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# Explaining International Comovements of Output and Asset Returns: The Role of Money and Nominal Rigidities

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## Abstract

Empirically, output and asset returns are highly positively correlated across the United States and the other major industrialized countries. Standard business cycle models that assume flexible prices and wages, in the Real Business Cycle tradition, have great difficulties explaining this fact. This paper presents a dynamic-optimizing stochastic general equilibrium model of a two-country world with sticky nominal prices and wages and a flexible exchange rate. The structure here predicts positive international transmission of country-specific monetary policy and technology shocks, and it generates sizable cross-country correlations of output and of asset returns.

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## I. INTRODUCTION

Empirically, output, interest rates and equity returns are highly positively correlated across the U.S. and the remaining major industrialized countries. In recent years, much attention in the International Macroeconomics literature has been devoted to dynamic-optimizing stochastic general equilibrium (DSGE) models of international business cycles that assume flexible prices and wages, in the Real Business Cycle (RBC) tradition. A widely discussed shortcoming of models of this type is that they generally fail to explain the high degree of comovement among the economies of the main industrialized countries (see the survey of International RBC models in Backus et al. (1995) and Baxter (1995)).

This paper presents a DSGE model of a two-country world with sticky nominal prices and wages. The model assumes a flexible exchange rate, fully integrated international bond markets and two types of exogenous shocks: productivity shocks and money supply shifts. Overlapping price and wage contracts, à la Calvo (1983), are postulated. In the baseline version of the model, the average duration between price and wage changes, at the microeconomic level, is set at 4 quarters (a duration consistent with empirical evidence on price and wage adjustment). In the structure here, firms with predetermined prices satisfy any demand that is addressed to them (at these prices)--the short run supply schedule of these firms is, thus, infinitely elastic. The analysis here stresses, thus, the role of changes in the demand for goods, as a source of short run output fluctuations.

In business cycle models without nominal rigidities, money supply shocks have a negligible effect on output. This changes when nominal rigidities are assumed. The nominal rigidities model here predicts that an exogenous money supply increase, in a given country, induces a sizable rise in domestic and *foreign* output, a fall in the domestic nominal interest rate, as well as a nominal and real depreciation of the country's currency. Nominal rigidities affect also the response of the economy to productivity shocks: in the nominal rigidities structure considered here, country-specific productivity shocks are much more strongly positively transmitted to foreign output, than in standard models without nominal rigidities. This explains why the nominal rigidities structure generates cross-country correlations of output that are markedly higher, and hence closer to the data, than the cross-country correlations that obtain when flexible prices and wages are assumed. In that structure, interest rates and equity returns are likewise predicted to be highly positively correlated across countries.

It appears also that the predicted variability of nominal and real exchange rates is higher--and closer to the data--when nominal rigidities are assumed, compared to structures without such rigidities (the nominal rigidities model presented here generates Dornbusch (1976) style exchange rate overshooting, in response to permanent money supply shocks).

Traditional Keynesian models typically predict a negative response of foreign output to a positive money supply shock at home, when the exchange rate is flexible (e.g., Mussa (1979)), as the depreciation in the home currency (that is induced by the home money supply shock) raises the price of foreign goods, relative to that of home goods, which induces agents to substitute foreign goods with home goods. The present analysis stresses two additional channels of international transmission that turn out to be, quantitatively, more important, in the structure here: (i) The demand for foreign goods rises, as part of the rise in aggregate demand in the home country (that is induced by the fall in the home interest rate, see above) is directed to foreign goods. (ii) The foreign price level falls, as the depreciation of the home currency reduces the foreign currency price of imports purchased by the foreign country; this raises foreign real balances, which reduces the foreign interest rate, and provides a further stimulus to demand for foreign goods. The same logic explains also why, in the structure with nominal rigidities, a productivity increase in the home country induces a sizable *rise* in foreign output.

In the model here, positive transmission of country specific money supply and technology shocks to *foreign* output occurs irrespective of whether nominal exchange rate movements are fully "passed through" into a country's export prices (denominated in *foreign* currency) or whether "pricing to market" behavior (incomplete exchange rate pass through) is assumed. The paper shows also that price and wage stickiness are *both* important for explaining observed international comovements (versions of the model that postulate that prices only are sticky or that only wages are sticky capture less well the high cross-country correlations of output and returns that are seen in the data).

It appears that the predicted responses of the world economy to exogenous shocks can be sensitive to the form of the policy rule followed by the monetary authorities, when nominal rigidities are assumed (the paper compares money supply rules that target the price level, output, and the exchange rate). In particular, vigorous countercyclical monetary policy (a policy of reducing the money growth rate when output rises) can dampen considerably the response of output, the exchange rate and asset returns to technology shocks and to autonomous monetary policy innovations, when there are nominal rigidities. However, the prediction of a sizable positive cross-country correlation of output and of asset returns holds for a range of plausible monetary policy rules.

The paper shows that nominal rigidities have important implications for the behavior of equity returns. For example, the nominal rigidities model here predicts that an unanticipated money supply increase in a given country induces, on impact, a significant increase in the national equity return, which is consistent with the data (e.g., Thorbecke (1997), Marshall (1992)). In contrast, standard business cycle models without nominal rigidities fail to generate a sizable response of equity returns to money supply shocks (Marshall (1992)).

The work here is related to Obstfeld and Rogoff's (1995) widely discussed dynamic-optimizing open economy model in which nominal prices are fixed in the short run, as firms are assumed to set their prices one period in advance. However, these authors' analysis is entirely qualitative and their model is more stylized than the structure here; e.g., that model abstracts from physical capital.[1] Furthermore, for plausible parameter values, that model predicts negative international transmission of money shocks.[2] Methodologically, the paper here builds on much recent work on calibrated DSGE models of *closed* economies with sticky prices or wages; see, e.g., Hairault and Portier (1993), Kim (1996), Yun (1996), Erceg (1997), Ireland (1997), Jeanne (1998) and Rotemberg and Woodford (1998).[3]

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[1]Also, the price adjustment mechanism assumed by Obstfeld and Rogoff generates very simple dynamics: e.g., after a permanent money supply shock, the economy is predicted to adjust to its new long run equilibrium in a single period. The model in the present paper yields richer dynamics.

[2]That model also cannot generate significant exchange rate volatility (no exchange rate overshooting in that model). Hau's (1998) version of the Obstfeld-Rogoff framework that assumes nominal *wage* rigidities (wages that are set one period in advance), rather than price rigidities in goods markets, likewise predicts negative international transmission of money supply shocks.

[3]The model here is an extension of the quantitative small open economy (SOE) model in Kollmann (1997) to a two-country world (because of the SOE assumption, that earlier model is not suited for studying the cross-country correlations that are the focus of the present paper). Quantitative (calibrated) dynamic-optimizing open economy models with sticky nominal *prices* have also recently been presented by Betts and Devereux (1997) [BD] and by Chari, Kehoe and McGrattan (1997) [CKM]. The paper here differs significantly from their work, i.a. by assuming incomplete international asset markets (see discussion below) and sticky *wages*, by considering a broader set of monetary policy rules and by examining model implications for a wider set of variables (i.a., asset returns). The focus of CKM's analysis is different from that of the paper here, although (as was brought to my attentions after the analysis here was completed) they too note that money supply shocks may generate positive cross-country correlations of output, when nominal rigidities are assumed. The BD model can likewise generate high cross-country correlations of output, when money supply shocks drive business cycles, but only when pricing to market (PTM) behavior by exporters is assumed (PTM is also postulated by CKM). Neither of these two models can capture the high cross-country correlations of interest rates that are seen in the data. The main results in the present paper do not hinge on PTM (empirical estimates of the incidence of PTM behavior vary widely, by country and industrial sector; see, e.g., Hooper and Marquez (1995) for references to the relevant literature). Also, the paper here shows that *productivity* shocks too generate substantial positive cross-country

The structure of the remainder of the paper is as follows: the model is outlined in Section II. Section III. discusses empirical regularities about international business cycles. Section IV. presents simulation results. Section V. concludes.

## II. THE MODEL

### A. Preferences

A world with two countries, indexed by i=1,2, is considered. Each country is inhabited by a representative household. The preferences of the country i household are described by:

$$E_0 \sum_{t=0}^{\infty} \beta^t \, U^i(C_t^i, \mathcal{M}_t^i/P_t^i, L_t^i). \tag{1a}$$

$E_0$ denotes the mathematical expectation conditional on information available in period t=0. $0<\beta<1$ is a subjective discount factor and $U^i(.)$ is an instantaneous utility function. $C_t^i$ is period t consumption in country i. $\mathcal{M}_t^i/P_t^i$ represents the household's real balances, where $\mathcal{M}_t^i$ denotes nominal money balances held at the beginning of period t, while $P_t^i$ is the price of consumption in period t. $L_t^i$ represents labor effort in period t. The household can provide labor services of different types. There exists a continuum of labor types, indexed by $h \in [0, 1]$. Let $l_t^i(h)$ denote the number of hours of type h labor. The variable $L_t^i$ that appears in the utility function is defined as: $L_t^i = \int_0^1 l_t^i(h)\, dh$.

The utility function $U^i$ is assumed to be of the following form:

$$U^i(C^i,\mathcal{M}^i/P^i,L^i) = (1/(1-\Psi)) \left\{ \left[ (C^i)^{\sigma} + \kappa\, (\mathcal{M}^i/P^i)^{\Gamma} \right]^{1/\sigma} \right\}^{1-\Psi} - L^i, \tag{1b}$$

where $\Psi$, $\sigma$, $\Gamma$ and $\kappa$ are parameters.[4]

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correlations of output, when nominal rigidities are assumed.

[4]Labor enters linearly in the period utility function. Such a specification is widely used in the Real Business Cycle literature, as it seems best suited for capturing the observed volatility of hours worked (e.g., Hansen (1985)).

## B. Technologies and Firms

Each country produces a single final good and a continuum of intermediate goods indexed by $s \in [0,1]$. The final good sector is perfectly competitive. Each country's final good is produced from domestic and imported intermediate goods. In contrast, there is monopolistic competition in the markets for intermediate goods--each intermediate good is produced by a single firm. Producers of intermediate goods use *domestic* physical capital and domestic labor as inputs (labor and physical capital are immobile internationally). Final goods cannot be traded internationally; however, intermediate goods are tradable. There exists a perfectly competitive rental market for physical capital, in each country.

### 1. Final Goods

The final good in country i is produced using the aggregate technology

$$Y_t^i = (D_t^i)^{1-\alpha} (F_t^i)^{\alpha}, \quad 0<\alpha<1 \tag{2}$$

where $\alpha$ is a parameter and $D_t^i$ and $F_t^i$ are indexes of domestic and imported intermediate goods, respectively:

$$D_t^i = \left\{ \int_0^1 d_t^i(s)^{1/(1+\nu)} \, ds \right\}^{1+\nu} \quad \text{and} \quad F_t^i = \left\{ \int_0^1 f_t^i(s)^{1/(1+\nu)} \, ds \right\}^{1+\nu}, \tag{3}$$

where $\nu>0$ is a parameter. $d_t^i(s)$ and $f_t^i(s)$ denote, respectively, the quantities of domestic and foreign intermediate good of type s that are used in the production of the final good in country i, at date t. Let $pd_t^i(s)$ and $pf_t^i(s)$ denote the prices of these two types of goods, in terms of the country i currency. Throughout the paper, all prices are expressed in the buyer's currency. Cost minimization conditions for final good producers can be written as:

$$d_t^i(s) = D_t^i \cdot \left(pd_t^i(s)/\mathfrak{PD}_t^i\right)^{-(1+\nu)/\nu}, \qquad f_t^i(s) = F_t^i \cdot \left(pf_t^i(s)/\mathfrak{PF}_t^i\right)^{-(1+\nu)/\nu} \tag{4a}$$

and

$$F_t^i/D_t^i = (\alpha/(1-\alpha))\ \mathfrak{PD}_t^i/\mathfrak{PF}_t^i, \tag{4b}$$

where $\mathfrak{PD}_t^i$ and $\mathfrak{PF}_t^i$ are price indexes, in country i currency, for intermediate goods produced in country i and for intermediate goods imported by that country, respectively:[5]

[5] $\mathfrak{PD}_t^i$ and $\mathfrak{PF}_t^i$ represent the minimal expenditure, in country i currency, needed to purchase one unit of the composite inputs $D_t^i$ and $F_t^i$, respectively,

$$\mathfrak{PD}_t^i \equiv \left\{ \int_0^1 pd_t^i(s)^{-1/\nu}\, ds \right\}^{-\nu} \quad \text{and} \quad \mathfrak{PF}_t^i \equiv \left\{ \int_0^1 pf_t^i(s)^{-1/\nu}\, ds \right\}^{-\nu}. \tag{5}$$

Perfect competition in the final goods market implies that the data t price of the final good in country i, $P_t^i$, is:

$$P_t^i = (1-\alpha)^{\alpha-1}\, \alpha^{-\alpha}\, (\mathfrak{PD}_t^i)^{1-\alpha}\, (\mathfrak{PF}_t^i)^{\alpha}, \tag{6}$$

at date t, where the expression of the right-hand side is the marginal cost of producing the good.

