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A MONETARY, OPEN-ECONOMY MODEL WITH CAPITAL MOBILITY

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ABSTRACT

This paper examines a two-country, monetary general-equilibrium model that includes a financial sector, capital mobility, and shocks to technologies and money-growth rates. Capital mobility allows agents in both countries to participate in rewards from relatively favorable shocks realized in either country. Currency exchange facilitates currency-intermediated international trade of consumption and capital goods. Qualitative and quantitative implications of the model for evolutions of variables are investigated. The quantitative analysis is performed by numerically solving and simulating the model. We focus on international monetary shock transmissions, and effects of monetary innovations on interest rates and nominal and real exchange rates.

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1. INTRODUCTION

This paper examines a two-country, monetary general-equilibrium model that includes a financial sector, capital mobility, and shocks to technologies and money-growth rates. Each country is inhabited by a representative household composed of members who trade in spatially and sometimes informationally distinct markets within each period, but meet to pool resources and information at each period's completion. The representative household construct of Lucas (1990) is utilized to abstract from effects on the distribution of wealth in a country that arise from monetary innovations. Qualitative features of the model are provided along with quantitative implications for the evolutions of exchange rates, interest rates, and other nominal and real variables. The quantitative analysis is performed by numerically solving and simulating the model using empirically plausible parameter values. Quantitative evaluation of the model involves comparing properties of simulated time-series of variables with properties of time-series drawn from actual economies.

Implications of technology shocks for evolutions of real variables across countries in dynamic, general equilibrium models have recently been investigated by, among others, Backus, Kehoe, and Kydland (1992), Baxter (1988), Cantor and Mark (1988), Dellas (1986), Mendoza (1991), and Stockman and Tesar (1990). Qualitative implications for international business cycle phenomena of alternative monetary, general equilibrium models have also been investigated in recent work by Grilli and Roubini (1991), Rotemberg (1981), Schlagenhauf and Wrase (1992), and Stockman and Svensson (1987). The objective of this study is to quantitatively evaluate the performance of a dynamic, open-economy model with capital mobility and cash-in-advance constraints used to characterize monetary transaction services. We focus on the predictive content of the model for exchange rate dynamics and responses of exchange rates, interest rates, and real activities to money shocks in the two countries.

International monetary shock transmission is examined in an environment in which all prices are flexible.

A typical household in each country of the model consists of a shopper, firm member, worker, and financial intermediary as in the closed-economy model of Fuerst (1990). Within a period, different household members trade separately in goods, labor, and financial markets. Shoppers face domestic and foreign cash-in-advance constraints on purchases of goods. Cash balances used by shoppers are obtained in the currency-exchange market. Firms face cash-in-advance constraints on input acquisitions. Cash required for a firm's domestic input acquisitions is obtained by renting capital to foreign firms and by borrowing from a financial intermediary. Financial intermediaries supply loanable currency derived from household deposits and from monetary injections. Foreign capital is acquired by renting capital from a foreign firm using cash obtained in the currency-exchange market.

A capital-rental market is included in the model for two reasons. First, the rental market provides capital mobility across countries within each period which allows all households to participate in rewards to relatively favorable technology shocks realized in either country. Second, the need for firms in a country to acquire units of foreign currency in advance of renting foreign capital subjects the nominal currency-exchange rate to additional sources of fluctuation relative to a model with immobile capital. Using a model similar to the one in this paper, with the exception that capital is immobile across countries, Schlagenhauf and Wrase (1992) report exchange rate volatilities in data simulated from the model that are low relative to volatilities in data drawn from actual economies. Of interest is the effect on exchange rate dynamics of allowing for capital mobility.

We consider alternative variants of the model that we construct, corresponding to alternative assumptions about information available when various household decisions are made. In one variant, all decisions are made with full contemporaneous information. In this setting, a country receiving a positive shock to its money growth rate realizes a currency depreciation, an increase in expected inflation and, for standard Fisherian reasons, nominal interest rates rise. In turn, increases in nominal interest rates raise the borrowing cost to firms of current input acquisitions which exerts downward pressure on employment and output. We also consider variants of the model in which household's portfolio decisions for a period are made prior to observing contemporaneous shock realizations. As in Lucas (1990), Fuerst (1990), Christiano (1991), and Christiano and Eichenbaum (1991, 1992), the portfolio rigidity allows for liquidity effects, in addition to anticipated inflation effects, of unanticipated monetary shocks on interest rates and real activities. The liquidity effect of a surprise increase in money growth in a country drives nominal interest rates down, to induce borrowing firms to disproportionately absorb additional currency, which exerts upward pressure on employment and output. The net effect of an unanticipated increase in a country's money growth rate on interest rates and other variables depends on relative magnitudes of anticipated inflation and liquidity effects.

The paper proceeds as follows. Section 2 describes the model. Trading opportunities and information sets of agents are described along with preferences, technologies, and shock processes. Section 3 displays the choice problem of a typical household, interprets optimality conditions, describes general equilibrium, and investigates effects of monetary shocks. To quantitatively analyze the model, we assign parameter values and discuss chosen values in section 4. Section 5 presents and discusses quantitative results. Section 6 concludes.

2. A TWO-COUNTRY MONETARY MODEL

We analyze a monetary model with two countries, domestic and foreign, each inhabited by a multi-member representative household. The representative household construct is utilized to abstract from effects on the wealth distribution in each country from monetary innovations while allowing different agents to face different trading opportunities. In each country, the representative household consists of members who trade in spatially and sometimes informationally distinct markets within each period, but meet to pool resources and information at the end of each period.

Trading Opportunities

The representative household in each country consists of a shopper, worker, financial intermediary, and firm manager. Household members have different tasks to perform in markets for goods, labor, and currencies. In any market, agents cannot tell who is or is not a member of their own households. Since the objective and constraints of the representative household in the two countries are isomorphic, we provide details only for the domestic household's objective and trading opportunities.

Time is discrete, composed of a series of periods. At the beginning of period t, the domestic household holds K_t^D units of capital and A_t^D units of domestic currency brought forward from the previous period. Prior to engaging in other trades, the domestic household enters the currency exchange market and trades currencies with foreign households to divide A_t^D into a domestic currency balance, $M_{D,t}^D$, and a foreign currency balance, $M_{F,t}^D$, at the nominal exchange rate e_t.[1] Thus,

(1) $$A_t^D = M_{D,t}^D + e_t M_{F,t}^D$$

After trading in the exchange market, the domestic household divides domestic currency balance $M^D_{D,t}$ by sending N^D_t with the intermediary to the domestic financial market and the remaining $M^D_{D,t} - N^D_t$ to the domestic goods market with the shopper. The household's foreign currency balance $M^D_{F,t}$ is also divided by sending B^D_t with the firm, for use in renting units of foreign capital from foreign firms, and the remaining $M^D_{F,t} - B^D_t$ to the foreign goods market with the shopper. The domestic shopper purchases $C^D_{D,t}$ units of the domestically produced good subject to the cash-in-advance (hereafter, CIA) constraint[2]:

(2) $$P^D_t C^D_{D,t} = M^D_{D,t} - N^D_t \ ,$$

where P^D_t is the domestic goods price level. The shopper also purchases $C^D_{F,t}$ units of the foreign produced good subject to the CIA constraint:

(3) $$P^F_t C^D_{F,t} = M^D_{F,t} - B^D_t \ ,$$

where P^F_t is the foreign price level. With the constraints specified as equalities, the shopper returns home at the end of the period with goods, but no leftover currency balances.

The typical domestic intermediary receives a domestic monetary injection X^D_t upon arrival at the financial market and therefore is able to lend $N^D_t + X^D_t$ units of domestic currency to domestic firms. Domestic firms agree to pay, at the end of the period, the gross domestic loan rate $(1 + i^D_{L,t})$ times the amount borrowed. Loanable cash supplied to the domestic financial markets by an intermediary is[3]:

(4) $\hat{\mathfrak{L}}^{D}_{s,t} = N^{D}_{t} + X^{D}_{t}$.

The domestic firm manager possesses the household's beginning capital stock, hires domestic labor, invests, and trades in a capital rental market. Prior to producing output, the manager performs three tasks. First, the manager rents $\tilde{K}^{D}_{F,t}$ units of foreign capital from foreign firms for use in current production at rental price Q^{F}_{t} subject to the CIA constraint

(5) $B^{D}_{t} = Q^{F}_{t}\tilde{K}^{D}_{F,t}$,

where B^{D}_{t} is the firm's foreign currency balance and Q^{F}_{t} is denominated in units of foreign currency per unit of foreign capital. Second, the manager allocates the household's capital K^{D}_{t} between an amount $\bar{K}^{F}_{D,t}$ which is supplied to foreign firms in the rental market and an amount $\tilde{K}^{D}_{D,t} = K^{D}_{t} - \bar{K}^{F}_{D,t}$ for use in domestic production. Third, the manager borrows $\hat{\mathfrak{L}}^{D}_{t}$ units of domestic currency from a domestic intermediary for use in acquiring domestic inputs.

Domestic input acquisitions by the firm must be entirely cash financed according to the CIA constraint facing the domestic firm, given by:

(6) $\hat{\mathfrak{L}}^{D}_{t} = W^{D}_{t}H^{D}_{t} + P^{D}_{t}(K^{D}_{t+1} - (1-\delta^{D})K^{D}_{t}) - Q^{D}_{t}\bar{K}^{F}_{D,t}$.

W^{D}_{t} is the domestic nominal wage, H^{D}_{t} is employment, $(K^{D}_{t+1} - (1-\delta^{D})K^{D}_{t})$ is domestic investment, with δ^{D} denoting a fixed rate of capital depreciation, and Q^{D}_{t} is the rental price of domestic capital. The domestic firm is allowed to use its capital rental receipts, $Q^{D}_{t}\bar{K}^{F}_{D,t}$, to acquire domestic inputs in the current period. After combining labor, and domestic and foreign capital with the production technology, output of the firm is taken to the goods market where shoppers purchase units of current consumption. Cash receipts from current goods market sales cannot be used by the household to purchase units of the good in the current period.

The domestic household's worker supplies $\tilde{H}_t^D$ units of labor in the domestic labor market at nominal wage W_t^D . At the end of the current period, the worker returns home with nominal wage receipts

$$(7) \qquad W_t^D \tilde{H}_t^D \ .$$

After the close of goods market trading, the firm manager passes by the financial market to pay its loan obligation $(1 + i_{L,t}^D)\mathfrak{L}_t^D$, and returns home with capital and cash profits. Using Y_t^D to denote real domestic output, the firm's cash profits are[4]:

$$(8) \qquad P_t^D Y_t^D - (1 + i_{L,t}^D)\hat{\mathfrak{L}}_t^D \ ,$$

Each domestic intermediary receives loan repayments $(1 + i_{L,t}^D)(N_t^D + X_t^D)$ and pays a gross deposit return $(1 + i_{D,t}^D)N_t^D$ on deposits. The typical household's intermediary member returns home at the end of the period with the household's deposit return, $(1 + i_{D,t}^D)N_t^D$, plus any cash derived from intermediary activities, $(1 + i_{L,t}^D)(N_t^D + X_t^D) - (1 + i_{D,t}^D)N_t$. Thus, the intermediary member brings home a domestic cash balance given by:

$$(9) \qquad (1 + i_{L,t}^D)(N_t^D + X_t^D) \ .$$

Upon reuniting, the household pools currency and consumes goods acquired in the current period. Combining cash brought home by the worker in (7), firm manager in (8), and intermediary in (9), the household's beginning domestic cash balance next period is

$$(10) \qquad A_{t+1}^D = W_t^D \tilde{H}_t^D + P_t^D Y_t^D - (1 + i_{L,t}^D)\hat{\mathfrak{L}}_t^D + (1 + i_{L,t}^D)(N_t^D + X_t^D) \ .$$

Preferences, Production Technologies, and Exogenous Shocks

Each of the identical, infinitely-lived domestic households orders sequences of consumptions $\{C_{D,t+j}^D\}$, $\{C_{F,t+j}^D\}$, and leisure $\{L_{t+j}^D\}$ according to the utility function

(11) $E_t \sum_{j=0}^{\infty} (\beta_D)^j \mu(C^D_{D,t+j}, C^D_{F,t+j}, L^D_{t+j}), \qquad 0 < \beta_D < 1,$

where E_t is the expectation operator conditional on information dated t and earlier, and β_D is the subjective discount factor. Total domestic household leisure for period t+j is

$L^D_{t+j} = 1 - \tilde{H}^D_{t+j}$, where the normalized household time endowment is unity and $\tilde{H}^D_{t+j}$ is the worker's labor supply, $0 \leq \tilde{H}^D_{t+j} \leq 1$.

