2.72	0.198 (0.036)
Benchmark, 6 Qtr.	3.56	0.407 (0.333)
Preferred, 6 Qtr.	28.7	0.088 (0.021)
Preferred, 12 Qtr.	30.0	0.235 (0.086)

Table 7. Exchange Rates and Prices

Statistics	Data	Benchmark 1 Qtr. Sticky	Benchmark 6 Qtr. Sticky	Preferred 6 Qtr. Sticky	Preferred 12 Qtr. Sticky
Standard Deviations Relative to GDP					
Price Ratio	0.74	0.20	0.18	1.30	1.83
		(0.02)	(0.03)	(0.21)	(0.39)
Nominal Exchange Rate	4.74	0.55	0.51	3.96	3.84
		(0.08)	(0.08)	(0.58)	(0.80)
Real Exchange Rate	4.44	0.40	0.48	4.07	4.14
		(0.04)	(0.06)	(0.57)	(0.84)
Autocorrelations					
Price Ratio	0.90	0.42	0.67	0.72	0.88
		(0.09)	(0.05)	(0.04)	(0.03)
Nominal Exchange Rate	0.86	0.67	0.70	0.69	0.74
		(0.09)	(0.08)	(0.07)	(0.07)
Real Exchange Rate	0.83	−0.04	0.60	0.67	0.77
		(0.11)	(0.09)	(0.07)	(0.07)
Cross correlations					
Real and nominal exchange rate	0.99	0.56	0.84	0.85	0.95
		(0.04)	(0.04)	(0.05)	(0.02)
Real exchange rate and GDP	0.10	0.67	0.63	0.66	0.62
		(0.06)	(0.11)	(0.12)	(0.15)
Real exchange rate and net exports	0.15	−0.91	−0.83	0.98	0.98
		(0.02)	(0.04)	(0.01)	(0.01)

NOTE: The statistics are based on logged and Hodrick-Prescott filtered data. The models' statistics are averages over 100 simulations of 92 periods each. The numbers in parentheses are standard deviations.

Table 8. Business Cycle Statistics

Statistics	Data	Benchmark 1 Qtr. Sticky	Benchmark 6 Qtr. Sticky	Preferred 6 Qtr. Sticky	Preferred 12 Qtr. Sticky
Standard Deviations					
GDP	1.76	6.80 (0.48)	8.03 (0.94)	1.27 (0.17)	1.73 (0.31)
Net exports/GDP	0.26	0.12 (0.01)	0.14 (0.02)	0.05 (0.01)	0.08 (0.02)
Standard Deviations Relative to GDP					
Consumption	0.79	0.44 (0.00)	0.47 (0.01)	0.44 (0.04)	0.44 (0.05)
Investment	3.28	3.28 (0.08)	3.28 (0.21)	3.28 (0.12)	3.28 (0.14)
Employment	0.72	1.52 (0.00)	1.54 (0.01)	1.73 (0.06)	1.78 (0.09)
Autocorrelations					
GDP	0.87	−0.09 (0.11)	0.54 (0.08)	0.62 (0.08)	0.72 (0.08)
Consumption	0.85	−0.09 (0.11)	0.57 (0.08)	0.64 (0.09)	0.74 (0.09)
Investment	0.91	−0.09 (0.11)	0.52 (0.08)	0.62 (0.07)	0.72 (0.08)
Employment	0.95	−0.09 (0.11)	0.55 (0.08)	0.70 (0.06)	0.79 (0.07)
Net exports/GDP	0.88	−0.09 (0.10)	0.59 (0.07)	0.66 (0.07)	0.77 (0.06)
Cross correlations					
Foreign and domestic GDP	0.52	0.03 (0.11)	0.02 (0.17)	0.02 (0.19)	0.05 (0.23)
Foreign and domestic consumption	0.27	0.00 (0.10)	−0.01 (0.17)	−0.03 (0.19)	0.00 (0.23)
Foreign and domestic investment	0.22	−0.02 (0.10)	−0.02 (0.16)	−0.02 (0.18)	0.00 (0.22)
Foreign and domestic employment	0.51	0.02 (0.11)	0.02 (0.17)	0.02 (0.19)	0.05 (0.26)
Net exports/GDP and GDP	−0.21	−0.69 (0.06)	−0.68 (0.09)	0.61 (0.14)	0.55 (0.17)

NOTE: The statistics are based on logged and Hodrick-Prescott filtered data. The models' statistics are averages over 100 simulations of 92 periods each. The numbers in parentheses are standard deviations.

Table 9. Exchange Rates and Prices

Statistics	Data	Complete Markets	Incomplete Markets
Standard Deviations Relative to GDP			
Price Ratio	0.74	0.96 (0.09)	0.96 (0.09)
Nominal Exchange Rate	4.74	2.04 (0.28)	2.08 (0.31)
Real Exchange Rate	4.44	1.57 (0.12)	1.60 (0.15)
Autocorrelations			
Price Ratio	0.90	0.40 (0.09)	0.40 (0.09)
Nominal Exchange Rate	0.86	0.70 (0.08)	0.69 (0.08)
Real Exchange Rate	0.83	−0.09 (0.11)	−0.08 (0.12)
Cross correlations			
Real and nominal exchange rate	0.99	0.37 (0.05)	0.39 (0.08)
Real exchange rate and GDP	0.10	0.69 (0.06)	0.69 (0.07)
Real exchange rate and net exports	0.15	0.96 (0.00)	0.61 (0.29)

NOTE: The statistics are based on logged and Hodrick-Prescott filtered data. The models' statistics are averages over 100 simulations of 92 periods each. The numbers in parentheses are standard deviations.

Table 10. Business Cycle Statistics

Statistics	Data	Complete Markets	Incomplete Markets
Standard Deviations			
GDP	1.76	1.71 (0.12)	1.71 (0.12)
Net exports/GDP	0.26	0.00 (0.00)	0.01 (0.00)
Standard Deviations Relative to GDP			
Consumption	0.79	1.02 (0.00)	1.02 (0.00)
Employment	0.72	1.00 (0.00)	1.00 (0.00)
Autocorrelations			
GDP	0.87	−0.11 (0.11)	−0.11 (0.11)
Consumption	0.85	−0.11 (0.11)	−0.11 (0.11)
Employment	0.95	−0.11 (0.11)	−0.11 (0.11)
Net exports/GDP	0.88	0.39 (0.09)	0.39 (0.10)
Cross correlations			
Foreign and domestic GDP	0.52	0.04 (0.11)	0.04 (0.11)
Foreign and domestic consumption	0.27	0.00 (0.11)	0.00 (0.11)
Foreign and domestic employment	0.51	0.03 (0.11)	0.03 (0.11)
Net exports/GDP and GDP	−0.21	0.66 (0.05)	0.32 (0.48)

NOTE: The statistics are based on logged and Hodrick-Prescott filtered data. The models' statistics are averages over 100 simulations of 92 periods each. The numbers in parentheses are standard deviations.