## 2. Intermediate Good Producers

The production function of the firm producing intermediate good 's', in country i, is:

$$y_t^i(s) = \theta_t^i\, (\mathcal{K}_t^i(s))^{\psi}\, (\mathcal{L}_t^i(s))^{1-\psi}, \tag{7}$$

at date t, where $y_t^i(s)$ is the firm's output. $\theta_t^i$ is an exogenous productivity parameter (productivity is identical for all intermediate goods producers in country i). $\mathcal{K}_t^i(s)$ is the physical capital stock used by the firm at date t, while $\mathcal{L}_t^i(s)$ is an index of the different types of labor used by the firm: $\mathcal{L}_t^i(s) = \left\{ \int_0^1 \ell_t^i(h;s)^{\gamma}\, dh \right\}^{1/\gamma}$, where $\ell_t^i(h;s)$ represents the quantity of type h labor used by the firm at date t; $\gamma<1$ is a parameter.

Let $R_t^i$ and $w_t^i(h)$ be the date t nominal rental rate of capital and the nominal wage rate for type h labor, respectively, in country i. The cost function of a firm in the intermediate goods sector of country i is:

$$\mathfrak{C}_t^i(y) \equiv \underset{\mathcal{K},\ell(h)}{\text{Min}}\; R_t^i \cdot \mathcal{K} + \int_0^1 w_t^i(h)\, \ell(h)\, dh \quad \text{s.t. } y = \theta_t^i\, \mathcal{K}^{\psi} \left( \left\{ \int_0^1 \ell(h)^{\gamma}\, dh \right\}^{1/\gamma} \right)^{1-\psi}.$$

Cost minimization implies:

$$\ell_t^i(h;s) = \mathcal{L}_t^i(s) \left( w_t^i(h)/W_t^i \right)^{1/(\gamma-1)}, \tag{8}$$

and

$$\mathcal{L}_t^i(s) = ((1-\psi)/\psi)\, R_t^i\, \mathcal{K}_t^i(s)/W_t^i, \tag{9}$$

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in period t.

where
$$W_t^i \equiv \left\{ \int_0^1 w_t^i(h)^{\gamma/(\gamma-1)} dh \right\}^{(\gamma-1)/\gamma} \tag{10}$$

is an aggregate wage index.[6] As the production function exhibits constant returns to scale, the firm's average and marginal cost are equal, and independent of its output level: $\mathfrak{G}_t^i(y)=y\cdot\mathfrak{G}_t^{i,}$, where $\mathfrak{G}_t^{i,}$ is the firm's marginal cost. (8)-(10) imply
$$\mathfrak{G}_t^{i,}=(1/\theta_t^i)\ (R_t^i)^{\psi}\ (W_t^i)^{1-\psi}\ \psi^{-\psi}\ (1-\psi)^{-(1-\psi)}. \tag{11}$$

The demand function of country i producer of intermediate good s in its domestic market is given in (4a). The firm faces the following demand function in its export market: $f_t^j(s) = F_t^j \left(pf_t^j(s)/\mathfrak{P}\mathfrak{F}_t^j\right)^{-(1+\nu)/\nu}$, where $pf_t^j(s)$ is the price (in country j currency) of the firm's good in country $j\neq i$. The firm's output equals the demand for its good:
$$y_t^i(s) = d_t^i(s) + f_t^j(s). \tag{12}$$

In period t, the nominal profit of the producer of intermediate good s, in country i, is thus:
$$pd_t^i(s)\ d_t^i(s) + e_t^{i,j}\ pf_t^j(s)\ f_t^j(s) - \mathfrak{G}_t^{i,}\cdot\ (d_t^i(s)+f_t^j(s)), \text{ with } j\neq i,$$
where $e_t^{i,j}$ is the bilateral nominal exchange rate between countries i and j, defined as the price of one unit of country j currency, in terms of the currency of country i.

Following Obstfeld and Rogoff (1995), it is assumed that there are no costs to trade between the countries, which implies that the price of each intermediate goods is the same in *both* markets, i.e.
$$pf_t^j(s)=pd_t^i(s)/e_t^{i,j} \text{ for } i\neq j, \tag{13a}$$
which implies
$$\mathfrak{P}\mathfrak{F}_t^i = \mathfrak{P}\mathfrak{D}_t^i/e_t^{i,j} \quad \text{for } i\neq j. \tag{13b}$$

Equations (13a), (13b) and the demand functions for intermediate goods (4a) imply that the nominal profit of the producer of intermediate good s in country i can be expressed as the following function of its home currency price, $pd_t^i(s)$:

6 $W_t^i$ represents the minimal expenditure, in country i currency, needed to purchase one unit of the composite labor input $\mathfrak{L}^i$ in period t.

$$\pi_t^i(pd_t^i(s)) \equiv (pd_t^i(s)-\mathfrak{G}_t^{i,}) \cdot (D_t^i+F_t^j) \cdot \left(pd_t^i(s)/\mathfrak{PD}_t^i\right)^{-(1+\nu)/\nu}, \quad \text{with } j\neq i. \tag{14}$$

*Determination of intermediate goods prices*

Prices for intermediate goods are set in a staggered fashion, à la Calvo (1983): producers of these goods are not allowed to change the *home currency* prices of their goods, unless they receive a random "price-change" signal. The probability that the price of an intermediate good of a given type, in terms of the home currency of its producer, can be changed in any particular period is 1–δ, a constant. As there is a continuum of goods, 1–δ represents also the fraction of all home currency prices that are changed each period; furthermore, the average time between price changes is 1/(1–δ).

Consider a producer of an intermediate good in country i that is "allowed" at date t to set a new home currency price for its good. Let $pd_{t,t}^i$ denote this new price. With probability $\delta^k$, the price $pd_{t,t}^i$ is still in effect at date t+k (k≥0). Hence, the firm sets $pd_{t,t}^i$ at

$$pd_{t,t}^i = \text{Arg}\ \underset{pd}{\text{Max}} \sum_{k=0}^{k=\infty} \delta^k E_t \rho_{t,t+k}^i\ \pi_{t+k}^i(pd)/P_{t+k}^i, \tag{15}$$

where $\rho_{t,t+k}^i$ is the pricing kernel used by the firm at date t to value random date t+k pay-offs (that are expressed in units of the composite consumption good). It is assumed that $\rho_{t,t+k}^i$ equals the intertemporal marginal rate of substitution in consumption of country i's representative household:

$$\rho_{t,t+k}^i = \beta^i\ U_{C,t+k}^i / U_{C,t}^i, \tag{16}$$

where $U_{C,t+k}^i$ is the household's marginal utility of consumption at date t+k.

Given the form of the profit function (14), the solution of the maximization problem in (15) is:

$$pd_{t,t}^i = (1+\nu)\ \left\{\sum_{k=0}^{k=\infty} \delta^k E_t\{\Xi_{t,t+k}^i\ \mathfrak{G}_{t+k}^{i,}\}\right\} \Big/ \left\{\sum_{k=0}^{k=\infty} \delta^k E_t \Xi_{t,t+k}^i\right\}, \tag{17}$$

$$\text{where} \quad \Xi_{t,t+k}^i \equiv \rho_{t,t+k}^i \cdot (1/P_{t+k}^i) \cdot (D_{t+k}^i + F_{t+k}^j) \cdot (\mathfrak{PD}_{t+k}^i)^{(1+\nu)/\nu}. \tag{18}$$

Note that the analysis here presupposes that firms that set a new price at date t satisfy the demand for their good, at that price, as long as the price remains in effect (see (12)). In other words, firms with predetermined prices (prices that were set in previous periods) have an infinitely elastic output supply schedule.[7]

[7]This assumption is standard in business cycle models with price rigidities

In period t, a fraction $(1-\delta)\delta^k$ of producers of intermediate goods are posting home currency prices that were set $k\geq 0$ periods ago. The definition of the price index $\mathfrak{PD}^i_t$ (see (5)) implies, hence, that the law of motion $\mathfrak{PD}^i_t$ is:

$$(\mathfrak{PD}^i_t)^{-1/\nu} = \delta\ (\mathfrak{PD}^i_{t-1})^{-1/\nu} + (1-\delta)\ (pd^i_{t,t})^{-1/\nu}. \tag{19}$$

For future reference, note that (4a), (7), (9), (12), (13a) and (13b) imply that the total demand for physical capital in country i can be expressed as:

$$\mathcal{K}^i_t \equiv \int_0^1 \mathcal{K}^i_t(s)\ ds = (D^i_t+F^j_t)\cdot(PD^i_t/\overline{PD}^i_t)^{-(1+\nu)/\nu}\cdot(1/\theta^i_t)\cdot((\psi/(1-\psi))\cdot W^i_t/R^i_t)^{1-\psi}, \tag{20}$$

where $\overline{PD}^i_t \equiv \{\int (pd^i_t(s))^{-(1+\nu)/\nu}\ ds\}^{-\nu/(1+\nu)}$ is a price index that evolves over time according to the following equation:

$$(\overline{PD}^i_t)^{-(1+\nu)/\nu} = \delta\ (\overline{PD}^i_{t-1})^{-(1+\nu)/\nu} + (1-\delta)\ (pd^i_{t,t})^{-(1+\nu)/\nu}. \tag{21}$$

Note, furthermore, that (8)-(10) imply that the total wage bill of intermediate goods producers located in country i is:

$$\int_0^1 \int_0^1 w^i_t(h)\ \ell^i_t(h;s)\ dh\ ds = ((1-\psi)/\psi)\ R^i_t\ \mathcal{K}^i_t. \tag{22}$$

(4a), (5), (13a), (13b) and (22) imply that total profits of country i producers of intermediate goods can be expressed as:

$$\Pi^i_t \equiv \int_0^1 \pi^i_t(pd^i_t(s))\ ds = \mathfrak{PD}^i_t\cdot(D^i_t + F^j_t) - (1/\psi)\ R^i_t\mathcal{K}^i_t. \tag{23}$$

### 3. Capital Rental Firms

Physical capital in country i is a homogeneous factor of production that is owned by firms that rent capital to producers of intermediate goods. The law of motion of the country i capital stock is:

$$K^i_{t+1} + \phi(K^i_{t+1},K^i_t) = K^i_t\ (1-d) + I^i_t, \tag{24a}$$

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(e.g., Mankiw (1997, ch.8)). Equation (17) implies that, up to a certainty equivalent approximation, the price $pd^i_{t,t}$ equals a weighted sum of current and expected future marginal production costs, multiplied by a constant mark-up factor, $1+\nu>1$. As long as the predetermined price $pd^i_{t,t}$ exceeds the firm's marginal (=average) cost, it is not in its interest to ration its customers.

where $I_t^i$, gross investment, denotes what quantity of final output produced in country i is required to change the capital stock from $K_t^i$ to $K_{t+1}^i$. $0<d<1$ is the depreciation rate of the capital stock and $\phi(.,.)$ is a convex adjustment cost function that is homogeneous of degree one in $K_{t+1}^i$ and $K_t^i$:

$$\phi(K_{t+1}^i, K_t^i) = 0.5\ \Phi\ \{K_{t+1}^i - K_t^i\}^2/K_t^i,\ \Phi>0. \tag{24b}$$

Capital rental firms located in country i maximize

$$\sum_{k=0}^{k=\infty} E_t \rho_{t,t+k}^i\ (R_{t+k}^i\ K_{t+k}^i - P_{t+k}^i\ I_{t+k}^i)/P_{t+k}^i,$$

where $R_{t+k}^i\ K_{t+k}^i - P_{t+k}^i\ I_{t+k}^i$ is the nominal cash flow of these firms, in period t+k. Optimal investment decisions by capital rental firms can be characterized by the following Euler equation:

$$1 = \beta\ E_t \left\{ \rho_{t,t+k}^i \cdot \left( \frac{R_{t+1}^i/P_{t+1}^i + 1-d + \phi_{2,t+1}^i}{1 + \phi_{1,t}^i} \right) \right\}, \tag{25}$$

where $\phi_{1,t}^i = \partial\phi^i(K_{t+1}^i, K_t^i)/\partial K_{t+1}^i$ and $\phi_{2,t+1}^i = \partial\phi^i(K_{t+2}^i, K_{t+1}^i)/\partial K_{t+1}^i$.