Firms in the domestic country combine inputs to produce output according to:

(12) $Y^D_t = f^D(\tilde{K}^D_{D,t}, \tilde{K}^D_{F,t}, Z^D_t H^D_t), \qquad Z^D_t = \exp(\mu^D t + \theta^D_t),$

where the exogenous shock to domestic labor productivity, Z^D_t, is the sum of a deterministic trend and random deviations about trend. Foreign firms utilize the technology

(13) $Y^F_t = f^F(\tilde{K}^F_{F,t}, \tilde{K}^F_{D,t}, Z^F_t H^F_t), \qquad Z^F_t = \exp(\mu^F t + \theta^F_t).$

Shocks to labor productivities evolve according to the bivariate autoregression

(14) $\theta_t = T\theta_{t-1} + \varepsilon_{\theta,t},$

where $\theta_t = (\theta^D_t, \theta^F_t)'$, and $\varepsilon_{\theta,t} = (\varepsilon_{\theta^D,t}, \varepsilon_{\theta^F,t})'$. The innovations $\varepsilon_{\theta,t}$ are serially independent with contemporaneous covariance matrix V^θ which permits contemporaneous correlation between the two country's shocks.

The exogenous money growth rates are $x^D_t = \dfrac{X^D_t}{M^s_{D,t}}$ and $x^F_t = \dfrac{X^F_t}{M^s_{F,t}}$, where $M^s_{D,t}$ and $M^s_{F,t}$ are aggregate per own-country-household stocks of domestic and foreign currencies. Money growth rates evolve according to the bivariate autoregression

(15) $x_t = Mx_{t-1} + \varepsilon_{x,t},$

where $x_t = (x^D_t, x^F_t)'$, and $\varepsilon_{x,t} = (\varepsilon_{x^D,t}, \varepsilon_{x^F,t})'$. The innovations $\varepsilon_{x,t}$ are serially independent with contemporaneous covariance matrix V^x.

The Economy's State, and Conversion to Nongrowing Economies

The state of the world economy in period t is represented by values taken by $M^s_{D,t}$, $M^s_{F,t}$, K^D_t, K^F_t, κ^D_t, κ^F_t, and s_t . κ^D_t and κ^F_t are the beginning-of-period aggregate per own-country-household stocks of domestic and foreign capital, respectively. s_t is a vector containing productivity and money-growth innovations in the two countries. The representative household in each country begins a period, say t, with knowledge of values taken by $M^s_{D,t}$, $M^s_{F,t}$, K^D_t, K^F_t, κ^D_t, κ^F_t . During the period, the current shocks, s_t, are realized. Shocks to the system form a Markov process with transition function $\Phi(s_{t+1} \mid s_t)$.

Prior to a full specification of the household's choice problems, it is useful to convert to nongrowing economies. To do so, define the following transformed variables:

$$c^D_{D,t} = C^D_{D,t}\exp(-\mu^D t) \quad k^D_{t+1} = K^D_{t+1}\exp(-\mu^D t) \quad c^F_{D,t} = C^F_{D,t}\exp(-\mu^D t) \quad y^D_t = Y^D_t\exp(-\mu^D t)$$

$$\tilde{k}^F_{D,t} = \tilde{K}^F_{D,t}\exp(-\mu^D t) \quad \bar{k}^F_{D,t} = \bar{K}^F_{D,t}\exp(-\mu^D t) \quad \tilde{k}^D_{D,t} = \tilde{K}^D_{D,t}\exp(-\mu^D t) \quad \bar{\kappa}^D_t = \kappa^D_t\exp(-\mu^D t)$$

$$c^F_{F,t} = C^F_{F,t}\exp(-\mu^F t) \quad c^D_{F,t} = C^D_{F,t}\exp(-\mu^F t) \quad k^F_{t+1} = K^F_{t+1}\exp(-\mu^F t) \quad y^F_t = Y^F_t\exp(-\mu^F t)$$

$$\tilde{k}^D_{F,t} = \tilde{K}^D_{F,t}\exp(-\mu^F t) \quad \bar{k}^D_{F,t} = \bar{K}^D_{F,t}\exp(-\mu^F t) \quad \tilde{k}^F_{F,t} = \tilde{K}^F_{F,t}\exp(-\mu^F t) \quad \bar{p}^D_t = P^D_t\exp(\mu^D t)$$

$$\bar{p}^F_t = P^F_t\exp(\mu^F t) \quad \bar{q}^D_t = Q^D_t\exp(\mu^D t) \quad \bar{q}^F_t = Q^F_t\exp(\mu^F t) \quad \bar{\kappa}^F_t = \kappa^F_t\exp(-\mu^F t)$$

These transformations serve to eliminate the deterministic productivity trends. In addition, we measure nominal variables relative to the corresponding money stocks $(M^s_{D,t}$ or $M^s_{F,t})$:

$$m^D_{D,t} = \frac{n^D_t}{M^s_{D,t}},\ n^D_{D,t} = \frac{N^D_t}{M^s_{D,t}},\ w^D_t = \frac{W^D_t}{M^s_{D,t}},\ \mathcal{L}^D_t = \frac{\hat{\mathcal{L}}^D_t}{M^s_{D,t}},\ p^D_t = \frac{\bar{p}^D_t}{M^s_{D,t}},\ x^D_t = \frac{X^D_t}{M^s_{D,t}},\ b^F_t = \frac{B^F_t}{M^s_{D,t}},$$

$$q^D_t = \frac{\bar{q}^D_t}{M^s_{D,t}},\ a^D_t = \frac{A^D_t}{M^s_{D,t}},\ m^F_{F,t} = \frac{M^F_{F,t}}{M^s_{D,t}},\ n^F_t = \frac{N^F_t}{M^s_{F,t}},\ w^F_t = \frac{W^F_t}{M^s_{F,t}},\ \mathcal{L}^F_t = \frac{\hat{\mathcal{L}}^F_t}{M^s_{F,t}},\ p^F_t = \frac{\bar{p}^F_t}{M^s_{F,t}},\ x^F_t = \frac{X^F_t}{M^s_{F,t}},$$

$$b^D_t = \frac{B^D_t}{M^s_{F,t}},\ q^F_t = \frac{\bar{q}^F_t}{M^s_{F,t}},\ a^F_t = \frac{A^F_t}{M^s_{F,t}},\ e^*_t = e_t\frac{M^s_{F,t}}{M^s_{D,t}}.$$

Three Variants of the Model

Three variants of the model are considered, corresponding to alternative information assumptions. In each variant, interest rates are considered in light of the theory of interest rate determination espoused by Irving Fisher (1930). According to Fisher's theory, nominal interest rates are determined by anticipated inflation and the real rate of interest:—the so-called "Fisherian fundamentals." We also consider the effect on exchange rate determination of alternative information assumptions.

In one variant of the model, referred to as the full-information (FI) setting, all decisions are made with full contemporaneous information. In this setting a strong relation exists between nominal interest rates and Fisherian fundamentals. In the second variant of the model, referred to as the sluggish-portfolio (SP) setting, households make portfolio decisions on currency balances, deposits, and capital rentals prior to observing current shock realizations. All other decisions are made with full contemporaneous information. The sluggish-portfolio assumption, intended to capture the idea that continuous portfolio reallocation is costly for households, corresponds to an environment analyzed in closed-economy models by Christiano (1991), Fuerst (1990), and Lucas (1990). In the SP setting, liquidity effects are introduced into interest rate determination which sever strict Fisherian ties between nominal interest rates and fundamentals. In the third variant of the model, referred to as the sluggish-capital (SC) setting, households predetermine nominal portfolios as in the SP setting, and also make investment decisions prior to observing current shocks. This setting captures the notion that capital investment plans take time to formulate and execute. In the SC setting, nominal interest rates depend on Fisherian fundamentals and liquidity effects as in the SP setting. In addition, monetary impulses have greater employment effects than in the alternative settings given the inability of firms to adjust investment in response to shocks.

3. THE DOMESTIC HOUSEHOLD'S PROBLEM, GENERAL EQUILIBRIUM, AND EFFECTS OF MONEY SHOCKS

Now consider the problem facing a typical domestic household stated in terms of transformed variables. For brevity, we focus on domestic household choices since foreign and domestic households face isomorphic problems. The domestic household's problem is specified below, optimality conditions are interpreted, and conditions necessary for general equilibrium are identified. We also discuss effects of monetary innovations on exchange rates, interest rates, and real activity. Begin by considering the FI setting, followed by the SP and SC variants of the model.

The Full-Information Setting

The representative domestic household's problem, in terms of transformed variables, is to maximize utility

$$(16) \qquad E_t \sum_{j=0}^{\infty} (\beta_D^*)^j \mu(c_{D,t+j}^D, c_{F,t+j}^D, L_{t+j}^D), \qquad \beta_D^* = \beta_D \exp[\phi^D(1-\gamma^D)\psi^D\mu^D + (1-\phi^D)(1-\gamma^D)\psi^D\mu^F]$$

subject to

$$(17) \qquad L_{t+j}^D = 1 - \tilde{H}_{t+j}^D$$

$$(18) \qquad y_t^D = f_D^*(\tilde{k}_{D,t}^D, \tilde{k}_{F,t}^D, H_t^D, \theta_t^D)$$

$$(19) \qquad p_t^D c_{D,t}^D = m_{D,t}^D - n_t^D$$

$$(20) \qquad p_t^F c_{F,t}^D = m_{F,t}^D - b_t^D$$

$$(21) \qquad \mathcal{L}_t^D = w_t^D H_t^D + p_t^D(k_{t+1}^D - (1-\delta_D^*)k_t^D) - q_t^D \bar{k}_{D,t}^F, \qquad (1-\delta_D^*) = (1-\delta_D)\exp(-\mu^D)$$

$$(22) \qquad b_t^D = q_t^F \tilde{k}_{F,t}^D$$

$$(23) \qquad \mathcal{L}_{s,t}^D = n_t^D + x_t^D$$

$$(24) \qquad a_{t+1}^D = \frac{1}{1+x_t^D}\left\{w_t^D \tilde{H}_t^D + p_t^D f_D^*(\tilde{k}_{D,t}^D, \tilde{k}_{F,t}^D, H_t^D, \theta_t^D) - (1+i_{L,t}^D)\mathcal{L}_t^D + (1+i_{L,t}^D)(n_t^D + x_t^D)\right\}$$

$$(25) \qquad a_t^D = m_{D,t}^D + e_t^* m_{F,t}^D$$

$$(26) \qquad k_t^D = \tilde{k}_{D,t}^D + \bar{k}_{D,t}^F$$

Equation (17) gives household leisure; (18) is the domestic production function written in terms of transformed variables; (19) and (20) are the shopper's CIA constraints; (21) is the firm's CIA constraint; (22) is the firm's cash constraint on rental of foreign capital; (23) is loan supply; (24)

is the household's end-of-period nominal wealth, rewritten from (10) using transformed variables; (25) is the nominal wealth allocation across currencies; and (26) is the division of domestic capital between the amount used in domestic production, $\tilde{k}^D_{D,t}$, and the amount supplied to foreign firms in the rental market, $\bar{k}^F_{D,t}$.

Restricting attention to stationary rational expectations equilibria in which prices, money shocks, and decision rules are fixed functions of the state of the system, we drop time subscripts below. The household begins a period with observations of the current state. Using primes to denote next-period values of variables, let $J^D(a^D,k^D,s)$ represent the value function corresponding to the domestic household's problem, satisfying the functional equation[5]

$$(27) \qquad J^D(a^D,k^D,s) = \max_{m^D_F,n^D,b^D,\tilde{H}^d,k^{D\prime},\bar{k}^F_D,\mathcal{L}^d} \{\mu(c^D_D,c^D_F,1-\tilde{H}^D) + \beta^*_D \int J^D(a^{D\prime},k^{D\prime},s')\Phi(s'|s)\},$$

where $a^{D\prime} = (1+x^D)^{-1}\{w^D\tilde{H}^D + p^D f^*(\tilde{k}^D_D,\tilde{k}^D_F,H^D,s) - (1+i^D_L)\mathcal{L}^d + (1+i^D_L)(n^D+x^D)\}$,

$k^D = \tilde{k}^D_D + \bar{k}^F_D$, $n^D \in [0,m^D_D]$, and $b^D \in [0,m^D_F]$. Binding CIA constraints for the shopper and firm are used to eliminate c^D_D, c^D_F, and H^D as separate decision variables, i.e.

$$c^D_D = \frac{m^D_D - n^D}{p^D} \; ; \quad c^D_F = \frac{m^D_F - b^D}{p^F}; \; H^D = \frac{\mathcal{L}^d - p^D(k^{D\prime}-(1-\delta^*_D)k^D) + q^D\bar{k}^F_D}{w^D}.$$

We eliminate m^D_D as a separate decision variable using $m^D_D = a^D - e^* m^D_F$ from (25), where a^D is predetermined and e^* is taken as given by the household. Using the CIA constraint on capital rentals, $\tilde{k}^D_F = \frac{b^D}{q^F}$, $\tilde{k}^D_F$ is eliminated as a separate decision since b^D is a choice variable and q^F is taken. Finally, since $k^D = \tilde{k}^D_D + \bar{k}^F_D$, k^D is predetermined, and $\bar{k}^F_D$ is a choice variable, we eliminate $\tilde{k}^D_D$ as a separate decision variable.