### C. Asset Markets, Household Consumption and Investment Decisions

The country i household can hold the following four assets: (i) local (country i) currency; (ii) a stock that represents a claim to the aggregate cash flow of all producers of intermediate goods and of all capital rental firms that are located in country i; (iii) nominal bonds denominated in domestic currency; (iv) nominal bonds denominated in foreign currency.[8] The bonds are risk-free and have a maturity of one period. Given this set of assets, the period t budget constraint of the country i household is:

$$\mathcal{M}_{t+1}^i + A_{t+1}^{i,i} + e_t^{i,j}\ A_{t+1}^{i,j} + \sigma_{t+1}^i\ S_t^i + P_t^i\ C_t^i = \mathcal{M}_t^i + T_t^i + A_t^{i,i}\ (1+r_t^i) + e_t^{i,j}\ A_t^{i,j}\ (1+r_t^j) + \sigma_t^i\ S_{t-1}^i\ (1+rs_t^i) + \int_0^1 l_t^i(h)\ w_t^i(h)\ dh, \quad \text{with } j\neq i \tag{26}$$

[8]The household's financial transactions are, thus, restricted to trade in bonds. This asset market structure is consistent with the well documented home-country bias in investors' equity portfolios (e.g., French and Poterba (1991)). Kollmann (1995, 1996, 1998) compares models of the international economy in which bonds only are traded internationally (as assumed in the present paper) to models that also allow for international trade in state-contingent assets--it is found that, empirically, the former models capture key international business cycle stylized facts better.

and $$(1+rs^i_t) \equiv \left(S^i_t + \Pi^i_t + R^i_t\, K^i_t - P^i_t\, I^i_t\right) \Big/ S^i_{t-1}. \qquad (27)$$

Here, $A^{i,i}_t$ represents the (net) stock of bonds denominated in country i currency that is held by the country i household, at the beginning of period t (end of period t-1), while $A^{i,j}_t$ represents its (net) holdings of bonds denominated in the foreign (country j≠i) currency. $r^i_t$ and $r^j_t$ are the nominal interest rates on these two types of bonds. $S^i_t$ is the nominal price (ex-dividend) of one equity share, in period t, while $\sigma^i_t$ is the number of equity shares held by the household, at the end of period t-1. $(1+rs^i_t)$ is the nominal gross return on country i equity, between periods t-1 and t (note that $\Pi^i_t + R^i_t K^i_t - P^i_t I^i_t$ is the total cash flow generated by all country i firms; see (23)). $T^i_t$ is a government cash transfer. The last term on the right-hand side of (26) is the household's total wage income.

The representative household's consumption and investment decisions in country i can be determined by maximizing the expected life-time utility function specified in (1a) subject to the restriction that the above budget constraint holds in all periods and for all states of the world. Ruling out Ponzi schemes, the following equations are first-order conditions of that decision problem:

$$1 = \beta\ (1+r^i_{t+1})\ E_t\left\{\left(U^i_{C,t+1}/U^i_{C,t}\right)\cdot\left(P^i_t/P^i_{t+1}\right)\right\}, \qquad (28)$$

$$1 = \beta\ (1+r^j_{t+1})\ E_t\left\{\left(U^i_{C,t+1}/U^i_{C,t}\right)\cdot\left(P^i_t/P^i_{t+1}\right)\cdot\left(e^{i,j}_{t+1}\ /e^{i,j}_t\right)\right\}, \qquad (29)$$

$$1 = \beta\ E_t\left\{\left(U^i_{C,t+1}/U^i_{C,t}\right)\cdot\left(P^i_t/P^i_{t+1}\right)\cdot(1+rs^i_{t+1})\right\}, \qquad (30)$$

$$\kappa\ (\Gamma/\sigma)E_t\left\{U^i_{C,t+1}\ (C^i_{t+1})^{1-\sigma}(\mathcal{M}^i_{t+1}/P^i_{t+1})^{\Gamma-1}/P^i_{t+1}\right\} = r^i_{t+1}\ E_t\left\{U^i_{C,t+1}/P^i_{t+1}\right\}. \qquad (31)$$

Equations (28)-(30) are Euler conditions, while equation (31) can be interpreted as a money demand equation.

### D. The Labor Market, Wage Determination

Overlapping nominal wage contracts of random duration are assumed. The nominal wage rate for labor of a given type can only be changed when a random "wage-change" signal is received. With an exogenously given probability $1-\mathfrak{D}$, the wage rate of a given labor type is changed in any particular period, in country i (hence, in each period, the wage rate of a constant fraction $1-\mathfrak{D}$ of labor types changes). Assume that, in country i, the wage for type h labor is changed in period t, and let $w^i_{t,t}(h)$ denote the new wage rate. With probability $\mathfrak{D}^k$, $w^i_{t,t}(h)$ is still in effect at date t+k (k≥0). It is assumed that the country i household makes a commitment at date t to provide $l^i_{t+k}(h)=\xi^i_t(h)\cdot\int_0^1 \ell^i_{t+k}(h;s)ds$ units of type h labor at date t+k at the wage rate $w^i_{t,t}(h)$, provided that $w^i_{t,t}(h)$ is still in effect at that date. Here, $\int \ell^i_{t+k}(h;s)ds$ is the total input of type h labor used by country i firms in period t+k; $\int \ell^i_{t+k}(h;s)ds$ is not determined at date t, but reflects the production decisions made by these firms at t+k and, hence, output demand at that date. In contrast, $\xi^i_t(h)$ is a decision variable for the household at date t, that allows the household to have an influence on her labor effort at date t+k (k≥0) (market clearing in the market for labor of type h requires $l^i_{t+k}(h)=\int \ell^i_{t+k}(h;s)ds$, i.e. $\xi^i_t(h)=1$; see (40), below). In Appendix II, the following first-order condition for the household's optimal choice of $\xi^i_t(h)$ is derived:

$$w^i_{t,t}\equiv w^i_{t,t}(h)=\left\{\sum_{k=0}^{k=\infty} (\beta\mathfrak{D})^k\ E_t\ \chi^i_{t+k}\right\}\Big/\left\{\sum_{k=0}^{k=\infty} (\beta\mathfrak{D})^k\ E_t\ \chi^i_{t+k}\ U^i_{C,t+k}/P^i_{t+k}\right\} \quad (32)$$

with

$$\chi^i_{t+k} \equiv ((1-\psi)/\psi)\ R^i_{t+k}\ \mathcal{K}^i_{t+k}\ (W^i_{t+k})^{\gamma/(1-\gamma)}. \quad (33)$$

(Note that $w^i_{t,t}(h)$ does not depend on the labor type h, i.e. the same wage rate is set for all labor types for which a wage change occurs at date t, in country i.)

For a fraction $(1-\mathfrak{D})\mathfrak{D}^k$ of labor types, the wage rate in effect at date t was set in period t-k (k≥0). Hence, it follows from (10) that the law of motion of the aggregate wage index in country i is:

$$(W^i_t)^{\gamma/(\gamma-1)} = \mathfrak{D}\ (W^i_{t-1})^{\gamma/(\gamma-1)} + (1-\mathfrak{D})\ (w^i_{t,t})^{\gamma/(\gamma-1)}.^{9} \quad (34)$$

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[9] N.B. When the wage rate is fully flexible ($\mathfrak{D}$=0), then (32), (33) imply $W^i_t/P^i_t=1/U^i_{C,t}$, which corresponds to the familiar first-order condition that prescribes the equalization of the marginal rate of substitution between consumption and leisure to the real wage rate (this marginal rate of substitution is given by $1/U^i_{C,t}$, as the marginal utility of leisure equals unity, for the utility function assumed here).

## E. Government

Each country has a government that prints the local currency. Let $M_t^i$ be the country i money supply, at the beginning of period t. Increases in the money stock are paid out to the representative household in the form of lump-sum transfers:

$$M_{t+1}^i = M_t^i + T_t^i. \tag{35}$$

The baseline version of the model assumed that the money supply is exogenous (the government makes no attempt to influence the exchange rate, i.e. the exchange rate floats freely).

## F. Market Clearing Conditions

Supply equals demand in the markets for intermediate as, by assumption, the producers of these goods always meet the demand that they face (see (12)).

Market clearing for the final good in country i requires:

$$C_t^i + I_t^i = Y_t^i. \tag{36}$$

Each country's currency is only held by its residents. Equilibrium in the country i money market requires, thus:

$$M_{t+1}^i = \mathcal{M}_{t+1}^i, \tag{37}$$

where $M_{t+1}^i$ is the country i money supply, while $\mathcal{M}_{t+1}^i$ represents the country i household's desired money balances.

Governments do not issue bonds. Market clearing in the market for bonds denominated in the currencies of the two countries requires, thus:

$$A_t^{1,1} + A_t^{2,1} = 0 \quad \text{and} \quad A_t^{1,2} + A_t^{2,2} = 0. \tag{38}$$

Market clearing in country i's rental market for capital requires:

$$\mathcal{K}_t^i = K_t^i, \tag{39}$$

where the left hand side is the total demand for physical capital in country i (as given by equation (20)), while the right hand side is the total supply of capital in that country.

Market clearing in country i's labor market requires that the supply of type h labor by the representative household ($l_t^i(h)$) equals the amount of type h labor purchased by firms:

$$l_t^i(h) = \int_0^1 \ell_t^i(h;s)ds \quad \text{for all } h\in[0, 1]. \tag{40}$$

Market clearing in the country i stock market requires that the demand for equity shares by the country's household equals the supply of shares.

Normalizing the supply of shares to unity, the market clearing condition in the country i stock market is, thus:

$$\sigma^i_t = 1. \tag{41}$$

When the market clearing conditions (37), (40) and (41) hold, then the household budget constraint (26) yields (using (22) and (23)) the following law of motion for country i's net foreign asset position:

$$A^{i,i}_{t+1} + e^{i,j}_t A^{i,j}_{t+1} = A^{i,i}_t (1+r^i_t) + e^{i,j}_t A^{i,j}_t (1+r^j_t) + \mathfrak{PD}^i_t (D^i_t + F^j_t) - (P^i_t C^i_t + P^i_t I^i_t). \tag{42}$$

### G. Solution Method

Given exogenous processes for productivity and the money supply $\{\theta^i_t, M^i_t\}^{t=\infty}_{t=0}$, and given $K^i_0, A^{i,i}_0, A^{i,j}_0, W^i_{-1}, \mathfrak{PD}^i_{-1}, \mathfrak{PF}^i_{-1}, \overline{PD}^i_{-1}, \overline{PF}^i_{-1}$ for i, j=1,2, equations (2), (4b), (6), (11), (13b), (16)-(21), (24a)-(39), and (42) determine the sequence of endogenous variables $\{Y^i_t, C^i_t, D^i_t, F^i_t, P^i_t, pd^i_{t,t}, \mathfrak{PD}^i_t, \mathfrak{PF}^i_t, \overline{PD}^i_t, \overline{PF}^i_t, w^i_{t,t}, W^i_t, R^i_t, K^i_{t+1}, I^i_t, r^i_t, rs^i_t, e^{i,j}_t, A^{i,i}_{t+1}, A^{i,j}_{t+1}, S^i_t\}^{t=\infty}_{t=0}$, for i, j=1,2. An approximate model solution can be obtained by taking a linear approximation of these equations around a deterministic steady state, i.e. around an equilibrium in which all exogenous and endogenous variables are constant. This approximation yields a system of linear expectational difference equations that can be solved using standard techniques (here, the formulae of Blanchard and Kahn (1980) are used). In the simulations below, the model is linearized around a deterministic steady state that is symmetric across countries (i.e. in which all variables have the same values in both countries), and in which each country's net stock of foreign currency bonds is zero.

### H. Parameter Values

#### 1. Preference, Technology and Price and Wage adjustment parameters

The simulations assume a coefficient of relative risk aversion of $\Psi=2$. This value lies in the range of risk aversion coefficients usually assumed in the business cycle literature (Friend and Blume (1975) present evidence consistent with this value of the risk aversion coefficient).