In a stationary equilibrium, domestic and foreign decision rules are fixed functions of the state. An equilibrium consists of prices, wages, interest rates, and an exchange rate as functions of the state consistent with equilibrium in the domestic and foreign labor, currency, goods, and capital-rental markets. In equilibrium p^D, p^F, w^D, w^F, i_L^D, i_L^F, q^D, q^F, and e^* along with value function $J^D(J^F)$ for the domestic (foreign) household satisfy (27) (the foreign analog to (27)). Also, decision rules associated with the households' problems satisfy:

$$m_F^D + m_F^F = 1;\ m_D^F + m_D^D = 1;\ H^D = \tilde{H}^D;\ H^F = \tilde{H}^F;$$

$$f_D^*(\tilde{k}_D^D,\tilde{k}_F^D,H^D,s) = c_D^D + c_D^F + (k^{D\prime} - (1-\delta_D^*)k^D);\ f_F^*(\tilde{k}_F^F,\tilde{k}_D^F,H^F,s) = c_F^F + c_F^D + (k^{F\prime} - (1-\delta_F^*)k^F);$$

$$\mathcal{L}^D = \mathcal{L}_s^D;\ \mathcal{L}^F = \mathcal{L}_s^F;\ \tilde{k}_F^D = \bar{k}_F^D;\ \tilde{k}_D^F = \bar{k}_D^F;\ \bar{\kappa}^D = k^D;\ \bar{\kappa}^F = k^F.$$

Combining first-order and envelope conditions for the domestic household's problem, optimal choices of m_F^D, n^D, b^D, $\tilde{H}^D$, $\mathcal{L}^D$, $k^{D\prime}$, and $\bar{k}_D^F$ satisfy:

(28) $$-\mu_{c_D^D}(t)\frac{e^*}{p^D} + \mu_{c_F^D}(t)\frac{1}{p^F} = 0$$

(29) $$-\mu_{c_D^D}(t)\frac{1}{p^D} + \beta_D^* \int \mu_{c_D^D}(t+1)\frac{1}{p^{D\prime}}(1+i_L^D)\frac{1}{1+x^D}\Phi(s'|s) = 0$$

(30) $$-\mu_{c_F^D}(t)\frac{1}{p^F} + \beta_D^* \int \mu_{c_D^D}(t+1)\frac{p^D}{p^{D\prime}}\frac{1}{1+x^D}f^*_{\tilde{k}_F^D}(\tilde{k}_D^D,\tilde{k}_F^D,H^D,\theta^D)\cdot\frac{1}{q^F}\Phi(s'|s) = 0$$

(31) $$\mu_{\tilde{H}^D}(t) + \beta_D^* \int \mu_{c_D^D}(t+1)\frac{p^D}{p^{D\prime}}\frac{w^D}{p^D}\cdot\frac{1}{1+x^D}\Phi(s'|s) = 0$$

(32) $$\frac{p^D}{w^D}f^*_{H^D}(\tilde{k}_D^D,\tilde{k}_F^D,H^D,\theta^D) - (1+i_L^D) = 0$$

(33) $$-\beta_D^* \int \mu_{c_D^D}(t+1)\frac{p^D}{p^{D\prime}}\frac{1}{1+x^D}\frac{p^D}{w^D}f^*_{H^D}(\tilde{k}_D^D,\tilde{k}_F^D,H^D,\theta^D)\Phi(s'|s)$$

$$+ (\beta_D^*)^2 \int \mu_{c_D^D}(t+2) \frac{p^{D'}}{p^{D''}} \frac{1}{1+x^{D'}} \left[f^*_{\tilde{k}_D^D}(\tilde{k}_D^{D'},\tilde{k}_F^{D'},H^{D'},\theta^{D'}) + \frac{p^{D'}}{w^{D'}}(1-\delta_D^*) f^*_{H^D}(\tilde{k}_D^{D'},\tilde{k}_F^{D'},H^{D'},\theta^{D'}) \right] \Phi(s'|s) = 0$$

(34) $$\frac{q^D}{w^D} f^*_{H^D}(\tilde{k}_D^D,\tilde{k}_F^D,H^D,\theta^D) - f^*_{\tilde{k}_D^D}(\tilde{k}_D^D,\tilde{k}_F^D,H^D,\theta^D) = 0,$$

where, for example, $\mu_{c_D^D}(t)$ represents the marginal utility of current domestic consumption of the domestically produced good. $p^{D''}$ is the domestic price level two periods forward.

Condition (28) is associated with the household's current choices of foreign and domestic currency balances. To identify the relevant margins, suppose that the household were to increase m_F^D by one foreign-currency unit while also cutting its domestic currency balance, m_D^D. According to the CIA constraint on foreign goods purchases, the unit increase in m_F^D enables the household to increase consumption of foreign-produced goods by $\frac{1}{p^F}$ units, the utility value of which is the second term in (28). On the cost side, in order to increase m_F^D by one unit, the household reduces its domestic money balance m_D^D by e^* units given the nominal exchange rate. With e^* fewer units of domestic currency, consumption of the domestically produced good is cut by $\frac{e^*}{p^D}$ units given the CIA constraint on domestic consumption purchases. The utility cost of this consumption reduction is the first term in (28) which is equated with the second, utility benefit, term in choosing currency holdings.

Condition (29) corresponds to the household's deposit decision. An increase in deposits, n^D, by one domestic currency unit reduces current domestic good consumption by $\frac{1}{p^D}$, according to the CIA constraint. This generates a utility cost measured by the first term in (29). The benefit from an additional unit of deposited currency derives from the additional loans that can be made by the intermediary. Per unit of domestic currency deposit, the intermediary brings home $(1+i_L^D)$ units of currency at the end of the period derived from lending to firms, which the household can use next period to purchase $\frac{1}{p^{D'}}(1+i_L^D)\frac{1}{1+x^D}$ additional units of domestic-good consumption. The discounted expected utility value of the additional consumption next period afforded by an additional current unit deposit is therefore given by the second term in (29). According to (29), the household's deposit choice balances the marginal utility cost and expected marginal benefit of deposited currency.

Condition (30) is associated with the choice of foreign currency, b^D, to utilize in renting foreign capital. To identify the margins, suppose that the household increases b^D by one foreign currency unit and, given the CIA constraint on foreign-good purchases, cuts current consumption of the foreign good by $\frac{1}{p^F}$ units. The consumption reduction generates a utility cost given by the first term in (30). On the benefit side, a unit increase in b^D allows the firm to rent $\frac{1}{q^F}$ units of foreign capital which provides $f^*_{\bar{k}_F^D}(t)\cdot\frac{1}{q^F}$ additional units of domestic output. Consequently, the firm's current revenue rises generating $\frac{p^D}{1+x^D}f^*_{\bar{k}_F^D}(t)\frac{1}{q^F}$ domestic currency units which the household can use next period to purchase domestic goods for consumption at a price of $p^{D'}$ per unit. Thus, the discounted expected utility benefit from allocating an additional unit of foreign currency to current foreign capital rental can be expressed as the second term in (30), which the household equates with the first, marginal cost, term.

Condition (31) states that labor is supplied to where the utility cost of a marginal reduction in leisure due to increasing labor supply further, $\mu_{\bar{H}^D}(t)$, equals the discounted expected future benefit. The benefit derives from extra consumption next period that can be purchased with the $\frac{w^D}{1+x^D}$ units of currency made available for next period by additional current nominal wage receipts. It is useful to note from condition (31) that for given future consumption and leisure values and a given current real wage, current labor supply is a decreasing function of anticipated inflation of the domestic price level. Intuitively, anticipated inflation acts as a tax on current labor supply by diminishing the expected reward to work effort. This follows from the fact that current nominal wage receipts cannot be used by the household to purchase units of goods until next period.

Condition (32) corresponds to the firm's loan choice. An additional unit of domestic currency from loan proceeds allows the firm to hire $\frac{1}{w^D}$ extra units of labor, according to the firm's CIA constraint on input acquisitions. The extra labor provides the household with $\frac{p^D}{w^D} f_{H^D}^*(t)$ additional units of domestic currency from goods market revenue which measures the benefit from extra borrowing in terms of additional currency carried into next period. The marginal cost of an extra unit of borrowed currency is $(1 + i_L^D)$, the loan obligation that must be paid at the end of the current period. According to (32), the firm borrows to where the marginal benefit and marginal cost in terms of end-of-period domestic currency are equal. The condition in (32) can alternatively be expressed as $f_H^*(t) = \frac{w^D}{p^D}(1 + i_D^L)$. From this, note that for a given current domestic real wage, an increase in the marginal cost of borrowing to finance input acquisitions, $(1 + i_D^L)$, reduces current labor demand. We have, from (31), that an increase in anticipated domestic price inflation exerts downward pressure on labor supply. From (32), an increase in anticipated domestic inflation exerts downward pressure on labor demand to the extent that higher anticipated inflation leads to increased nominal interest rates. Thus, an increase in anticipated inflation puts downward pressure on equilibrium employment.

Condition (33) is associated with the firm's investment decision. To identify the relevant margins, suppose that the firm were to increase $k^{D'}$ by one unit and, for a given amount of borrowing and capital rental revenue, cut labor employment by $\frac{p^D}{w^D}$ in accord with its CIA constraint on input acquisitions. Current revenues of the firm would then decrease such that next period's beginning domestic currency balance is reduced by $\frac{p^D}{1 + x^D} \frac{p^D}{w^D} f_{H^D}^*(t)$. The household could then satisfy its CIA constraint on domestic goods consumption next period by reducing domestic goods consumption, the discounted expected utility cost of which is expressed as the first term in (33). On the benefit side, an additional unit of capital acquired in the current period becomes productive next period and can be allocated for use in domestic production. In addition, given a unit increase in $k^{D'}$, the firm can satisfy its CIA constraint on input acquisitions next period by increasing labor demand by $\frac{p^{D'}}{w^{D'}}(1-\delta_D^*)$ units. Thus, given a unit increase in current investment, the firm's revenues next period would increase and, consequently, domestic currency available to the household for purchases of domestic consumption goods two periods ahead would increase by $\frac{p^{D'}}{1+x^{D'}}\left[f^*_{\bar{k}_D^D}(t+1) + \frac{p^{D'}}{w^{D'}}(1-\delta_D^*)f^*_{H^D}(t+1)\right]$. The discounted expected utility value of the implied extra domestic-goods consumption two periods forward is given by second term in (33). According to (33), the firm invests to where the discounted expected future utility benefit and cost are equal.

The remaining condition is (34), corresponding to the domestic firm's choice of units of capital to supply to the rental market, $\bar{k}_D^F$. Since the firm's total capital is allocated according to $k^D = \bar{k}_D^D + \bar{k}_D^F$, an extra unit supplied to the rental market implies one fewer unit devoted to domestic production since k^D is predetermined. The cost of increasing $\bar{k}_D^F$ by one unit can therefore be measured by the domestic output loss given as the second term in (34). The benefit is measured by the first term in (34). By renting a unit of capital to foreign firms, the domestic firm acquires q^D units of domestic currency which can be used to hire $\frac{q^D}{w^D}$ extra units of labor which, in turn, generate $\frac{q^D}{w^D}f^*_{H^D}(t)$ extra units of current output.

Effects of Monetary Shocks

Given the optimality conditions governing household choices for the FI setting above, now consider effects on interest rates, exchange rates, and real activity of monetary shocks. With persistence in money growth rates, current money shocks are nonneutral. Consider a domestic money growth shock with foreign money growth held fixed. The contemporaneous effect of a positive shock to domestic money growth is an increase in both the nominal exchange rate and domestic nominal interest rate, while domestic employment and output respond negatively.