As mentioned above, equation (31) can be interpreted as a money demand equation. Up to a certainty equivalent approximation, (31) can be written as:

$$k\ (\Gamma/\sigma)\ (M^i_{t+1}/P^i_{t+1})^{\Gamma-1} = (c^i_{t+1})^{\sigma-1}\ r^i_{t+1} + \upsilon^i_{t+1}, \tag{43}$$

where $\upsilon_{t+1}^{i}$ is a forecast error $(E_t \upsilon_{t+1}^{i}=0)$. Hence, the elasticities of money demand with respect to consumption and with respect to the domestic nominal interest rate are given by $\varepsilon_{m,c} \equiv (\sigma-1)/(\Gamma-1)$ and $\varepsilon_{m,r} \equiv 1/(\Gamma-1)$, respectively. The simulations assume $\varepsilon_{m,c}=0.20$ and $\varepsilon_{m,r}=-0.01$, which pins down the preference parameters $\sigma$ and $\Gamma$ (see (1b)): $\sigma=-19$, $\Gamma=-99$. These values of $\varepsilon_{m,c}$ and $\varepsilon_{m,r}$ are in the range of estimates of the transactions elasticity and interest rate elasticity of money demand that are reported in econometric work on U.S. money demand (e.g., McCallum (1989) and Goldfeld and Sichel (1990)) as well in Fair's (1987) study of money demand in 27 industrialized countries.[10]

The preference parameter $\kappa$ (see (1b)) is set in such a way that the steady state consumption velocity (ratio of nominal consumption expenditure to the money stock) equals unity.[11]

The technology parameter $\alpha$ (see (2)) determines the ratio of the value of imports to the value of final good output. The simulations assume $\alpha=0.1$, as for the US, the ratio of imports to GDP has been approximately 10% during the post-Bretton Woods era.

The subjective discount factor $\beta$ is set at $\beta=1/1.01$, which implies that the steady state real interest rate is 1%--in steady state, $\beta\cdot(1+r)=1$ holds, where r is the steady state interest rate (business cycle models that are calibrated to quarterly data commonly assume a steady state real interest rate in the range of 1% per quarter, a value that corresponds roughly to the long run average return on capital).

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[10] These estimates pertain to short-run (quarterly) money demand elasticities. Estimates of short-run elasticities are used to calibrate the model, because the focus of the present paper is on high frequency movements in interest rates, exchange rates and other macroeconomic variables (long-run elasticities of money demand with respect to the transactions proxy are generally higher than short-run elasticities--e.g., estimation results presented by McCallum (1989) suggest that the long run elasticity is approximately 0.50). Note also that (as is common in the literature) the money demand functions estimated by the authors cited above use GNP as a scale variable, and not consumption per se.

[11] The key model predictions discussed below are not sensitive to the assumed steady state velocity (a unit velocity is roughly consistent with data on the M1 consumption velocity in the G7 countries; e.g., in the U.S. that velocity was 0.93 in 1994).

In steady state, the markup of price over marginal cost in the production of intermediate goods equals $\nu$ (the own-price elasticity of the demand for intermediate goods is $(1+\nu)/\nu$; see (4a)). $\nu$ is set at $\nu=0.2$, a value close to the estimates of mark ups (in U.S. manufacturing) reported in Basu and Fernald (1993).[12]

In the U.S. and in the remaining G7 countries, the share of total value added going to labor is roughly 0.66. In the model, the steady state share of wage payments to GDP is $(1-\psi)/(1+\nu)$, where $\psi$ is the elasticity of the production function of intermediate goods with respect to capital (see (7)). Hence, $\psi$ is set at $\psi=0.208$.

The capital adjustment cost parameter $\Phi$ (see (24b)) is set at $\Phi=8$, in order to enable the model to match the observed variability of investment (for lower values of $\Phi$, investment is excessively volatile).

The simulations consider a baseline case in which the average time between price changes (in home currency) at the firm level is 4 periods, where 1 period represents one quarter in calendar time (as the model is calibrated to quarterly data). This is motivated by recent empirical studies that suggest average time intervals between price adjustments in the range of 1 year, for a wide range of products (Romer (1996, p.294)). Thus, the parameter $\delta$ is set at $\delta=0.75$, i.e. a fraction 0.25 $(=1-\delta)$ of all prices are changed each period. The average interval between wage changes is likewise assumed to be four quarters, i.e. $\mathfrak{D}=0.75$ is used.[13]

## 2. Exogenous Variables

Table 1 reports estimation results for a vector autoregression (VAR) of order 1 that was fitted to quarterly money (M1) growth rates in the U.S. and in an aggregate of the remaining G7 countries (G6, henceforth), for the

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[12] The main simulation results are robust to the choice of $\nu$. In order to solve the model for the aggregate price and quantity variables on which the discussions below focus, no specific value has to be assigned to the parameter $\gamma$ that determines the elasticity of substitution between different types of labor (the linearization of the model yields a system of equations in the aggregate variables that does not depend on $\gamma$). N.B. The aggregate technology (2) implies that the elasticity of substitution between imported and domestic (intermediate) goods equals unity. That elasticity is in the range of estimated elasticities reported in the international trade literature (see Backus et al. (1995)).

[13] Taylor and Hall (1997, p.434) argue that wage adjustments for non-union workers occur typically once every year, in the U.S. (wage contracts of union workers are changed less frequently).

period 1973:Q3-1994:Q3.[14] The results show that the growth rate of money is positively serially correlated: the estimates of the diagonal elements of the matrix of autoregressive coefficients of the VAR are positive and highly statistically significant; in contrast, the off-diagonal elements are not statistically significant--the data are consistent with the hypothesis that a money supply innovation in one country has no effect on the money supply in the other country, in subsequent periods. Based on these findings, the simulations assume the following money supply process:

$$\begin{bmatrix} \Delta\ln(M^1_{t+1}) \\ \Delta\ln(M^2_{t+1}) \end{bmatrix} = \begin{bmatrix} 0.3 & 0 \\ 0 & 0.3 \end{bmatrix} \cdot \begin{bmatrix} \Delta\ln(M^1_t) \\ \Delta\ln(M^2_t) \end{bmatrix} + \begin{bmatrix} \zeta^1_t \\ \zeta^2_t \end{bmatrix}, \qquad (44)$$

where $\Delta$ is the difference operator (i.e. $\Delta\ln(M^1_{t+1})\equiv\ln(M_{t+1})-\ln(M_t)$); $\zeta^1_t$ and $\zeta^2_t$ are i.i.d. normal random variables with mean zero and a standard deviation of 0.009; the correlation between $\zeta^1_t$ and $\zeta^2_t$ is 0.20.[15]

Log productivity is assumed to follow a VAR:

$$\begin{bmatrix} \ln(\theta^1_t) \\ \ln(\theta^2_t) \end{bmatrix} = \begin{bmatrix} 0.906 & 0.088 \\ 0.088 & 0.906 \end{bmatrix} \cdot \begin{bmatrix} \ln(\theta^1_{t-1}) \\ \ln(\theta^2_{t-1}) \end{bmatrix} + \begin{bmatrix} \varepsilon^1_t \\ \varepsilon^2_t \end{bmatrix}, \qquad (45)$$

where $\varepsilon^1_t$ and $\varepsilon^2_t$ are i.i.d. normal random variables with mean zero and a standard deviation of 0.0085. The correlation between $\varepsilon^1_t$ and $\varepsilon^2_t$ is 0.258. The parameters of this process are taken from Backus et al. (1995) who argue that (45) captures well the time series properties of total factor productivity in the U.S. and in an aggregate of European countries. (45)

[14] See Section III. and Appendix I for a discussion of the data. Standard Augmented Dickey-Fuller unit root fail to reject the hypothesis that log U.S. and G6 money supplies follow unit root processes and Phillips and Ouliaris (1990) cointegration tests suggest that these series are not cointegrated. This implies that the series can be modeled as VAR in first differences (see Campbell and Perron (1991, p.170). The order of the VAR was chosen based on the Akaike information criterion.

[15] To simplify the discussion of the results, a symmetric shock process is assumed (the assumed autocorrelation of the money growth rate, 0.30, corresponds roughly to the mean of the diagonal elements of the autocorrelation matrix in Table 1; the standard deviations of the innovations in (44) are set at the mean value of the standard deviations of U.S. and G6 money supply innovations). N.B. as $M^i_{t+1}$ represents the money stock at the end of period t, the money supply innovation in (44) is assumed to belong to the date t information set.

implies that productivity is highly positively serially correlated, and that positive productivity innovations that occur in a given country raise productivity in the *other* country, with a lag.

## III. STYLIZED FACTS (POST-BRETTON WOODS ERA)

The last Columns of Table 3 (labelled "Data") document the business cycle stylized facts described in Section I, for the U.S. and for the aggregate of the remaining G7 countries referred to here as the G6. Standard deviations of (detrended) quarterly macroeconomic and financial variables are reported, as well as cross-correlations between these variables, for the period 1973:Q1-94:Q3. The time series for the G6 are weighted averages of time series for each of the G6 countries, using as weights the shares of these countries in total G6 output, in 1980 (for interest rates and stock returns, a weighted arithmetic average is used; for the remaining variables, a geometric average is used). The empirical measure of output used in Table 3 is real GDP, consumption is total private consumption and the money supply measure is M1; interest rates and equity returns are expressed on a quarterly basis. Detailed information on the data is provided in Appendix I. All historical time series have been detrended using the Hodrick and Prescott (1997) filter; before applying this filter, all series (with the exception of interest rates and equity returns) were logged.

Table 3 reports that the standard deviations of output, consumption, investment and the money supply are almost twice as large in the U.S. as in the G6 (the standard deviations of output and money are 1.8% and 2.3%, respectively, in the U.S. and 1.1% and 1.3%, respectively in the G6). In contrast, the standard deviations of the price level, the interest rate, dividends and equity returns are roughly similar across the U.S. and the G6.

In the U.S. and the G6, physical investment is more volatile than output, while consumption and the price level are roughly as volatile as output. Standard deviations of interest rates are smaller than those of output. In contrast, the real and nominal exchange rates between the U.S. and the G6, as well as stock returns are much more volatile than output (standard deviation of exchange rates and stock returns about 7%-8%). Dividends are more volatile than output, but less than half as volatile as stock returns.

Output, consumption, physical investment, the price level and the nominal interest rate are highly positively correlated across the U.S. and the G6 (the cross-country correlations of these variables are roughly in the 0.45-0.60 range; these cross-correlation are all statistically significant at the 1% level). The cross-country (U.S.-G6) correlations of money stocks and of dividends are somewhat lower (in the range of 0.30). Cross-country correlations of stock returns (around 0.70) are higher than those of output.

## IV. MODEL PREDICTIONS

Theoretical counterparts to the empirical standard deviations and cross-correlations that were just discussed are reported in Columns (1)-(6) of Table 3, as well in Tables 4 and 5. Columns (4)-(6) of Table 3 present model predictions for the baseline nominal rigidities model, while Columns (1)-(3) of that Table report results for a structure *without* nominal rigidities (i.e., in which the price/wage adjustment parameters $\delta$ and $\mathfrak{D}$ are set at $\delta=\mathfrak{D}=0$). Table 4 considers versions of the model with additional wage and price adjustment rules, while Table 5 considers versions of the model that assume alternative monetary policy arrangements. In these Tables, the theoretical output variable for country i is defined as $D^i_t+F^j_t$, with $j\neq i$ (this corresponds to country i's real GDP, in the model), consumption is $C^i_t$, the price level is $P^i_t$, the real exchange rate is defined as $e^{1,2}_t \cdot P^2_t/P^1_t$ and the theoretical measure of dividends is the aggregate cash flow $(\Pi^i_t + R^i_t K^i_t - P^i_t I^i_t)$. The model statistics reported in Tables 3-5 pertain to Hodrick-Prescott (1997) filtered variables. Prior to filtering, all variables (with the exception of interest rates and equity returns) were expressed in logs.

In Tables 3-5, results are presented for versions of the model that just assume money supply shocks, just technology shocks (see Columns labelled "Shocks to M" and "Shocks to $\theta$", respectively), as well as for versions in which the world economy is subjected to the two types of shocks simultaneously (Columns labelled "Shocks to M&$\theta$").

### A. Structure With Flexible Prices and Wages (Columns (1)-(3), Table 3)

Column (1) of Table 3 reports results for the case in which the structure with fully flexible prices and wages is subjected just to money supply shocks. In that structure, money supply shocks have almost no effect on output, consumption, investment, the real exchange and on real equity returns (the predicted standard deviations of these variables are all below 0.08%); in contrast, the predicted standard deviation of the price level matches roughly that seen in the data. The predicted standard deviation of the nominal exchange rate is close to that of the price level, and it is thus much too small, when compared to the data.