To understand the forces acting on interest rates and real activities, note that a positive current domestic monetary injection leads to an upward revision of expected domestic inflation. For standard Fisherian reasons, with a relatively small effect on the real interest rate, the upward revision of anticipated inflation leads to an increase in domestic nominal interest rates.[7] Since the nominal rate of interest is the rate at which firms borrow, increases in the domestic nominal rate exert downward pressure on investment and labor demand by domestic firms. As noted earlier, higher expected domestic inflation also places downward pressure on domestic labor supply. Thus, domestic employment, investment, and output fall while the domestic nominal interest rate increases in response to a domestic monetary injection when money growth is persistent. In addition, an increase in the domestic nominal interest rate, by raising the cost to domestic firms of acquiring currency from intermediaries, provides an incentive for domestic firms to substitute toward currency acquisition via capital rentals to foreign firms. This puts upward pressure on rental capital supplied by domestic firms.

With respect to international transmission of a domestic monetary injection, first note that the induced decline in the domestic capital rental price leads to an increase in domestic capital rented by foreign firms. Second, note that a domestic monetary injection also serves to increase the domestic price level which, in turn, reduces desired consumption of domestically produced goods by households in each country. With nonseparable arguments of the utility functions, changes in consumption of domestically produced goods influences marginal utilities of leisure and consumption of foreign-produced goods for households in both countries. As a result of the rental price and goods price level effects, a domestic monetary shock influences the foreign price level, anticipated foreign inflation, and foreign real activities. Additional international effects are provided if there are spillover effects between money growth shocks in the two countries (nonzero values of M_{12} and M_{21} in (15)) or if money innovations across countries are correlated (nonzero off-diagonals V^x_{12} and V^x_{21}). With spillovers or correlated innovations present, when one country realizes a monetary shock, the other country's money growth is shocked as well.

In the full-information setting, a strong Fisherian connection exists between anticipated inflation and nominal interest rates in a country. A positive shock to money growth in a country, with persistence in the money growth rate, causes the nominal interest rate in that country to rise and output to fall. Such a result is, however, inconsistent with a prevailing view that positive monetary innovations in a country lead to nominal interest rate declines and to increases in output in that country. Indeed, empirical support for this view is reported by Christiano and Eichenbaum (1991), who find that in U.S. data the nominal federal funds rate is negatively correlated with various money supply measures and with real output. This leads us to consider alternative variants of the model, identified earlier as the sluggish-portfolio and sluggish-capital settings, which correspond to alternative assumptions about information available to agents when making current period choices.

The Sluggish-Portfolio Setting

In the sluggish-portfolio variant of the model, the domestic (foreign) household chooses m^D_D, m^D_F, n^D, b^D, and $\bar{k}^F_D$ (m^F_F, m^F_D, n^F, b^F, and $\bar{k}^D_F$) prior to observing current shock realizations. All decisions other than the currency balance, deposit, and capital rental decisions are made with full contemporaneous information. We include capital rental decisions as part of the households' portfolio decisions. Capital rented by firms provides a source of currency which can be used to acquire current inputs. The households' problems, equilibrium, and interpretations of optimality conditions are similar to what is described for the FI setting above. The exceptions are that now, in the SP setting, last period's shock realizations, rather than current realizations, will be in household information sets when decisions on currency balances, deposits, and capital rentals are made.

In the SP setting, liquidity effects enter into interest rate determination which sever the strong relation between nominal interest rates and Fisherian fundamentals found in the FI setting. Given slow portfolio adjustment, nominal interest rates depend not only on Fisherian fundamentals, but also on liquidity effects.[8] Intuitively, liquidity effects operate as follows. Given a positive domestic monetary injection received by intermediaries and an inability of households to adjust portfolios, downward pressure is exerted on the domestic nominal interest rate to induce firms to disproportionately absorb the additional currency injected into the economy. The effect of a monetary shock on interest rates and real activities is ambiguous, depending on relative magnitudes of anticipated inflation and liquidity effects.

With a sufficiently large liquidity effect following a domestic monetary injection, domestic nominal interest rates can fall even with higher anticipated inflation. Then, by reducing the cost to domestic firms of borrowing to finance input acquisitions, decreases in nominal interest rates can generate increased domestic employment, investment, and output. Thus, in accord with prevailing views, the SP setting is capable of producing a decrease in the nominal interest rate and an increase in output in a country in response to a monetary injection. However, if liquidity effects are outweighed by anticipated inflation effects, then a positive monetary innovation will lead to nominal interest rate increases and decreases in output in a country. Schlagenhauf and Wrase (1992) find that anticipated inflation effects of a monetary injection do outweigh liquidity effects when a sluggish-portfolio, open-economy model with capital im̲mobility is quantitatively evaluated using empirically plausible parameter values. This leads us to consider an environment with sluggish capital adjustment.

Before proceeding to the sluggish-capital setting, it is of interest to identify the effect on exchange rate determination of introducing the portfolio rigidity. In the FI setting, currency balances are chosen after observing current shocks and the nominal exchange rate is consequently a function of current shock realizations. In contrast, in the model variants which incorporate the nominal portfolio rigidity, currency balances for a period are predetermined by households prior to observing the period's shock realizations. The nominal exchange rate is therefore a function of the previous period's shocks. As a result of the difference in timing of portfolio choices in the FI and other variants of the model, predictions for nominal and real exchange rate volatilities will differ.[9] In addition, an implication of allowing for the portfolio rigidity is that goods prices adjust more rapidly to shocks than the nominal exchange rate. We discuss this adverse implication further, and a possible remedy, in sections 5 and 6.

The Sluggish-Capital Setting

In the sluggish-capital variant of the model, we retain the sluggish-portfolio assumption used in the SP setting, and also assume that the domestic (foreign) household chooses $k^{D'}$ $(k^{F'})$ prior to observing current shocks. All other decisions are made with full current information. The households' problems, equilibrium, and interpretations of optimality conditions parallel the FI setting. The capital rigidities assumed in the SC setting preclude firms from using monetary injections, borrowed from intermediaries, to contemporaneously finance capital good purchases or alter capital rentals. Consequently, positive monetary innovations in a country have the potential of generating larger positive employment and output responses than in the SP setting.

4. NUMERICAL SOLUTION AND PARAMETERIZATION OF THE MODEL

Solving the Models

Solving each model variant involves combining first-order and envelope conditions for the domestic household's problem, analogous conditions for the foreign household, and equilibrium conditions to obtain policy functions satisfying equilibrium and household optimality conditions. Since it is not possible to find closed-form solutions, we solve the models using the approximation procedure in Christiano (1990) which involves: (i) linearization of optimality conditions, with equilibrium conditions imposed, by taking first-order Taylor series expansions about the models' nonstochastic steady-state; (ii) conjecturing decision rules for choice variables that are linear in state variables and shocks; (iii) determining coefficient values for the linear decision rules using a method of undetermined coefficients.

Parameter Values

For each variant of the model, results of simulations are based on the following specifications of period utility functions, written here in terms of nontransformed variables:

$$\text{Domestic} \qquad \mu(C_{D,t}^D, C_{F,t}^D, L_t^D) = \frac{\left[(C_{D,t}^D)^{\phi^D(1-\gamma^D)}(C_{F,t}^D)^{(1-\phi^D)(1-\gamma^D)}(L_t^D)^{\gamma^D}\right]^{\psi^D}}{\psi^D}$$

$$\text{Foreign} \qquad \mu(C_{F,t}^F, C_{D,t}^F, L_t^F) = \frac{\left[(C_{F,t}^F)^{\phi^F(1-\gamma^F)}(C_{D,t}^F)^{(1-\phi^F)(1-\gamma^F)}(L_t^F)^{\gamma^F}\right]^{\psi^F}}{\psi^F}$$

where ϕ^D, γ^D, ϕ^F, and γ^F are each between zero and unity.

Production technologies, written in terms of nontransformed variables, are specified to be of the following forms:

$$\text{Domestic} \qquad f^D(\tilde{K}_D^D, \tilde{K}_F^D, H^D, \theta^D) = (\tilde{K}_{D,t}^D)^{\alpha^D\eta^D}(\tilde{K}_{F,t}^D)^{\alpha^D(1-\eta^D)}(Z_t^D H_t^D)^{(1-\alpha^D)}, \qquad 0 < \alpha^D < 1,\ 0 < \eta^D < 1,$$

$$\text{Foreign} \qquad f^F(\tilde{K}_F^F, \tilde{K}_D^F, H^F, \theta^F) = (\tilde{K}_{F,t}^F)^{\alpha^F\eta^F}(\tilde{K}_{D,t}^F)^{\alpha^F(1-\eta^F)}(Z_t^F H_t^F)^{(1-\alpha^F)}, \qquad 0 < \alpha^F < 1,\ 0 < \eta^F < 1,$$

To investigate quantitative properties of the model, we must assign values to the following parameters: β_j, ϕ^j, γ^j, ψ^j, α^j, η^j, δ^j, μ^j, x^j, for j=D,F, and to parameters of the productivity and money growth shock processes. Parameter values used in baseline simulations are summarized in Table 1.

The parameters ψ^D and ψ^F, which determine curvatures of domestic and foreign utility functions, are each set to -1 to allow for risk aversion. Discount rates β_D and β_F are each set to .99, which implies that agents in both countries face a steady state real interest rate of approximately one percent per quarter. A quarterly real rate of one percent is close to the average rate of return on capital over the last century in the United States. The share of domestic (foreign) goods in the domestic (foreign) household's total consumption bundle is governed by $\phi^D(\phi^F)$. We set ϕ^D and ϕ^F each equal to .50, values employed by Stockman and Tesar (1990). We also report results using alternative values to check for sensitivity of the results to values taken by ϕ^D and ϕ^F.

On the technology side, θ^D and θ^F are simply scale variables which we set to unity. The depreciation rate of capital is set equal to ten percent per annum for each country. Thus, we set $\delta_D^* = \delta_F^* = .025$. These values are used by Stockman and Tesar (1990), and are close to the average depreciation rate of capital for the U.S. over a sample period 1972:1–1989:4.[10] We also set the average growth rates of technologies, μ^D and μ^F, each equal to .004, the average growth rate in per capita real GNP in the U.S. data sample period. The share of domestic (foreign) capital in the domestic (foreign) firm's total capital input is governed by $\eta^D(\eta^F)$. Estimating these shares from data is difficult, so we proceed by setting η^D and η^F each equal to .50 for baseline values, and also report results using alternative values to check for sensitivity of results to values taken by η^D, η^F.

The stochastic processes that we assume govern shocks to technologies and money growth rates for the two countries are specified in (14) and (15). Parameters of the bivariate productivity shock process are based on results of Backus, Kehoe, and Kydland (1991) (BKK). BKK estimate parameters of a bivariate productivity shock process using Solow residuals for the United States (the domestic country) and an aggregate of six major European countries (the foreign country). Based on their estimates, we set

$$T = \begin{bmatrix} .892 & .062 \\ .156 & .906 \end{bmatrix},$$

where the standard deviation of domestic and foreign productivity innovations are, respectively, .01359 and .01261. The correlation between innovations is .263.[11]

Values for parameters of the bivariate money-growth process are taken from an estimated autoregression. For the domestic money measure, U.S. monetary base data were used. For the foreign measure, we constructed a monetary base variable using data for the countries used by BKK to estimate the productivity shock process.[12] The foreign base measure was created by converting each country's base into pounds using average 1985 exchange rates. Exchange rates were held constant so that the foreign money measure reflects only monetary base changes. From our estimate of (15) over the period 1972:1–1989:4 we set

$$M = \begin{bmatrix} .566 & .081 \\ -.001 & .445 \end{bmatrix}$$

The standard deviation of domestic and foreign money growth innovations are, respectively, .00383 and .00662. The covariance between the innovations is .00026. In addition, based on our estimates of (15), mean money growth for the U.S. (the domestic country) and for the composite foreign sector (the foreign country) are both approximately .018.

It remains to specify technology parameters α^D and α^F, and preference parameters γ^D and γ^F. The technology that we have specified for each country has a Cobb–Douglas form of composite-capital and labor substitution. This conforms with the relatively constant share of output accruing to labor observed in the U.S., in spite of large secular real wage increases. Labor's share for the domestic and foreign countries are governed by $1-\alpha^D$ and $1-\alpha^F$, respectively. The parameters γ^D and γ^F govern shares of period utilities accounted for by leisure in each country. We treat the domestic and foreign countries symmetrically for most simulations by setting $\gamma^D = \gamma^F$ and $\alpha^D = \alpha^F$. We report sensitivity of the results, however, to alternative settings. For baseline simulations, we use $1-\alpha^D = 1-\alpha^F = .65$ and $\gamma^D = \gamma^F = .76$, standard values used in closed economy real business cycle models. The .65 value for labor's share in each country conforms to postwar data for the U.S. economy. Also, given the form of the utility functions that we employ and parameter values assigned above, a .76 value for leisure share parameters is consistent with a steady state allocation in each country of roughly twenty six percent of nonsleeping time endowments to market activity.

5. QUANTITATIVE RESULTS

Using parameter values assigned above, along with decision rules obtained from the approximation procedure used to solve the model, we simulate each variant of the model economy. To quantitatively evaluate the models, we begin by considering the nonstochastic steady state. We then consider contemporaneous and longer-term responses of variables to monetary shocks, and compare volatilities of variables implied by the models with volatilities found in data from actual economies.

Nonstochastic Steady State

Each variant of the model shares a common nonstochastic steady state. Table 2 displays the models' implications, given parameter values assigned above, for steady state ratios of capital-to-output, and leisure-to-market activity, denoted in the table by $\frac{K^D}{Y^D}\left(\frac{K^F}{Y^F}\right)$ and $\frac{1-H^D}{H^D}\left(\frac{1-H^F}{H^F}\right)$, for the domestic (foreign) country. With symmetric parameter settings, these steady state ratios are the same for both countries. For comparison with the model implications, to serve as a first-moment check, Table 2 also provides sample averages of the capital-to-output and leisure to market-activity ratios for data drawn from the U.S. economy for the sample period 1972:1-1989:4.[13] As the first row of Table 2 indicates, steady state ratios implied by the models are quite close to the U.S. sample counterparts when baseline parameter values are used. The remaining rows of Table 2 are presented to provide information on sensitivity of the model's steady state to alternative parameter values.

Contemporaneous Responses of Variables to a Domestic Money Shock

Univariate Money Growth Processes

Table 3 reports contemporaneous responses of select variables to a one percent shock to the domestic money growth rate for each variant of the model. In Table 3A, baseline parameter values in Table 1 are used to obtain the responses with the exception of the money growth process. For money growth, parameter values from estimated univariate autoregressions for domestic and foreign money growth are used to abstract at first from the positive contemporaneous correlation between money growth rate shocks in the two countries and spillover effects in money growth rates found in our estimated bivariate money growth process. We can then identify contemporaneous responses of the models' variables due solely to a domestic money growth rate shock. By spillover effects, we mean that shocks to either country's money growth influences the other country's money growth rate via nonzero off-diagonal elements M_{12} and M_{21} in equation (15). Using univariate money growth processes amounts to setting $M_{12} = M_{21} = 0$, and $V_{12}^{x} = V_{21}^{x} = 0$ in the money-growth-innovations covariance matrix. According to our univariate estimates, we set $M_{11} = .1055$ and $M_{22} = .1139$.[14] The estimated standard deviations of domestic and foreign money growth innovations are, respectively, .00394 and .00673.

Begin by considering responses of variables to a domestic money growth rate shock given in rows (1)-(3) of Table 3A. Row (1) shows that in the FI variant of the model, a one-percent increase in domestic money growth, by increasing anticipated domestic inflation, raises the domestic nominal interest rate. Since an increase in the nominal rate raises the borrowing cost to firms of acquiring inputs, labor demand falls. Also, the increase in anticipated domestic inflation acts as a tax on work effort and leads to a decline in labor supply. Thus, in equilibrium, domestic employment and output fall. Domestic firms respond to the increased nominal borrowing cost of input acquisitions by increasing current capital rentals to foreign firms, $\bar{k}_{D}^{F}$, as a means of acquiring currency. Thus, relative to pre-shock levels, more of the domestic capital stock is rented to foreign firms, and less is used in domestic production. The decline in $\tilde{k}_{D}^{D}$ contributes to the negative domestic output response to the money shock.

There are two effects of the positive domestic money shock on foreign output. The first effect involves capital rentals. As noted above, foreign rentals of domestic capital increase in response to the shock. In addition to the increase in $\bar{k}_{D}^{F}$, domestic firms rent fewer units of foreign capital and, consequently, more of the foreign capital stock is devoted to foreign production relative to pre-shock levels. Thus, the foreign composite-capital input increases which exerts upward pressure on foreign output. The second effect on foreign output derives from price level effects. As the domestic price level is driven up in response to the domestic money shock, households cut back on consumption of the domestically-produced good and increase consumption of the foreign- produced good. Stronger demand for foreign goods drives the foreign price level up. With positive persistence in domestic money growth, the foreign price effect is anticipated to persist and anticipated foreign inflation increases. Anticipated foreign inflation effects exert downward pressure on foreign employment and output. According to row (1) of Table 3A, the positive capital rental effect on foreign output of the domestic money shock is outweighed by the negative anticipated inflation effect. On net, foreign output falls. With respect to exchange rates, higher domestic prices strengthen demands for domestic currency to accomodate planned expenditures which drives the nominal exchange rate up. The increased nominal exchange rate in conjunction with the domestic price increasing by a greater magnitude than the foreign price level leads to a decline in the real exchange rate.

Now consider the SP variant of the model where nominal interest rates and real activities are subject to liquidity effects as well as anticipated inflation effects. As row (2) of Table 3A indicates, the negative effect of increased liquidity on the domestic nominal interest rate is outweighed in equilibrium by the positive effect of higher anticipated inflation induced by the domestic money growth impulse. Due to the dominant anticipated inflation effect, labor demand is lower on net, as is labor supply, leading to the reductions in domestic employment and output shown in the table. Relative to the FI setting, domestic employment and output actually decrease by greater magnitudes in the SP setting. This reflects the fact that in the SP setting, firms are unable to respond to the increased nominal interest rate by increasing capital rentals in order to obtain currency. In contrast, the ability of domestic firms to respond by altering capital rentals to foreign firms in the FI setting effectively attenuates the negative domestic employment and output responses to the domestic money growth shock. In addition, since capital rentals are unresponsive to contemporaneous shocks in the SP setting, the positive response of capital rentals by domestic firms to foreign firms present in the FI setting is not present in the SP setting. This leaves only the negative anticipated foreign inflation effect on foreign employment and output.

As the domestic money infusion drives the domestic price level up, consumptions of domestically-produced goods fall in the SP setting. This reflects the CIA constraints since domestic prices are higher and shopping balances cannot respond to the money shock by assumption. As c_D^D and c_D^F fall, the marginal utility of consumption of foreign goods rises for households in each country and desired foreign goods consumptions rise. However, as the foreign price level rises, households are forced by their CIA constraints and predetermined foreign shopping balances to cut back on consumption of foreign goods in equilibrium. In addition, the anticipated foreign inflation effects identified above for the FI setting lead here to reductions in foreign employment and output. Thus, as row (2) of the table reveals, c_F^D and y^F fall in response to the domestic money growth shock.

Aside from its failure to display dominant domestic liquidity effects, the SP model carries with it adverse implications for nominal and real exchange rate responses to money shocks. The nominal exchange rate does not respond contemporaneously to the domestic money shock while the real exchange rate decreases by a large amount relative to the FI model. The lack of contemporaneous nominal exchange rate response is due to the assumption that agents make currency balance decisions prior to observing current shocks. Since households arrange domestic and foreign currency balances in the exchange market, the nominal exchange rate is contemporaneously unresponsive to current shocks. However, since domestic and foreign price levels are functions of current shocks, the real exchange rate responds in the period of the shock. Thus, modifying a basic FI cash-in-advance model to include sluggish nominal portfolio adjustment leads to the implication that the nominal exchange rate is slower to adjust than prices to monetary and technological shocks. We comment further on this feature of the SP model, and ways to eliminate it, in the final section.

For the SC model, the portfolio rigidity of the SP setting is augmented by the assumption that firms' investment choices are temporarily inflexible. As a result, there is a stronger positive effect of a domestic money infusion on domestic labor demand relative to the SP setting. As row (3) of Table 3A shows, in the SC model liquidity effects of the positive domestic money growth shock dominate anticipated inflation effects in equilibrium leading to a domestic nominal interest rate reduction and increased domestic output. As the domestic nominal interest rate falls, domestic firms are induced to borrow the newly injected currency received by intermediaries. Since the only contemporaneous shock-responsive input in the production process is labor, firms demand more labor. The positive labor demand response outweighs the negative effect on labor supply of increased anticipated domestic inflation. Consequently, domestic employment and output increase and the domestic price level falls.

As domestic prices fall, domestic and foreign consumptions of domestic goods rise given predetermined shopping balances and CIA constraints. This causes the marginal utility of consumption of foreign goods to fall in each country. Households therefore desire to consume fewer foreign goods which exerts downward pressure on foreign prices. Anticipated foreign inflation also falls leading to increased foreign employment and output which also exerts downward pressure on the foreign price level. Given predetermined shopping balances and CIA constraints on foreign goods purchases, the foreign price level reduction forces increased consumption in equilibrium of foreign goods by households in each country. As in the SP setting, the nominal exchange rate is unaffected contemporaneously by the domestic money growth shock while relative prices and the real exchange rate adjust.

Bivariate Money Growth Process

The results above provide information about dynamic properties of the models when a univariate process is used to characterize money growth for each of the two countries. Table 3B provides contemporaneous responses of variables in the models to a domestic money growth rate shock when we use our estimated bivariate process to characterize money growth rates. With our estimated bivariate process, we are allowing for spillover effects in money growth rates and a positive contemporaneous correlation between money growth rate shocks in the two countries. Now, a current positive shock to domestic money growth is accompanied by a positive foreign money growth shock with persistence in money growth in each country.

Comparing Tables 3A and 3B reveals that qualitatively and quantitatively responses of variables to a one percent domestic money growth shock do not differ much between the univariate and bivariate environments. The only qualitative difference involves responses in foreign output, consumptions of foreign goods, and the foreign price level for the SC setting (Row (3) of Table 3A for the univariate case and row (6) of Table 3B for the bivariate case). The signs of the responses of foreign output, y^F, domestic consumption of the foreign good, c_F^D, and the foreign price level are opposite across the univariate and bivariate environments. This reflects the influence of allowing spillovers across countries in money growth rates and a positive contemporaneous money shock correlation across countries on the strength of anticipated foreign inflation effects on foreign variables.

Contemporaneous And Longer-Term Responses to a Domestic Monetary Impulse

To provide a view of contemporaneous and longer-term effects of monetary shocks in the models, impulse responses are provided in Figure 1. The figure displays contemporaneous and lagged responses of select variables for each model variant to a one standard-deviation domestic money growth shock in quarter 10, assuming that a period in the model is one-quarter. The two countries are in nonstochastic steady state prior to the shock. The impulse responses are based on baseline parameter values and univariate money growth processes. Using univariate processes allows us to study the models' dynamic properties in the absence of money growth spillovers and money shock correlations between countries. We examine dynamic responses of variables due solely to a domestic money growth innovation.

There are five key features of the impulse responses. First, in all models (FI, SP, and SC) the nominal exchange rate rises (i.e. the domestic currency depreciates) in response to the positive domestic money growth shock. However, the responses in the SP and SC models lag the money shock by one period reflecting the portfolio rigidity in these models. The persistence in nominal and real exchange rate responses reflects persistence in domestic money growth. Second, reflecting responses of the nominal exchange rate and price levels, the real exchange rate falls in the period of the domestic money shock for the FI and SP models, and rises for the SC model. In the SC model, domestic and foreign prices fall in the period of the shock reflecting increased domestic and foreign output levels. Since the foreign price response is small relative to the domestic price response, the real exchange rate rises. Following the period of the shock, the domestic price level rises above its steady state value and then resembles the longer term responses in the other models by gradually falling to steady state. This contributes to real exchange rate overshooting in that after an initial rise, the real exchange rate falls below its steady state value and then gradually rises back to steady state.

The third key feature of the impulse responses is that the dominant liquidity effect on the domestic nominal interest rate in the SC model lacks persistence. The positive domestic money growth shock leads to a reduction in the domestic nominal interest in the period of the shock, but this liquidity effect exists only in the period of the money shock. Lack of persistence of liquidity effects is overcome in a closed-economy framework by Christiano and Eichenbaum (1991) who introduce costs of adjusting nominal flows originating from a household (depositor) sector and flowing to firms via financial intermediaries. Presumably, one remedy for the lack of liquidity effect persistence in our open-economy model is to introduce Christiano and Eichenbaum's nominal flow adjustment cost mechanism. Fourth, note the inverse responses of foreign (domestic) goods consumption by the domestic household and foreign (domestic) prices in the SP and SC models. These inverse responses reflect the effects of CIA constraints given that shopping balances in the SP and SC models are not contemporaneously responsive to shocks. Thus, when the domestic (foreign) price level changes in response to the domestic money shock, consumption of output produced in the domestic (foreign) country responds in the opposite direction of the price movement. Fifth, notice that in the SP model there is a relatively large domestic investment increase in the period of the money shock. The SC model prohibits a contemporaneous investment response and, since labor is the only contemporaneously shock-responsive input, domestic employment responds positively to the money shock. Domestic firms absorb the injected currency and use it to hire more labor inputs.