Technology shocks have a much stronger effect on real variables than money shocks, in the structure without nominal rigidities (e.g., in that structure the predicted standard deviation of output is 0.84% when there are just technology shocks; see Column (2), Table 3). However, technology shocks explain only roughly one-seventh of the observed standard deviation of the US-G6 real exchange rate, and an even smaller fraction of the standard deviations of stock returns; the predicted standard deviations of the price level, the nominal interest rate and the nominal exchange rate are likewise much too small, compared to the data, when just technology shocks are assumed.[16]

Note also that technology shocks induce *negative* cross-country correlations of output and investment, when prices and wages are fully flexible (a detailed discussion of this prediction is provided below). Interestingly, *money* supply shocks induces positive cross-country correlations of output, in the structure without nominal rigidities; however as, in that structure, money shock have a very weak effect on output, the predicted cross-country correlation of output is *negative* when that structure is simultaneously subjected to money supply shocks and to technology shocks, as can be seen in Column (3) of Table 3. (The predicted cross-country correlations of interest rates and equity returns are positive when both types of shocks are used, but much too small, when compared to the data.) These results confirm the widely discussed failure of standard business cycle models with flexible prices and wages to generate strong positive international transmission mechanisms of business cycles (Schmitt-Grohé (1998)) and to capture the high positive cross-country correlations of real economic activity seen in the data; see, e.g, Backus et al. (1995) and Baxter (1995).

### B. Baseline Nominal Rigidities Model (Columns (4)-(6), Table 3)

#### 1. Money Supply Shocks

Column (4) of Table 3 reports results for the version of the baseline nominal rigidities model in which just money supply shocks are assumed. It appears that, in the nominal rigidities model, money supply shocks have a much stronger impact on real variables, than in the structure without nominal rigidities: the baseline nominal rigidities model driven just by exogenous money supply shocks generates standard deviations of output, consumption, and dividends that are roughly consistent with the data. The predicted standard deviations of the (nominal and real) exchange rate and of equity returns (that are induced by money shocks) increase also noticeably, compared to the structure without nominal rigidities: the baseline nominal rigidities structure with money shocks captures roughly 40% of the historical standard deviation of the U.S.-G6 exchange rate, during the post-Bretton Woods era, and roughly one-fourth to one third of the historical standard deviations of equity returns.

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[16]The results here confirm previous studies that show that, in business cycle models without nominal rigidities, the predicted variability of exchange rates and stock returns tends to be much too low, when compared to the data, and that irrespective of whether money supply shocks and/or productivity shocks are assumed (see, e.g., Marshall (1992), Canova and De Nicolo' (1995), Schlagenhauf and Wrase (1995)).

Note also that this structure generates high positive cross-correlations of output, investment and consumption; these predicted correlations are not significantly different from the corresponding historical cross-country correlations, at the 10% level (see the standard deviations of the historical cross-country correlations reported in the "Data" Columns in Table 3). The baseline nominal rigidities structure with just money supply shocks captures almost perfectly the high cross-country correlation of the nominal interest rate that is seen in the data (0.57), and it generates cross-country correlation of *real* stock returns that are quite close to the correlations seen in the data (the predicted cross-country correlations of *nominal* stock returns are smaller than those of *real* stock returns, although they are higher than those generated by the structure without nominal rigidities). However, the predicted cross-country correlation of the price level, 0.10, is much smaller than that seen in the data, 0.64 (the model without nominal rigidities underpredicts likewise the cross-country correlation of the price level).

### *Impulse Response Functions*

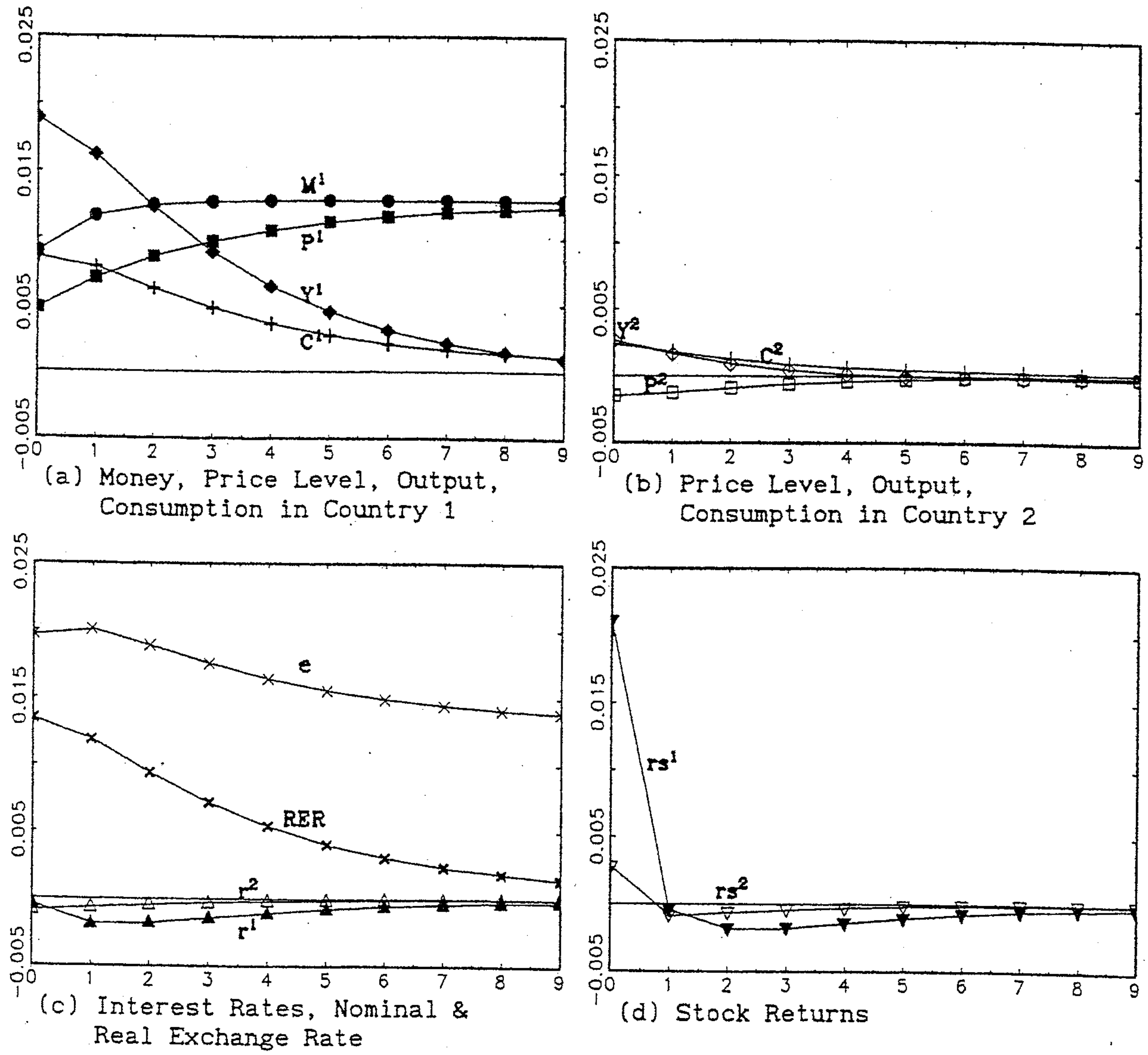
Figure 1 shows impulse response functions that help to understand why the baseline nominal rigidities model driven by money shocks generates sizable positive cross-country correlations of output, interest rates and equity returns. Specifically, it appears that, in that model, a country specific money supply increase induces a rise in domestic *and* foreign output and equity returns, and a fall in domestic *and* foreign interest rates.

For the baseline model, Figure 1 shows the dynamic effects of a one standard deviation (i.e., 0.90%) innovation to the money growth rate in country 1. The nominal exchange rate in the Figure is defined as the price of one unit of the currency of country 2, in terms of the country 1 currency ($e_t^{1,2}$). The responses of all variables (with the exception of the interest rate and the equity return) are expressed as relative deviations from the "unshocked" steady state.[17]

The country 1 money supply increase induces a rise in that country's price level. However, the price level increases less rapidly than the money supply and, as a result, real money balances rise in country 1, which helps to understand why the shock induces a persistent reduction in that country's interest rate (see Panel (c), Figure 1). The reduction in the interest rate raises consumption and investment demand in country 1--hence, country 1 output increases, on impact (see Panel (a)).

[17]The response of a given variable $z_t$ is shown as $(z_t-z)/z$, where z is the value of that variable in the unshocked steady state. In contrast, responses of interest rates and equity returns are shown as differences from that steady state (e.g., $r_t-r$, where r is the steady state interest rate).

Figure 1. Baseline Nominal Rigidities Model: Country 1 Money Supply Shock




Dynamic Responses to 1 Standard Deviation Innovation to Country 1 Money Growth Rate. Responses of Interest Rates and Stock Returns Expressed as Differences From Initial Position; Responses of Other Variables Shown as Relative Deviations From Initial Position. Period t Responses of Money Stocks, Interest Rates and Stock Returns Pertain, Respectively, to End of Period Money Stocks ($M_{t+1}$), Interest Rates Between t and t+1 ($r_{t+1}$) and to Realized Stock Returns Between t-1 and t ($rs_t$).

Abscissa: Periods After Shock.

●: Country 1 Money (M), ×: Nominal Exch. Rate (e), ✖: Real Exch. Rate (RER).

*Country 1/Country 2*
■/□: Price Level (P), ◆/◇: Output (Y), +/+: Consumption (C),
▲/△: Nominal Interest Rate (r), ▼/▽: Nominal Stock Return (rs).

Panel (c) of Figure 1 shows that, on impact, a 0.9% money supply innovation induces a depreciation of the country 1 nominal exchange rate by about 2%.[18] In subsequent periods, the exchange rate appreciates and converges to its new long-run level.[19] The long-run effect of the money supply shock is a depreciation of the exchange rate by approximately 1.2% (it appears that the country 1 money supply and price level rise by roughly 1.2%, in the long run). As in Dornbusch's (1976) exchange rate model, the initial response of the exchange rate to a permanent money supply shock exceeds thus the long-run response, i.e. there is exchange rate "overshooting". In contrast, no exchange rate overshooting occurs when there are no nominal rigidities, which explains why the nominal exchange rate is more volatile in the nominal rigidities model, as discussed above (impulse response functions for the structure without nominal rigidities are available from the author). Because of the sluggishness of the price level, the nominal depreciation of country 1's exchange rate is accompanied by a substantial *real* depreciation (see Panel (c) in Figure 1), which explains why the predicted standard deviation of the *real* exchange rate increases strongly when nominal rigidities are assumed (from 0.01% in the case without nominal rigidities to 2.17% in the baseline nominal rigidities model, when just money supply shocks are assumed).

Panel (b) in Figure 1 shows that, in response to a positive money supply shock in country 1, country 2 output rises (though by less than country 1 output). The rise in country 2 output is due to the following two mechanisms: (i) The rise in consumption and investment demand in country 1 raises the demand for intermediate goods produced in country 2. (ii) The fall in the external value of the country 1 currency reduces the price of imports (in terms of country 2 currency) purchased by country 2, which lowers the price level in country 2; this raises country 2 real balances and, thus, induces a persistent reduction in that country's interest rate (see Panel (c), Figure 1), which provides a further stimulus to demand for country 2 goods.

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[18]The prediction that a positive money supply shock induces a rise in domestic output, a fall in the domestic interest rate and an exchange rate depreciation is consistent with recent empirical evidence on the effect of money supply shocks (e.g., Eichenbaum and Evans (1995), Grilli and Roubini (1996)).

[19]Conditions (29) and (30) imply that, up to a certainty equivalent approximation, Uncovered Interest Parity holds, in equilibrium: $(1+r^1_{t+1})\simeq(1+r^2_{t+1})(E_t e^{1,2}_{t+1}/e^{1,2}_t)$. As discussed above, a positive money supply shock reduces the interest rate in country 1 (the country 2 interest rate falls as well, but by less); hence, the country 1 currency has to *appreciate* in the periods that follow the money supply shock.

In contrast to the model here, traditional Keynesian models typically predict a *negative* response of foreign output to a positive money supply shock at home, when the exchange rate is flexible (e.g., Mussa (1979)), as the depreciation in the home currency (that is induced by the home money supply shock) raises the price of foreign goods, relative to that of home goods, which induces agents to substitute foreign goods with home goods. This effect operates in the model here, but turns out to be quantitatively less important than the two positive channels of international transmission described in the preceding paragraph.