The impulse responses indicate that when the SP model is evaluated using empirically plausible parameter values, it fails to predict dominant liquidity effects. Results for the SC setting reveal that a model with the portfolio rigidities of the SP setting and with an additional rigidity on capital stock adjustment predicts a negative nominal interest rate response and positive employment and output responses to a shock to a country's money growth. However, for both the SP and SC models, nominal interest rate responses to a money shock lack persistence. In addition, both models imply that relative prices of goods across countries adjust more rapidly to shocks than the nominal exchange rate.

Volatilities of Variables with Correlations with Domestic Output

To evaluate the models along additional dimensions, Table 4 provides volatilities of variables, and cross-correlations with domestic output implied by the models compared to corresponding properties of data drawn from actual economies. For each variable listed in the table, the first row of numbers are moments for data drawn from actual economies for the sample period 1972:1-1989:4. Moments calculated for the models are from data obtained by simulations based on baseline parameter values in Table 1, including parameters for the bivariate money growth process. Properties of trade-weighted as well as country-specific nominal and real exchange rates found in actual data are provided separately in Table 5. As Table 5 reveals, standard deviations of measured nominal and real exchange rates are high relative to the standard deviation of U.S. output. Exchange rates are also positively autocorrelated and in general are negatively correlated with contemporaneous U.S. output. Standard deviations of trade-weighted nominal and real exchange rates in the data summarized in Table 5 are, respectively, 8.970 and 8.048. Expressed relative to the standard deviation of domestic (U.S.) real output, standard deviations of trade-weighted nominal and real exchange rates in the data are, respectively, 4.544 and 4.460. As Table 4 reveals, nominal and real exchange rate volatilities relative to domestic output volatility implied by the models are much lower. When the rigidities of the SP and SC models are introduced, the implied real exchange rate volatility rises, but remains well below the real exchange rate volatility found in the data.

It is of interest to compare exchange rate volatilities in Table 4 with volatilities implied by a variant of the model in which capital is immobile across countries (i.e. $\eta^D = \eta^F = 1$).[15] Shutting down capital mobility leads to nominal exchange rate volatilities for each information variant of the model that are roughly one-half of the volatilities shown in Table 4 for the mobile capital model. Real exchange rate volatilities in the immobile capital setting are roughly thirty-five percent lower than those reported in Table 4. Including a capital rental market as in this paper, with currency acquired in the currency exchange market used to rent capital, leads to increased exchange rate volatilities relative to a model with households exchanging currencies for use solely in purchasing units of consumption. However, the exchange rate volatilities implied by the mobile capital model in Table 4 remain well below volatilities found in actual data.

The standard deviation of domestic employment relative to output implied by the models fall short of what is found in actual data. The result for the SC model comes closest to the data moment since the assumed investment rigidity leads to greater effects of shocks on employment than in the other models. The SC model also generates much more nominal interest rate volatility and less domestic investment volatility than in actual data and in the FI and SP models. As firms are precluded in the SC model from altering investment in the period of a shock, the effect of shocks on employment and nominal interest rates are magnified, leading to increased volatilities of these variables relative to the other models. Notice also that in the SP and SC models in which shopping balances are rigid, domestic consumption volatility rises relative to the FI model and the data. This reflects the effects of predetermined shopping balances and binding CIA constraints. As prices respond to shocks, consumptions must respond proportionately and in the opposite direction.

With respect to cross-correlation of variables with domestic output reported in Table 4, there are three notable features. First, the detrended domestic price level is negatively correlated with domestic output in the data and for all models. The negative correlations in the models reflect that the importance of monetary shocks for the dynamics is small relative to the importance of technology shocks.[16] Second, the nominal exchange rate is negatively correlated with the contemporaneous value of domestic output in the data and each of the models. However, the real exchange rate is negatively correlated with contemporeanous domestic output in the data while a positive correlation is implied by each model. Third, note that in the actual data, the nominal exchange rate leads the cycle in that detrended domestic output is more highly correlated with earlier values of the nominal exchange rate than with the contemporaneous value. Interestingly, it is also the case in models with the portfolio rigidity that the nominal exchange rate leads the cycle. In the FI setting in which there is no portfolio rigidity, in contrast, the nominal exchange rate is more nearly coincident with the cycle in that the strongest cross-correlation is with the contemporaneous value of domestic output. The real exchange rate in the data also leads the cycle while, in contrast, the real exchange rate is more nearly coincident with the cycle in the models.

The dynamic properties of the models indicate that, at least along the international dimension of exchange rate behavior, the models considered here do not perform well quantitatively. There are three primary shortcomings. First, nominal and real exchange rate volatilities implied by the models are far below what are found in the data. Second, the portfolio rigidity of the SP and SC models implies that the nominal exchange rate responds to shocks with a lag while relative price levels and the real exchange rate respond contemporaneously. Third, dominant liquidity effects on the nominal interest rate in the SC model lack persistence.

6. CONCLUSION

We have constructed an open-economy, monetary general equilibrium model with capital mobility and money introduced via cash-in-advance constraints. The model is used to examine qualitative and quantitative implications of an open-economy, cash-in-advance model with and without portfolio rigidities similar to those in closed-economy models by Lucas (1990), Fuerst (1990), and Christiano (1991). Capital mobility across countries in the model is included by incorporating a capital-rental market. The need for firms in a country to acquire foreign currency in the currency-exchange market prior to renting foreign capital subjects exchange rates to additional sources of fluctuations relative to a model with immobile capital. Relative to a model with capital immobility, as in Schlagenhauf and Wrase (1992), the mobile-capital model in this paper implies greater nominal and real exchange rate volatilities.

A variant of our model in which all household decisions are made with full information about current technology and monetary shocks (our FI model) fails to allow for liquidity effects of monetary innovations. In addition, along an international dimension, the FI model implies exchange rate volatilities that are low relative to data from actual economies. Modifying the model to allow for liquidity effects by incorporating portfolio and capital rigidities (our SP and SC models) helps by increasing real exchange rate volatilities predicted by the model. However, the rigidities also hurt since by assuming that households choose foreign and domestic currency balances prior to observing a period's shocks, the modified models imply that nominal exchange rates are slower in responding to shocks than domestic and foreign prices. Useful extensions of the model analyzed in this paper would be to allow for deposit mobility across countries and to alter the timing of currency choices. By altering currency choice timing, the implications of the SP and SC model in this paper that nominal exchange rates are slower to respond to shocks than prices can be overturned.

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ENDNOTES

1. We generally use a subscript to refer to the country of origin of a good or money balance and a superscript to denote the residence of the agent choosing the variable.

2. Typically such a constraint, along with the other CIA constraints which follow, is specified as a weak inequality allowing for the possibility that an agent may choose not to spend all cash. Since our simulations will be performed using parameter values for which agents drive their cash constraints to bind as equalities, we work with binding constraints in the model to ease exposition.

3. As long as the loan rate is nonnegative in equilibrium, intermediaries will lend all their cash to firms. If the loan rate is zero, intermediaries will be indifferent between lending and storing cash, in which case assuming that they lend does not sacrifice generality.

4. Note that the domestic (foreign) capital stock is owned solely by domestic (foreign) households. Capital flows across countries within a period via rentals, but ownership remains with the country of origin. In addition, currencies flow across countries within a period in the exchange, goods, and capital-rental markets, but each country's money stock is carried from period to period by resident households. Additions to a country's capital stock derive solely from investment by resident firms.

5. Strictly, the value function depends on all state variables, and not just a^D, k^D, and s as written. To make equations less cumbersome we have included explicitly only the dependencies that are necessary to expose the household's optimality conditions.

6. Any temporary monetary shock in either country will be neutral. For example, when a transitory domestic monetary injection is received by domestic intermediaries, the fully informed households choose currency balances and deposits such that there are equiproportionate increases in cash balances used by shoppers in the domestic goods market and by domestic firms. The result is equiproportionate increases in current and future nominal exchange rates, domestic wages, and prices. Domestic inflation, nominal and real interest rates, and all foreign variables are unaffected. For both countries, current and future levels of consumption, investment, employment, and output are all unchanged.

7. The domestic (foreign) nominal interest rate is governed by Fisherian fundamentals —the real interest rate and the expected rate of inflation. To see this formally, note that (29) implies, using time subscripts:

$$(*) \qquad \frac{\mu_{c_D^D}(t)/p_t^D}{\beta_D^* E_t \mu_{c_D^D}(t+1)/p_{t+1}^D} = \frac{(1+i_{L,t}^D)}{1+x_t^D} = R_t^D,$$

where R_t^D denotes the domestic nominal interest rate and E_t is the expectations operator conditional on information dated t and earlier. According to (*), the domestic household equates the nominal rate with the relative marginal utility values of a unit of domestic currency in periods t and t+1.

Next, note that according to the standard condition for optimal intertemporal consumption allocation, the real rate of interest, r_t, is

$$(**) \qquad \frac{\mu_{c_D^D}(t)}{\beta_D^* E_t \mu_{c_D^D}(t+1)} = r_t.$$

Combining (*) and (**) gives

(***) $$R_t^D = E_t\left[\frac{\mu_{c_D^D}(t)}{\beta_D^{*}\mu_{c_D^D}(t+1)}\,\frac{p_{t+1}^D}{p_t^D}\right] = r_t E_t \frac{p_{t+1}^D}{p_t^D} + \mathrm{cov}_t\left[\frac{\mu_{c_D^D}(t)}{\beta_D^{*}\mu_{c_D^D}(t+1)},\ \frac{p_{t+1}^D}{p_t^D}\right].$$

According to (***), if the covariance term is small enough to ignore, the domestic nominal interest rate is approximately the sum of the real rate and the expected gross rate of inflation. Thus, the FI setting contains a strong connection between nominal rates of interest and Fisherian fundamentals.

8. To see liquidity effects formally, consider the choice of domestic deposits for the SP setting. Since the domestic household now chooses deposits prior to observing current shocks, the condition governing choice of n^D, analogous to (29) in the FI setting, is

(+) $$E_{t-1}\mu_{c_D^D}(t)\frac{1}{p_t^D} = E_{t-1}\beta_D^{*}\frac{(1+i_{L,t}^D)}{1+x_t^D}\mu_{c_D^D}(t+1)\frac{1}{p_{t+1}^D}.$$

For comparability with the FI setting, we can alternatively express the condition above by first defining $\Lambda_t^D = \frac{(1+i_{L,t}^D)}{1+x_t^D}E_t\beta_D^{*}\mu_{c_D^D}(t+1)\frac{1}{p_{t+1}^D} - \mu_{c_D^D}(t)\frac{1}{p_t^D}$, where from (+) $E_{t-1}\Lambda_t^D = 0$

Solving for $\frac{(1+i_{L,t}^D)}{1+x_t^D} = R_t^D$ gives (++) $$R_t^D = \frac{\Lambda_t^D + \mu_{c_D^D}(t)\frac{1}{p_t^D}}{\beta_D^{*}E_t\mu_{c_D^D}(t+1)\frac{1}{p_{t+1}^D}}.$$

The new variable, Λ_t^D, is what Christiano (1990) and Fuerst (1990) have termed a liquidity effect. Here, the liquidity effect measures a relative valuation of domestic currency in the domestic consumption—goods and financial markets. If, say, Λ_t^D is positive then the domestic financial market can be thought of as relatively illiquid. That is, relative to what would arise under full information, the domestic nominal interest rate turns out to be high. If domestic shoppers were able to do so, they would act by increasing deposits which would provide more loans to domestic firms. Shoppers cannot do so, however, since deposits are predetermined before current shocks are realized. In the FI setting, shoppers and firms act with equal information and $\Lambda_t^D = 0$ for all t (there are no liquidity effects). In the SP setting, however, Λ_t^D is only zero on average. Thus, the strong connection between nominal interest rates and fundamentals that holds under FI will hold only on average in the SP setting due to liquidity effects.

9. In the model, agents choose currency balances $m_{D,t}^D$, $m_{F,t}^D$, $m_{F,t}^F$, and $m_{D,t}^F$ at the beginning of period t. An alternative is to assume that period t beginning domestic and foreign currency balances for households in each country are predetermined, having been chosen in period t-1 and obtained in an exchange market that opens at the end of period t-1 at a nominal exchange rate that we could denote by $\tilde{e}_t^{*}$. This alternative assumption implies that even in a full-information setting, where choices in t-1 of ending balances $m_{D,t}^D$, $m_{F,t}^D$, $m_{F,t}^F$, and $m_{D,t}^F$ are made with full information concerning t-1 shocks, the nominal exchange rate $\tilde{e}_t^{*}$ will be a function of t-1 shock realizations. $\tilde{e}_t^{*}$ will not depend on period t shock realizations since currency exchanges take place prior to observing period t shocks. We choose, therefore, the timing of currency balance choices in the text to allow for

one model variant (FI) to imply a nominal exchange rate that depends on contemporaneously-dated shocks.