Finally, note that as a positive money supply innovation in country 1 induces a persistent reduction in the interest rate and a rise in real economic activity, in both countries, nominal stock returns are predicted to rise in both countries, on impact (the rise is considerably smaller in country 2 than in country 1). In the periods after the shock, stock returns are predicted to fall *below* their pre-shock level.[20]

### 2. Baseline Model with Nominal Rigidities: Technology Shocks

Column (5) of Table 3 reports results for the version of the baseline nominal rigidities in which just technology shocks are assumed. The main consequence of nominal rigidities for the response of the economy to technology shocks is that the cross-country correlations of macroeconomic aggregates and of asset returns that are induced by these shocks increase considerably; e.g., the predicted cross-country correlation of output is 0.51, in the baseline nominal rigidities model, when just technology shocks are assumed (compared to -0.05 in the structure without nominal rigidities).

For the nominal rigidities model, Figure 2 shows the effect of a one standard deviation (i.e. 0.85%) productivity innovation in country 1. That shock raises output (and consumption) in country 1; it also induces a fall in that country's price level and in its nominal interest rate, as well as a nominal and real depreciation of its currency (as the nominal money supply is held constant in the experiment considered in Figure 2, the fall in the

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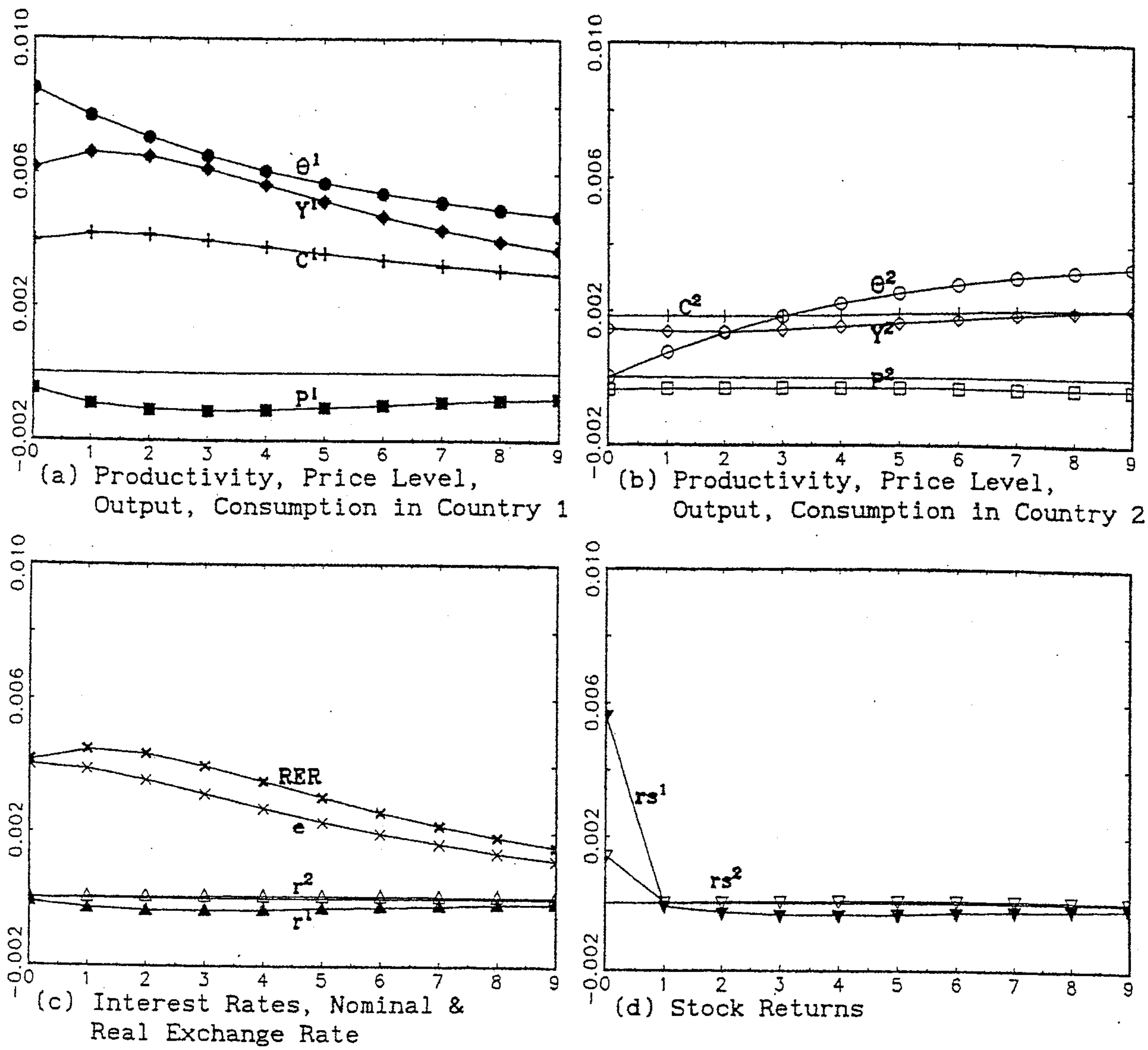
[20]Up to a certainty equivalent approximation, equations (28) and (30) imply that the date t nominal interest rate ($r^i_{t+1}$) equals the expected stock return, between t and t+1: $r^i_{t+1} \approx E_t rs^i_{t+1}$. Given the persistent reduction in nominal interest rates that is induced by a positive money supply shock, this explains the predicted drop in nominal stock returns, in the periods *after* such a shock.

Thorbecke (1997) documents empirically that unanticipated expansionary monetary policy shocks induce a significant rise in equity returns, on impact. The transitory nature of the predicted rise in stock returns is consistent with estimated responses of stock returns to money supply shocks that are reported by Marshall (1992, p.1335).

Figure 2. Baseline Nominal Rigidities Model: Country 1 Productivity Shock




Responses to 1 Standard Deviation Innovation to Country 1 Productivity. Responses of Interest Rates and Stock Returns Expressed as Differences From Initial Position; Responses of Other Variables Shown as Relative Deviations From Initial Position. Period t Responses of Money Stocks, Interest Rates and Stock Returns Pertain, Respectively, to End of Period Money Stocks ($M_{t+1}$), Interest Rates Between t and t+1 ($r_{t+1}$) and to Realized Stock Returns Between t-1 and t ($rs_t$).

Abscissa: Periods After Shock.

×: Nominal Exch. Rate (e), **×**: Real Exch. Rate (RER).

*Country 1/Country 2*

●/○: Productivity (θ),

■/□: Price Level (P), ◆/◇: Output (Y), +/+: Consumption (C),

▲/△: Nominal Interest Rate (r), ▼/▽: Nominal Stock Return (rs).

price level in country 1 raises real balances in that country--which helps to understand why the interest rate falls).

It can also be noted that, in the model here, a productivity increase in country 1 triggers a *rise* in country 2 output--which explains the predicted high positive cross-country correlation of output, in that structure. The positive response of foreign output is due to the fact that the productivity increase in country 1 raises the wealth of that country's representative household, which increases that country's demand for foreign intermediate goods. In the structure without nominal rigidities, by contrast, a positive productivity shock in country 1 induces a fall in country 2 output, on impact (impulse responses available from the author), which explains the predicted negative cross-country correlation of output, in that structure.

The intuition for this difference between the two structures is that a positive country 1 productivity shock induces a delayed rise in country 2 productivity (as can be seen in Panel (b) of Figure 2)--the shock raises, thus, the wealth of the country 2 household. On impact, this induces a fall in the number of hours that the country 2 household wishes to work (leisure being a normal good, in the model here). In the structure without nominal rigidities, this induces a fall in working hours (on impact), in country 2 and, thus, a fall in country 2 output (see Baxter (1995) for a detailed discussion of the international transmission of productivity shocks, in dynamic trade models without nominal rigidities). When the wage rate is sticky, by contrast, the *desire* of the country 2 household to work less is not fulfilled, as hours worked are (in the short run) determined by labor demand, at the given (predetermined) wage rate--in fact, country 2 hours rise, on impact (not shown in Figure), in the structure with nominal rigidities, as country 2 producers of intermediate goods raise their production, in order to meet the increase in demand that they face.

## 3. Baseline Model with Nominal Rigidities: Combined Effect of Money Supply Shocks and of Technology Shocks

In the baseline nominal rigidities model, the predicted standard deviations of output and other variables are larger when just money supply shocks are assumed than when there are just technology shocks (as can be seen by comparing Columns (4) and (5) of Table 3)--in the baseline model, money supply shocks are, thus, the dominant source of economic fluctuations. When that model is simultaneously subjected to the two types of shocks, the predicted statistics are, thus, mostly quite close to those that are generated when just money supply shocks are assumed (see Column (6), Table 3). Note in particular that, when the two types of shocks are used simultaneously, the baseline nominal rigidities model generates predicted cross-country correlations of output, investment, interest rates and equity returns that are significantly higher--and hence much closer to the data--than the cross-country correlations that obtain when flexible prices and wages are assumed.

### C. Alternative Assumptions about Price/Wage Adjustment

The sensitivity of model predictions to alternative assumptions about the price/wage adjustment mechanism is investigated in Table 4. Columns (1)-(3) of that Table consider a version of the model in which producers of intermediate goods can price discriminate between their domestic market and their export market. Interest in that version of the model is motivated by empirical work that documents "pricing to market" (PTM) behavior in international trade, mainly by non-U.S. firms (e.g., Hooper and Marquez (1995), Knetter (1993)). The results here suggest that the predicted cross-country correlation of output is hardly affected by PTM. Table 4 considers also versions of the model in which prices only *or* wages only are sticky; interest in these two cases is motivated by the fact that the literature on dynamic stochastic general equilibrium models (of closed economies) with nominal rigidities has almost exclusively assumed that either prices or wages are sticky--but not both (exception to this are Kim (1996) and Erceg (1997)). It appears that price and wage stickiness are *both* important for explaining international comovements: versions of the model that postulate that prices only are sticky or that only wages are sticky capture less well the high cross-country correlations of real economic activity and returns that are seen in the data.

#### 1. Pricing to Market Behavior (Columns (1)-(3), Table 4)

The baseline model assumes that producers of intermediate goods charge the same price (when expressed in a common currency) in their domestic market and in their export market (see (13a)); as the prices of intermediate goods are assumed to be sticky, in terms of the producer's home currency, this implies that export prices, in terms of foreign currency, are highly responsive to exchange rate movements--ceteris paribus, a firm responds to a 1% fall in the external value of its home currency by reducing its export price, in foreign currency, by 1%. Recent empirical research on export pricing suggests that, overall, the behavior of U.S. firms is consistent with this prediction, while non-U.S. firms appear to be less likely to pass exchange rate movements through to their foreign customers (e.g., Knetter (1993)).

Therefore, a version of the model is explored that departs from the baseline structure by assuming "pricing to market" (PTM) behavior, in the sense that intermediate goods producers (located in both countries) can set *different* prices in domestic and export markets. In both markets, staggered price setting à la Calvo (1983), in terms of the local currency, is assumed; the average duration between price adjustments is assumed to be 4 periods, in both markets.[21] All other aspects of the model are unchanged, compared to

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[21] Consider an intermediate good producer in country i that is "allowed", at

the baseline model. Results for the PTM case are shown in Columns (1)-(3) of Table 4.