10. *Using per capita capital stock and investment series, the sample average rate of depreciation* on capital for the U.S. is $\delta = .020$. This average is of $1-(K_{t+1}-I_t)/K_t$, where K_t is the per capita capital stock and I_t is per capita investment. The capital stock data are for the period 1972:1-1989:4 and have been provided to us by John Musgrave.

11. The values for the variance-covariance matrix are different from those reported in BKK. This is due to the fact that technology shocks enter the production functions differently in the two papers. We have adjusted their variance-covariance estimate so as to be consistent with the specification employed in this paper. BKK's sample period is 1969:2-1987:3. Their foreign-country composite includes: United Kingdom, Finland, Italy, Germany, Switzerland, and Austria.

12. The monetary base data for the United States are defined as monetary base adjusted for reserve ratio changes taken from the CITIBASE data tape. The monetary base data for other countries are from International Financial Statistics and are defined as reserve money (Series 14) for each country. We seasonally adjust using a census 11 type procedure. The foreign countries used correspond to those used by BKK.

13. The U.S. data used in Table 2 are per capita capital stock and investment series identified in note 10 and per capita hours-worked data of Hansen (1984) updated to 1989:4 and divided by a quality adjusted population series consistent with Hansen's definition.

14. Results of estimated univariate, first-order money-growth autoregressions for the U.S. and for the composite of six foreign countries for the period 1974:1 to 1989:4 are:

$$\text{U.S.:}\quad x_t^D = \underset{(.00215)}{.007328} + \underset{(.10549)}{.5946827}\, x_{t-1}^D \;;\; \text{SEE} = .003936,\quad \bar{R}^2 = .3281$$

$$\Rightarrow \text{steady state growth } x^D = .01807$$

$$\text{Foreign:}\quad x_t^F = \underset{(.00217)}{.009789} + \underset{(.113921)}{.44466}\, x_{t-1}^F \;;\; \text{SEE} = .006728,\quad \bar{R}^2 = .1843$$

$$\Rightarrow \text{steady state growth } x^F = .01763$$

x_t^D and x_t^F denote, respectively, monetary base growth for the U.S. and foreign economies.

Data scources are provided in note 12 above. The foreign monetary base variable was constructed by taking a sum of (seasonally adjusted) foreign money supplies, each expressed in pounds using the average exchange rate for each country in 1985.

15. A model similar to the one used in this paper, except for capital mobility, is analyzed by Schlagenhauf and Wrase (1992).

16. Although not repored, we find that when variances V_{11}^x and V_{22}^x of money growth rate innovations are set to zero, output volatilities implied by the models do not differ substantially from those in Table 4. Monetary shocks have a relatively small influence on output volatilities in the models.

TABLE 1

BASELINE PARAMETER VALUES

PARAMETER		DOMESTIC COUNTRY	FOREIGN COUNTRY
Preferences			
Subjective Discount Factor	β	0.993	0.993
Utility Curvature	ψ	−1.000	−1.000
Leisure Share	γ	0.760	0.760
Home-Produced-Consumption Share	ϕ	0.500	0.500
Technology			
Composite-Capital Share	α	0.350	0.350
Home-Capital Share	η	0.500	0.500
Depreciation	δ^*	0.025	0.025
Scale Factor	θ	1.000	1.000
Trend Technology Growth	μ	0.004	0.004
Trend Money Growth	x	0.018	0.018

Shock Processes

Technology Shocks: $\begin{bmatrix} T_{11} & T_{12} \\ T_{21} & T_{22} \end{bmatrix} = \begin{bmatrix} .892 & .062 \\ .156 & .906 \end{bmatrix}, \begin{bmatrix} \sigma_{\varepsilon_t^D} & \sigma_{\varepsilon_t^D,\varepsilon_t^F} \\ \sigma_{\varepsilon_t^F,\varepsilon_t^D} & \sigma_{\varepsilon_t^F} \end{bmatrix} = \begin{bmatrix} .01359 & .01910 \\ .01910 & .01261 \end{bmatrix}$

Money Growth Shocks: $\begin{bmatrix} M_{11} & M_{12} \\ M_{21} & M_{22} \end{bmatrix} = \begin{bmatrix} .566 & .081 \\ -.001 & .445 \end{bmatrix}, \begin{bmatrix} \sigma_{x^D} & \sigma_{x^D x^F} \\ \sigma_{x^F,x^D} & \sigma_{x^F} \end{bmatrix} = \begin{bmatrix} .00383 & .00026 \\ .00026 & .00662 \end{bmatrix}$

σ_v represents the standard deviation of variable v.

$\sigma_{v^i v^j}$ represents the covariance between variables v^i, v^j.

TABLE 2

CAPITAL-TO-OUTPUT AND LEISURE-TO-MARKET ACTIVITY RATIOS

PARAMETERS[a]					STEADY STATE OF THE MODELS (FI, SP, SC)	
Row	Consump. Shares $\phi^D = \phi^F$	Composite-Capital Shares $\alpha^D = \alpha^F$	Home-Capital Shares $\eta^D = \eta^F$	Leisure Shares $\gamma^D = \gamma^F$	$\frac{K^D}{Y^D} = \frac{K^F}{Y^F}$	$\frac{1-H^D}{H^D} = \frac{1-H^F}{H^F}$
(1)	.5	.35	.5	.76	10.206	3.824
(2)	.5	.45	.5	.76	13.121	4.077
(3)	.5	.35	.5	.65	10.064	2.255
(4)	.7	.35	.5	.76	10.206	3.824
(5)	.5	.35	1	.76	10.205	3.824

Row	ϕ^D	ϕ^F	α^D	α^F	η^D	η^F	$\gamma^D = \gamma^F$		$\frac{K^D}{Y^D}$	$\frac{K^F}{Y^F}$	$\frac{1-H^D}{H^D}$	$\frac{1-H^F}{H^F}$
(6)	.7	.5	.35	.35	.5	.5	.76	.76	12.509	8.414	3.758	3.916
(7)	.7	.5	.35	.30	.5	.5	.76	.76	9.444	9.513	3.792	3.754
(8)	.5	.5	.35	.35	.7	.5	.76	.76	10.047	10.489	3.891	3.749

Sample Averages for U.S. Data[b], 1972:1-1989:4 $\frac{K}{Y} = 10.30$ $\frac{1-H}{H} = 3.69$

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ow (1) shows results from baseline parameter values in Table 1.

ow (2) shows that increasing the composite-capital shares drives capital to output ratios up relative to baseline results.

ow (3) shows that decreasing leisure shares reduces leisure to market activity ratios relative to baseline results.

ow (4) shows that increasing the share parameter on home produced consumption in each country's composite consumption s no effect on steady state ratios relative to baseline results.

ow (5) shows that increasing the share parameter on home capital in each country's composite capital input has a negligible ect on steady state ratios relative to baseline results.

ow (6)-(8) shows effects on increasing ϕ^D or η^D or of decreasing α^F while leaving all other parameters at their baseline ttings.

[a] Parameters not listed in the table are set at the baseline values in Table 1.
[b] Data Sources are provided in endnote 11.

TABLE 3

CONTEMPORANEOUS RESPONSES TO A ONE PERCENT INCREASE IN DOMESTIC MONEY GROWTH

3A. No Correlation Between Domestic and Foreign Money Growth Shocks, and No Spillovers[a]

Row	Model	Responses of Variables in the Period of the Money Shock[b]									
		$e(x^D)$	$re(x^D)$	$R^D(x^D)$	$Y^D(x^D)$	$Y^F(x^D)$	$c_D^D(x^D)$	$c_F^D(x^D)$	$H^D(x^D)$	$k_D^F(x^D)$	$k_F^D(x^D)$
(1)	FI	1.302	−0.437	0.294	−0.796	−0.094	−0.092	0.128	−0.178	0.240	−0.238
(2)	SP	0.000	−1.691	0.256	−0.842	−0.064	−0.871	−0.009	−0.199	0.000	0.000
(3)	SC	0.000	0.413	−2.924	0.501	0.085	0.254	0.042	0.118	0.000	0.000

3B. Positive Contemporaneous Correlation Between Domestic and Foreign Money Growth Shocks, and Positive Spillovers[c]

Row	Model	Responses of Variables in the Period of the Money Shock[b]									
		$e(x^D)$	$re(x^D)$	$R^D(x^D)$	$Y^D(x^D)$	$Y^F(x^D)$	$c_D^D(x^D)$	$c_F^D(x^D)$	$H^D(x^D)$	$k_D^F(x^D)$	$k_F^D(x^D)$
(4)	FI	1.213	−0.317	0.276	−0.717	−0.067	−0.081	0.079	−0.148	0.174	−0.172
(5)	SP	0.000	−1.503	0.223	−0.782	−0.208	−0.841	−0.074	−0.184	0.000	0.000
(6)	SC	0.000	0.636	−2.966	0.563	−0.077	0.285	−0.038	0.133	0.000	0.000

a. Univariate money growth processes were used (see endnote 12). Aside from parameters of the money growth process, all other parameter values are baseline values in Table 1.

b. Responses of variables are denoted by:

$e(x^D) = \frac{d\log e}{d\varepsilon_{x^D}}$ is the percentage change in the nominal exchange rate;

$re(x^D) = \frac{d\log\left(e \cdot \frac{p^F}{p^D}\right)}{d\varepsilon_{x^D}}$ is the percentage change in the real exchange rate;

$R^D(x^D) = \frac{dR^D}{d\varepsilon_{x^D}}$ is the percentage point change in the domestic nominal interest rate;

$Y^D(x^D) = \frac{d\log Y^D}{d\varepsilon_{x^D}}$ is the percentage change in domestic real output;

$Y^F(x^D) = \frac{d\log Y^F}{d\varepsilon_{x^D}}$ is the percentage change in foreign real output;

$c_D^D(x^D) = \frac{d\log c_D^D}{d\varepsilon_{x^D}}$ is the percentage change in domestic consumption of domestically produced goods;

$c_F^D(x^D) = \frac{d\log c_F^D}{d\varepsilon_{x^D}}$ is the percentage change in domestic consumption of foreign produced goods;

$H^D(x^D) = \frac{d\log H^D}{d\varepsilon_{x^D}}$ is the percentage change in domestic employment;

$k_D^F(x^D) = \frac{d\log c_F^D}{d\varepsilon_{x^D}}$ is the percentage change in foreign rentals of domestic capital;

$k_F^D(x^D) = \frac{d\log k_F^D}{d\varepsilon_{x^D}}$ is the percentage change in domestic rentals of foreign capital.

All derivatives are evaluated in nonstochastic steady state.

c. The bivariate money growth process was used. All parameters take baseline values in Table 1 in generating the responses in 3B.