It appears that the predicted cross-country correlation of output is hardly affected, by PTM (compared to the baseline case). In contrast, the predicted cross-country correlations of investment, consumption and of rates of return fall, when PTM is assumed, but PTM raises the predicted variability of nominal and real exchange rates.[22]

Figure 3 shows dynamic responses to a one standard deviation (0.90%) money supply innovation in country 1, for the structure with PTM. In that structure, a country 1 money supply increase induces a much smaller fall in the country 2 price level than in the baseline model, as the index of import prices in country 2 ($\mathfrak{PF}^2_t$) is much less responsive to exchange rate movements, when PTM is assumed. This helps to understand why, under PTM, the interest rate in country 2 is hardly affected by the country 1 money supply shock (recall that, by contrast, the country 2 interest rate experiences a noticeable fall, in the baseline nominal rigidities structure). The weaker response of the country 2 interest rate explains why the cross-country correlation of the interest rate is smaller under PTM, which helps to explain why consumption, investment and equity returns are likewise less highly positively correlated across countries.[23]

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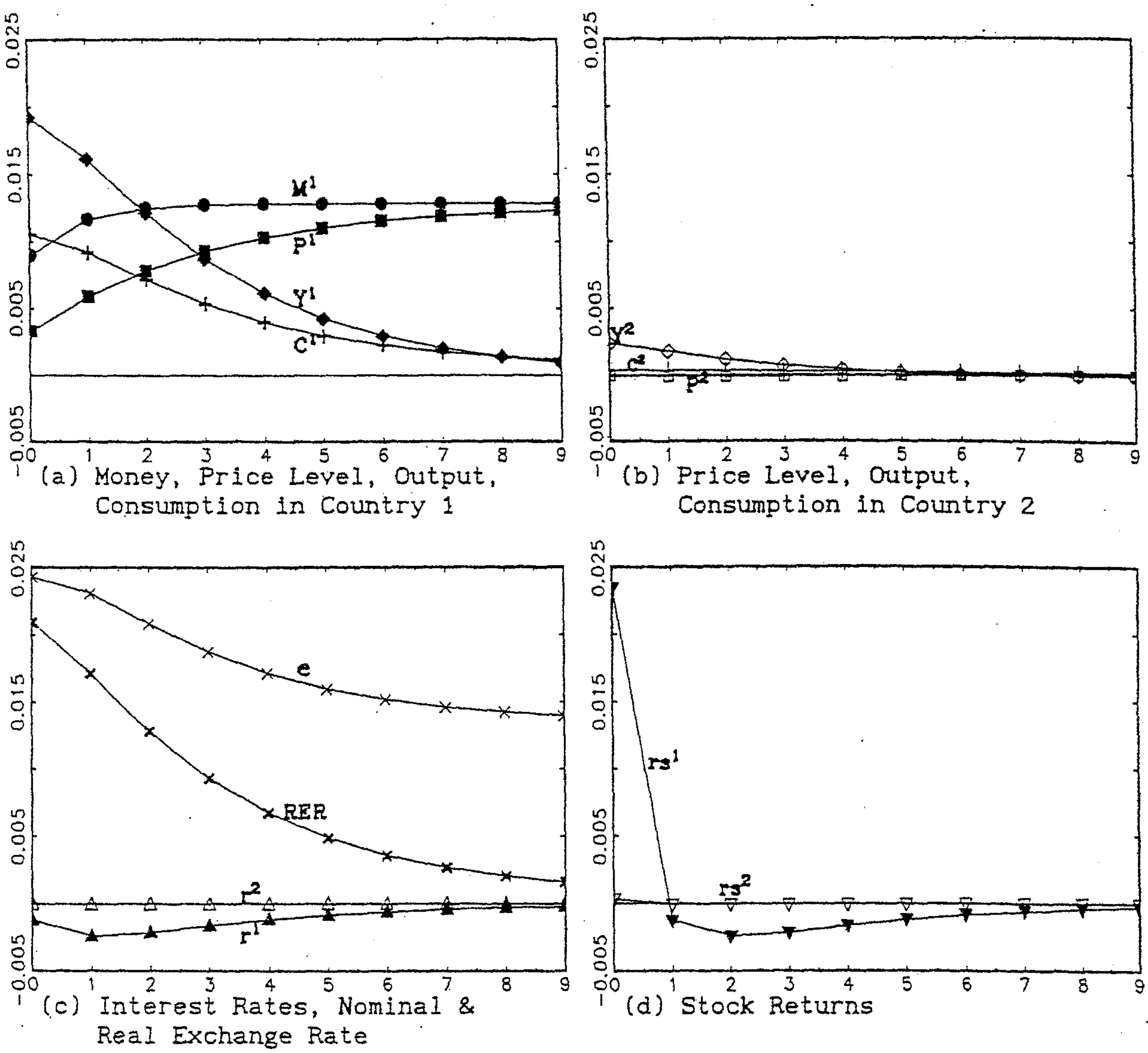
date t, to reset its export price, in terms of the currency of its foreign customers. Let $pf^j_{t,t}$, with $j \neq i$, denote that price. Under PTM, $pf^j_{t,t}$ is set at: $pf^j_{t,t} = \text{Arg} \max_{pf} \sum_{k=0}^{k=\infty} \delta^k E_t \rho^i_{t,t+k} \cdot (pf \cdot e^{i,j}_{t+k} - \mathfrak{G}^{i}_{t+k}) \cdot F^j_{t+k} \cdot (pf/\mathfrak{PF}^j_{t+k})^{-(1+\nu)/\nu} / P^i_{t+k}$.

A producer of an intermediate good in country i that resets its price in the domestic market, at date t, sets the following price, under PTM:
$pd^i_{t,t} = \text{Arg} \max_{pd} \sum_{k=0}^{k=\infty} \delta^k E_t \rho^i_{t,t+k} \cdot (pd - \mathfrak{G}^{i}_{t+k}) \cdot D^i_{t+k} \cdot (pd/\mathfrak{PD}^i_{t+k})^{-(1+\nu)/\nu} / P^i_{t+k}$.

[22] When the model with PTM is simultaneously subjected to money supply and to technology shocks, the predicted standard deviation of the nominal exchange rate and the cross-country correlations of the interest rate and of investment are 3.84%, 0.23 and 0.26, respectively, compared to 3.29%, 0.57 and 0.56 in the baseline model. The working paper version of this paper considers a case in which only exporters located in one of the two countries use PTM; predictions in that case change less, compared to the baseline model (the standard deviation of the nominal exchange rate and the cross-country correlations of the interest rate and investment are 3.55%, 0.47 and 0.43, respectively, in that case).

[23] The above discussion of the baseline nominal rigidities model has focused

Figure 3. Version of Nominal Rigidities Model with Pricing to Market (PTM): Country 1 Money Supply Shock




Dynamic Responses to 1 Standard Deviation Innovation to Country 1 Money Growth Rate. Responses of Interest Rates and Stock Returns Expressed as Differences From Initial Position; Responses of Other Variables Shown as Relative Deviations From Initial Position. Period t Responses of Money Stocks, Interest Rates and Stock Returns Pertain, Respectively, to End of Period Money Stocks ($M_{t+1}$), Interest Rates Between t and t+1 ($r_{t+1}$) and to Realized Stock Returns Between t-1 and t ($rs_t$).

Abscissa: Periods After Shock.

●: Country 1 Money (M), ×: Nominal Exch. Rate (e), ×: Real Exch. Rate (RER).

*Country 1/Country 2*
■/□: Price Level (P), ◆/◇: Output (Y), +/+: Consumption (C),
▲/△: Nominal Interest Rate (r), ▼/▽: Nominal Stock Return (rs).

The much weaker response of the country 2 interest rate, under PTM, implies also that the interest rate *differential* between countries 1 and 2 $(r_t^1 - r_t^2)$ falls more strongly, in response to a positive money supply shock in country 1 (see Panel (c), Figure 3), which implies that exchange rate overshooting, in response to a money supply shock, is stronger under PTM. This explains why the predicted variability of the exchange rate increases when PTM is assumed.

## 2. Versions of Model in which Prices Only or Wages Only are Sticky (Columns (4) and (5), Table 4)

When only prices are sticky (i.e. when $\delta=0.75$, $\mathfrak{D}=0$) or when only wages are sticky ($\delta=0$, $\mathfrak{D}=0.75$), then the predicted cross-country correlations of output and asset returns fall, compared to the baseline nominal rigidities structure--the model captures, thus, less well the high cross-country correlations seen in the data. Also, the predicted standard deviations of the variables considered here (with the exception of the price level) tend to fall.[24]

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on two mechanisms that induce *positive* transmission of a country 1 money supply increase to country 2 output (rise in country 1 absorption that raises demand for country 2 goods; fall in the country 2 interest rate induced by reduction in the country 2 price level) and one *negative* transmission effect (negative substitution effect due to the depreciation of the country 1 currency). When PTM is assumed, the second of these *positive* international transmission channels is weakened considerably (as the country 2 interest rate is hardly affected by the money supply shock). However, the *negative* international transmission effect is likewise weakened, compared to the baseline structure (under PTM, the assumed stickiness of prices, in the buyers' currencies, dampens the short run effect of movements in the nominal exchange rate on the relative price between domestic and foreign intermediate goods faced by the buyers of these goods). The net result is that PTM does not affect the response of country 2 output to a country 1 money supply shock (as can be seen by comparing Panel (b) in Figures 1 and 3), which explains why the predicted cross-country correlation of output is hardly affected by PTM, as discussed above.

[24]E.g., when only wages are sticky, then the predicted cross-country correlations of output, the nominal interest rate and the nominal equity return are 0.29, 0.13 and 0.37, respectively, when money supply and technology shocks are used simultaneously (see Column (4), Table 4), compared to 0.42, 0.57 and 0.45, in the baseline structure, while the predicted standard deviations of output and the nominal exchange rate drop to 1.93% and 2.73%, respectively, from 2.65% and 3.29% in the baseline case.

## D. Alternative Monetary Arrangements

As is standard in the macroeconomics literature, the analysis so far has assumed that the money supply is exogenous. In what follows, versions of the model with endogenous money are explored. It appears that the quantitative effects of exogenous shocks can be sensitive to the form of the policy rule followed by the monetary authorities. In particular, vigorous countercyclical monetary policy (a policy of reducing the money growth rate when output rises) can considerably dampen the responses of output, exchange rates and returns to technology shocks and autonomous money supply innovations. However, the prediction of a sizable positive cross-country correlation of real economic activity and of asset returns holds for a range of plausible monetary policy rules.

### 1. Empirical Evidence on Money Supply Rules

In what follows, policy rules are considered that assume a response of the money growth rate to domestic inflation, the domestic output growth rate and to variations in the nominal exchange rate. Support for rules of this type is provided in Table 2, where the following reaction function is estimated (by instrumental variables), for the U.S. and the G6, using quarterly data for the period 1973:Q3-1994:Q3:

$$\Delta\ln(M^i_{t+1}) = \mathfrak{e}^i\ \Delta\ln(M^i_t) + \mathfrak{f}^i\ \Delta\ln(P^i_t) + \mathfrak{g}^i\ \Delta\ln(Y^i_t) + \mathfrak{h}^i\ \Delta\ln(e^{i,j}_t) + \mathfrak{z}^i + \mathfrak{q}^i\cdot t + \zeta^i_t, \quad \text{with } j\neq i. \tag{46}$$

Table 2 suggests that U.S. and G6 monetary authorities respond to a rise in domestic inflation and in the growth rate of domestic output by *reducing* the growth rate of the domestic money supply: the estimates of the reaction coefficients $\mathfrak{f}^i$ and $\mathfrak{g}^i$ are negative and mostly statistically significant.[25] There is also evidence that monetary policy responds to the exchange rate: the estimates of the response parameter $\mathfrak{h}^i$ suggest that G6 monetary policy is tightened when the (composite) G6 currency depreciates

[25] Table 2 reports estimates of reaction functions in which $\Delta\ln(P^i_t)$, $\Delta\ln(Y^i_t)$, $\Delta\ln(e^{i,j}_t)$ and $\ln(e^{i,j}_t)$ are used separately, as right hand side variables, as well as specifications in which $\Delta\ln(M^i_{t+1})$ is regressed on these variables jointly. Reaction functions were also estimated that add *foreign* (country j) money growth, inflation and output growth to these regressors. The coefficients of the *foreign* variables are not statistically significant.

against the U.S. dollar ($\mathfrak{h}^i$<0), which suggests that G6 monetary authorities attempt to stabilize the U.S.-G6 exchange rate (Table 2 suggests also that U.S. monetary policy has *intensified* exchange rate fluctuations--the point estimates of $\mathfrak{h}^i$ for the U.S. are *positive*; however these estimates are not statistically significant).

## 2. Versions of Model with Endogenous Money

Table 5 reports predictions generated by versions of the nominal rigidities model that assume endogenous money supplies. In order to facilitate the interpretation of the results, it is assumed that the monetary authorities react to a single endogenous variable only (all remaining parameters are unchanged compared to the baseline model). Columns (1)-(2) in Table 5 report results for a case where, in both countries, a rise in the domestic inflation rate induces a reduction in the domestic money growth rate--specifically, $f^i$=-0.63, $g^i$=$\mathfrak{h}^i$=0 for i=1,2 is assumed in that case. Columns (3)-(4) assume that the domestic money growth rate responds negatively to the domestic output growth rate: $g^i$=-0.70, $f^i$=$\mathfrak{h}^i$=0, for i=1,2. ($f^i$=-.63 and $g^i$=-0.70 are the arithmetic averages of the estimates of the parameters $f^i$ and $g^i$ that are reported in Table 2.) Finally, Columns (5)-(6) of Table 5 consider the case where *country 2* attempts to stabilize the exchange rate, by linking its money stock to the external value of its currency; specifically, $\mathfrak{h}^2$=-0.10 is assumed there (while the money supply is exogenous in country 1: $\mathfrak{h}^1$=0; also, $g^i$=$f^i$=0 for i=1,2, in that case).