TABLE 4

Moments of Select Variables[a]

Variable, v_t	Model	Standard Deviation	Correlation of Domestic Real Ouput With		
			v_{t-1}	v_t	v_{t+1}
Nominal Exchange Rate (e^*)	Data	8.970	−0.246	−0.145	−0.089
	FI	1.608	−0.239	−0.382	−0.205
	SP	1.616	−0.286	−0.178	−0.101
	SC	1.605	−0.276	−0.141	−0.066
Real Exchange Rate $\left[e^* \frac{p^F}{p^D}\right]$	Data	8.804	−0.213	−0.122	−0.083
	FI	0.769	−0.551	0.790	0.445
	SP	1.971	0.429	0.583	0.327
	SC	3.059	0.223	0.649	0.291
Domestic Nominal Interest Rate $(1+i_L^D)$	Data	0.388	0.054	0.306	0.408
	FI	0.426	0.054	0.039	−0.010
	SP	0.391	−0.023	0.086	0.049
	SC	1.873	0.224	−0.562	−0.229
Domestic Real Output (Y^D)	Data	1.974	0.872	1.000	0.872
	FI	1.574	0.673	1.000	0.673
	SP	1.545	0.672	1.000	0.672
	SC	1.824	0.490	1.000	0.490
Foreign Real Output (Y^F)	Data	1.399	0.752	0.754	0.647
	FI	1.340	0.102	0.164	0.215
	SP	1.337	0.103	0.219	0.218
	SC	1.736	0.007	0.184	0.123
Domestic Consumption (c^D)	Data	0.502	0.850	0.783	0.617
	FI	0.482	0.389	0.546	0.444
	SP	0.810	−0.065	0.392	0.327
	SC	0.935	−0.278	0.431	0.220
Domestic Investment (I^D)	Data	3.344	0.880	0.953	0.862
	FI	2.418	0.638	0.971	0.640
	SP	2.148	0.854	0.817	0.544
	SC	1.842	0.934	0.495	0.266

Domestic Employment (H^D)	Data FI SP SC	0.976 0.335 0.388 0.648	0.738 0.542 0.455 0.047	0.785 0.885 0.861 0.864	0.702 0.604 0.577 0.222
Domestic Price Level (p^D)	Data FI SP SC	1.795 1.715 1.692 2.426	-0.374 -0.637 -0.641 -0.312	-0.529 -0.958 -0.957 -0.973	-0.639 -0.634 -0.628 -0.476
Foreign Price Level (p^F)	Data FI SP SC	1.388 1.773 2.285 3.235	-0.675 -0.108 0.149 0.303	-0.688 -0.142 0.004 0.012	-0.647 -0.152 -0.041 -0.012

a. Results in this table are based on data that have been logged and then Hodrick-Prescott filtered. Actual percent standard deviations are reported for all variables except c^D, I^D, H^D where the standard deviations have been divided by the standard deviation of domestic output. Nominal interest rates are expressed at a gross quarterly rate prior to logging and filtering. Data for domestic variables except employment are from the CITIBASE tape defined as:

Y^D(GNP82), c^D(GCS82 + GCN82), I^D(GIF82), p^D(PUNEW), $1+i_L^D$ (FYGN3). Employment data are Hansen's (1984) series updated to 1989:4 and divided by a quality-adjusted population series consistent with Hansen's definition. Foreign variables are constructed by combining data for the UK, Finland, Italy, Germany, Switzerland, and Austria from the International Monetary Fund's International Financial Statistics. Foreign output is the pound value of real GNP for each country evaluated at 1985 exchange rates. The foreign price level is the weighted average of consumer price index of the countries where weights are the 1985 shares of the total pound value of GNP for the six countries. The exchange rate series are trade-weighted data defined in Table 5. c^D corresponds to

$c_{D,t}^D + e(s)\frac{p^F(s)}{p^D(s)}c_{F,t}^D$ in the model, where $e(s)\frac{p^F(s)}{p^D(s)}$ is the steady-state real exchange rate.

TABLE 5

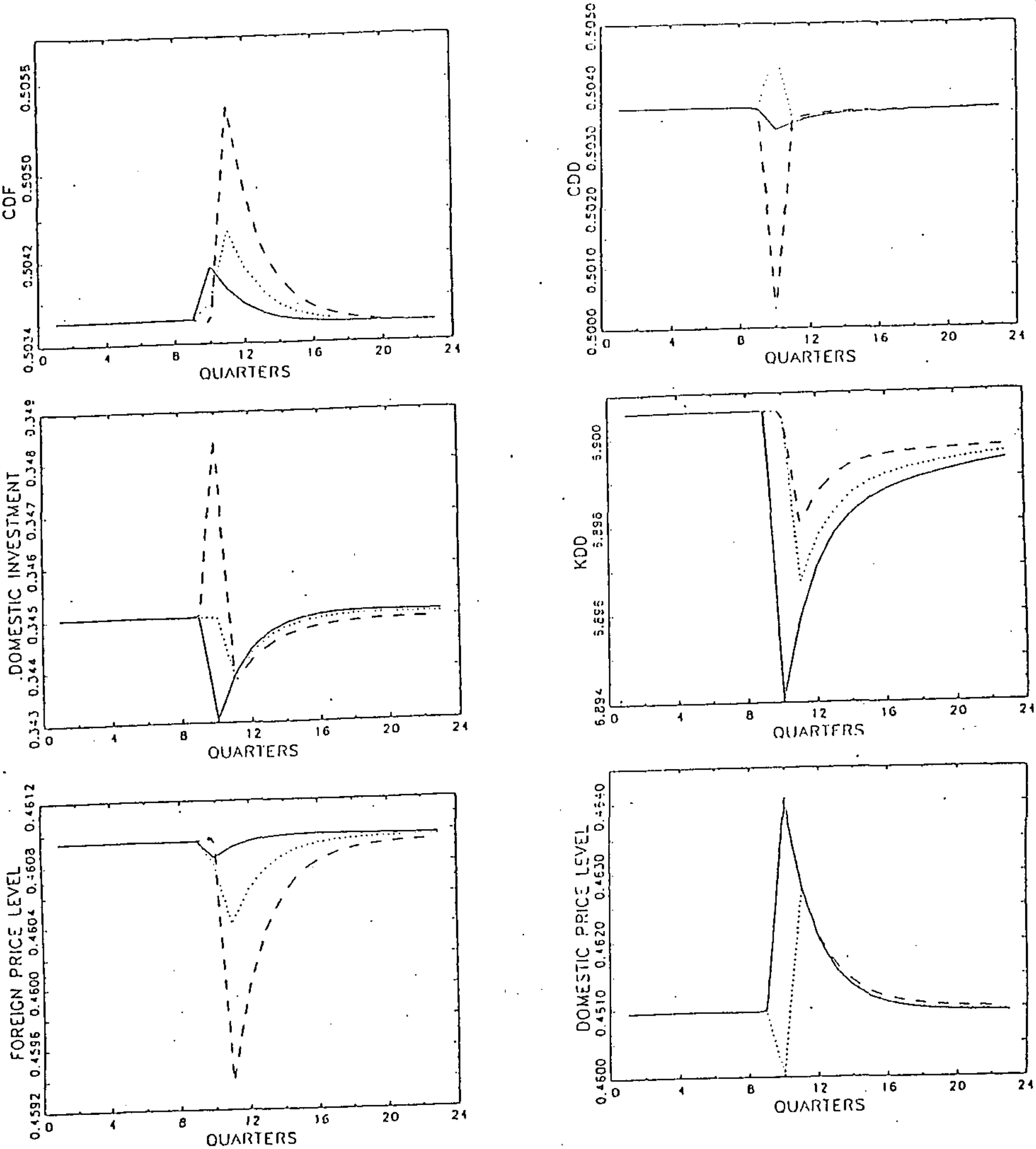
PROPERTIES OF EXCHANGE RATES: 1972:1–1989:4[a]

Nominal Exchange Rate, v_t	Standard Deviation (percent)	Autocorrelation			Cross-Correlations of Domestic (U.S.) Real Output With:		
		v_{t-1}	v_{t-2}	v_{t-3}	v_{t-1}	v_t	v_{t+1}
Trade Weighted	8.970	.847	.659	.532	–.246	–.145	–.089
Austria	9.432	.803	.586	.458	–.208	–.118	–.089
Finland	7.146	.823	.625	.516	–.123	.009	.113
Germany	9.815	.807	.587	.461	–.266	–.181	–.150
Italy	9.537	.853	.689	.536	–.198	–.136	–.136
Switzerland	10.333	.782	.558	.413	–.218	–.143	–.117
United Kingdom	9.523	.847	.667	.548	–.256	–.140	–.053

Real Exchange Rate, v_t	Standard Deviation (percent)	Autocorrelation			Cross-Correlations of Domestic (U.S.) Real Output With:		
		v_{t-1}	v_{t-2}	v_{t-3}	v_{t-1}	v_t	v_{t+1}
Trade Weighted	8.804	.839	.640	.509	–.213	–.122	–.083
Austria	9.198	.799	.573	.437	–.227	–.166	–.154
Finland	6.129	.777	.554	.454	–.071	.016	.072
Germany	9.640	.798	.565	.425	–.269	–.206	–.187
Italy	8.494	.815	.618	.429	–1.322	–.089	–.118
Switzerland	10.204	.774	.537	.384	–.196	–.133	–.116
United Kingdom	8.634	.821	.619	.499	–.180	–.091	–.039

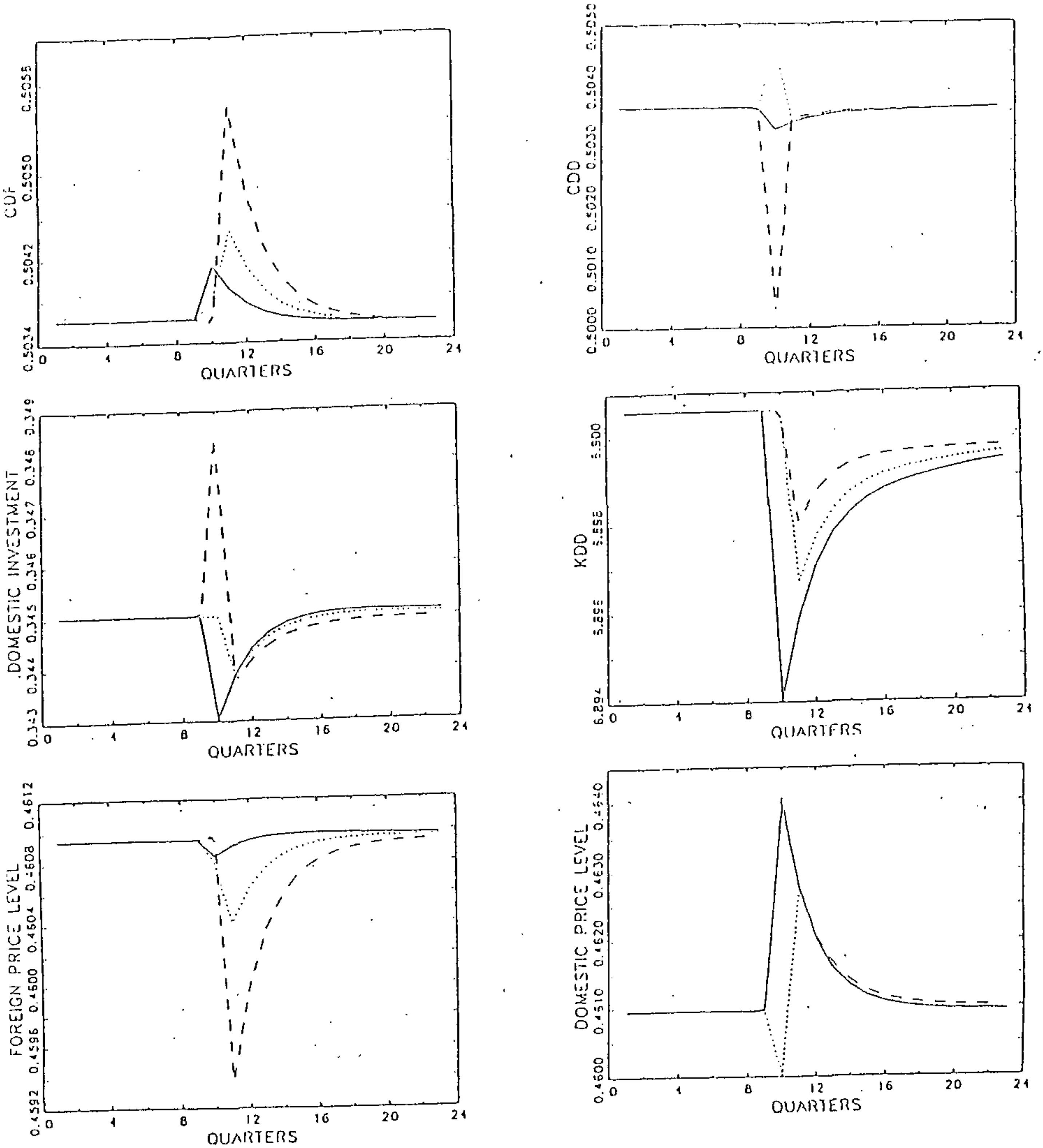
a. Results in this table are based on data that have been logged and then Hodrick–Prescott filtered. Data on exchange rates and prices are from the International Monetary Fund's International Financial Statistics. Exchange rates are series AE and price levels are series GD. The trade weighted index is the weighted index of spot rates for the six countries, where weights are 1985 trade shares taken from the International Monetary Fund's Direction of Trade publication.

FIG. 1: IMPULSE RESPONSES



a. Responses have been calculated using baseline parameter values from Table 1 except for parameters of the money growth process. Univariate money growth processes were used, with M_{11} = .1055, M_{12} = M_{21} = 0, M_{22} = .1139, and with standard deviations of domestic and foreign money growth innovations set to .00394 and .00673, respectively.

IG. 1: IMPULSE RESPONSES



. Responses have been calculated using baseline parameter values from Table I except for parameters of the money growth process. Univariate money growth processes were used, with M_{11} = .1055, M_{12} = M_{21} = 0, M_{22} = .1139, and with standard deviations of domestic and foreign money growth innovations set to .00394 and .00673, respectively.