### *Case where money growth rate responds to inflation rate*

When a rise in domestic inflation induces a tightening of domestic monetary policy, then the predicted cross-country correlations of the money supply, output and asset returns rise, compared to the baseline nominal rigidities model, whereas the predicted standard deviations fall.[26]

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[26] Assume that an autonomous positive money supply shock occurs in country 1, say. That shock raises the country 1 price level, and it reduces the price level in country 2, as discussed above. When $f^1$<0, this induces a rise in the country 2 money supply (it also implies that the country 1 money stock rises *less* than in the baseline case). Hence, the cross-country correlation of money rises, compared to the baseline case, which helps to understand why the cross-country correlations of real economic activity and of returns rise, as well.

*Case where money growth rate responds to output growth rate*

Countercyclical monetary policy dampens the effect of autonomous monetary policy shifts and of productivity shocks on output, nominal and real exchange rates and stock returns: when $g^i$=-0.70 is assumed, the standard deviations of these variables are reduced by a factor of two to three (compared to the baseline case), when the economy is simultaneously subjected to money supply and technology shocks (see Column (4) in Table 5). In contrast, the predicted cross-country correlations of output and of equity returns change much less.

In the nominal rigidities model here, money supply changes have a sizable impact on real activity. $g^i$=-0.70 implies that changes in the growth rate of output induce strong changes in the growth rate of money. Hence, it is not surprising that setting $g^i$=-0.70 dampens considerably the impact of exogenous shocks on real activity and on asset returns. Other work on money supply rules suggests that the money supply reacts less sharply to changes in output--e.g., Taylor (1993, p.47) presents estimates of a U.S. money supply rule that imply that, on impact, a 1% rise in real output induces a reduction in the money supply by 0.11% only. When $g^i$=-0.11 is assumed, then the impact of the money supply rule on the two-country world is barely noticeable, in the model here, compared to the version of the model in which money is exogenous (simulation results available from the author).

*Exchange rate "targetting"*

Exchange rate "targetting" by country 2 raises the predicted cross-country correlations, compared to the baseline model (e.g., the cross-country correlations of output and the interest rate rise to 0.58 and 0.77, respectively, compared to 0.42 and 0.57 in the baseline model, when the economy is simultaneously subjected to money supply shocks and to technology shocks).[27] Not surprisingly, the variability of the exchange rate falls when one of the countries "targets" the exchange rate (the standard deviation of the nominal exchange rate falls to 2.69%, from 3.29% in the baseline model, when both types of shocks are used simultaneously). Furthermore, the standard deviations of output, consumption and investment fall in the country that seeks to reduce exchange rate fluctuations. Given the evidence presented above that G6 monetary policy seeks to stabilize the

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[27] Assume that a positive autonomous money supply shift occurs in country 1; such a shock induces a depreciation of the country 1 currency, which raises the country 2 money supply, when $\mathfrak{h}^2$=-0.10--hence, the cross-country correlation of money increases (to 0.38, from 0.20 in the baseline model), which helps to understand why output and the other variables considered in Table 5 are likewise more closely correlated across the two countries.

G6-U.S. exchange rate, this prediction is consistent with the empirical finding that the cyclical variability of the G6 is smaller than that of the U.S economy.

## V. CONCLUDING REMARKS

One of the major challenges facing International Macroeconomics is to explain the high correlations of output and financial returns across the main industrialized countries that can be seen in the data. This paper has presented a two-country dynamic-optimizing stochastic general equilibrium model of a two-country world that postulates sticky nominal prices and wages. The structure here predicts positive international transmission of country specific money supply shocks and technology shocks. It generates cross-country correlations of output and of asset returns that are markedly higher, and hence closer to the data, than the cross-country correlations that obtain when flexible prices and wages are assumed. The predicted variability of nominal and real exchange rates and of equity returns is likewise higher (and closer to the data) when nominal rigidities are assumed, compared to structures without such rigidities.

TABLE 1. VAR fitted to U.S. and G6 Money Growth Rates

$$\begin{bmatrix} \Delta\ln(M_{t+1}^{US}) \\ \\ \Delta\ln(M_{t+1}^{G6}) \end{bmatrix} = \begin{bmatrix} 0.38^{**} & -0.18 \\ (0.10) & (0.14) \\ 0.04 & 0.18^{\dagger} \\ (0.08) & (0.08) \end{bmatrix} \cdot \begin{bmatrix} \Delta\ln(M_{t}^{US}) \\ \\ \Delta\ln(M_{t}^{G6}) \end{bmatrix} + \begin{bmatrix} \zeta_t^{US} \\ \\ \zeta_t^{G6} \end{bmatrix}$$

$$\text{Var } \zeta_t^{US} = 0.0104^2, \text{ Var } \zeta_t^{G6} = 0.0079^2, \text{ Corr}(\zeta_t^{US}, \zeta_t^{G6}) = 0.20$$

Note: Estimates of the autoregressive coefficients of a first order VAR fitted to quarterly U.S. and G6 log money (M1) growth rates are reported, as well as the variances of the regression residuals and the correlation between U.S. and G6 regression residuals. (Also included in the regressions were a constant and a linear time trend--not reported in Table; the time trend is statistically significant at the 1% level, in the G6 money growth rate equation.)

Estimation method: OLS. Figures in parentheses are standard errors. **, *, †, §: coefficient significant at 1%, at 5%, at 10%, or at 20% level, respectively (significance levels for two-sided tests).

Sample period: 1973:Q3-94:Q3.

TABLE 2. Estimates of U.S. and G6 Monetary Policy Reaction Functions:
$$\Delta\ln(M^i_{t+1}) = e^i \Delta\ln(M^i_t) + f^i \Delta\ln(P^i_t) + g^i \Delta\ln(Y^i_t) + h^i \Delta\ln(e^{i,j}_t) + \zeta^i_t$$

| Country | $e^i$ | $f^i$ | $g^i$ | $h^i$ | $R^2$ | $\sigma_{\zeta^i}$ | $\rho(\zeta^1,\zeta^2)$ |
|---|---|---|---|---|---|---|---|
| U.S. | 0.31 ** | -0.32 | — | — | .15 | .0102 | |
| | (0.11) | (0.28) | | | | | .13 |
| G6 | 0.14 § | -0.61 † | — | — | .24 | .0079 | |
| | (0.11) | (0.35) | | | | | |
| U.S. | 0.40 ** | — | -0.40 § | — | .16 | .0123 | |
| | (0.10) | | (0.26) | | | | .24 |
| G6 | 0.19 † | — | -0.03 | — | .21 | .0081 | |
| | (0.11) | | (0.78) | | | | |
| U.S. | 0.33 ** | — | — | 0.12 | .15 | .0110 | |
| | (0.10) | | | (0.10) | | | .29 |
| G6 | 0.17 † | — | — | -0.14 † | .24 | .0094 | |
| | (0.10) | | | (0.07) | | | |
| U.S. | 0.33 ** | -0.62 * | -0.66 * | 0.08 | .21 | .0127 | |
| | (0.11) | (0.31) | (0.29) | (0.10) | | | .24 |
| G6 | 0.14 § | -0.99 * | -1.72 † | -0.12 § | .28 | .0156 | |
| | (0.10) | (0.47) | (1.00) | (0.07) | | | |

Note: Estimates of policy reaction functions are shown, for U.S. and G6. A constant and a linear time trend were included in all regressions (estimates of constants and time trends not reported in Table; trend is significant, at 5% level (or below), in the G6 reaction functions).
Sample period: 1973:Q3-94:Q3 (quarterly data). Figures in parentheses are standard errors.
**, *, †, §: coefficient significant at 1%, at 5%, at 10%, or at 20% level, respectively (significance levels for two-sided tests).

$\sigma_{\zeta^i}$: standard deviation of innovation $\zeta^i$; $\rho(\zeta^1,\zeta^2)$: cross-country correlation of innovations $\zeta^1$, $\zeta^2$.

Estimation method: instrumental variables (see Appendix III.).

$M^i$, $P^i$, $Y^i$, $e^{i,j}$: Money supply (M1), price level (CPI), real GDP, exchange rate (price of one unit of country j currency, in terms of country i currency).

Rows 1-2 set $g^i = h^i = 0$, rows 3-4 set $f^i = h^i = 0$, rows 5-6 set $f^i = g^i = 0$, for i=U.S., G6.

TABLE 3. Model Predictions for Model *Without* Nominal Rigidities and For Baseline Nominal Rigidities Model; Historical Statistics (1973:Q1-94:Q3)

| Statistics | Model without nominal rigidities: Shocks to M | θ | M&θ | Baseline nominal rigidities model: Shocks to M | θ | M&θ | Data: U.S. | | G6 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | | (8) | | |
| **Standard deviations (in %):** | | | | | | | | | | | |
| Output | 0.05 | 0.84 | 0.84 | 2.47 | 0.96 | 2.65 | 1.83 | (.23) | 1.09 | (.12) | |
| Consumption | 0.07 | 0.55 | 0.55 | 1.19 | 0.65 | 1.35 | 2.00 | (.25) | 0.99 | (.12) | |
| Investment | 0.05 | 2.39 | 2.39 | 10.48 | 2.80 | 10.84 | 7.84 | (.95) | 4.34 | (.59) | |
| Money | 1.51 | 0.00 | 1.51 | 1.51 | 0.00 | 1.51 | 2.33 | (.41) | 1.26 | (.16) | |
| Price level | 1.51 | 0.16 | 1.52 | 1.12 | 0.16 | 1.13 | 1.68 | (.26) | 1.32 | (.15) | |
| Nom interest rate | 0.25 | 0.06 | 0.26 | 0.28 | 0.05 | 0.28 | 0.45 | (.05) | 0.33 | (.03) | |
| Nom exchange rate | 1.91 | 0.75 | 2.05 | 3.22 | 0.69 | 3.29 | | 7.33 | (1.04) | | |
| Real exchng. rate | 0.01 | 1.00 | 1.00 | 2.17 | 0.80 | 2.31 | | 6.86 | (1.04) | | |
| Nominal dividend | 1.48 | 0.53 | 1.57 | 5.13 | 1.87 | 5.45 | 3.35 | (.58) | 4.19 | (.45) | |
| Nom. stock return | 0.89 | 0.45 | 1.00 | 2.17 | 0.60 | 2.25 | 8.16 | (1.0) | 7.80 | (1.0) | |
| Real stock return | 0.01 | 0.58 | 0.58 | 1.88 | 0.66 | 1.99 | 8.27 | (1.0) | 7.82 | (.99) | |
| **Cross-country correlations:** | | | | | | | | | | | |
| Output | 0.39 | -0.05 | -0.05 | 0.41 | 0.51 | 0.42 | | 0.61 | (.12) | | ** |
| Consumption | 0.16 | 0.52 | 0.52 | 0.59 | 0.79 | 0.64 | | 0.47 | (.09) | | ** |
| Investment | 0.57 | -0.40 | -0.40 | 0.57 | 0.43 | 0.56 | | 0.53 | (.13) | | ** |
| Money | 0.20 | u | 0.20 | 0.20 | u | 0.20 | | 0.30 | (.12) | | * |
| Price level | 0.19 | -0.31 | 0.19 | 0.10 | 0.60 | 0.11 | | 0.64 | (.07) | | ** |
| Nom interest rate | 0.19 | -0.99 | 0.13 | 0.59 | -0.09 | 0.57 | | 0.57 | (.07) | | ** |
| Nominal dividend | 0.19 | -0.93 | 0.06 | 0.53 | -0.07 | 0.46 | | 0.28 | (.20) | | § |
| Nom. stock return | 0.20 | 0.12 | 0.18 | 0.44 | 0.63 | 0.45 | | 0.73 | (.05) | | ** |
| Real stock return | 0.58 | 0.00 | 0.00 | 0.63 | 0.67 | 0.63 | | 0.73 | (.05) | | ** |

Note: The Columns numbered (1)-(6) report model predictions. Columns (7)-(8) report empirical statistics. "Nom" is abbreviation of "Nominal".

The Columns labelled "Shocks to M" ("Shocks to θ") pertain to versions of the model in which just money supply shocks (just technology shocks) are assumed; the Columns labelled "Shocks to M&θ" subject model to money supply and technology shocks simultaneously.

The series have all been detrended using the Hodrick and Prescott (1997) filter. Interest rates and the equity returns were expressed at a gross quarterly rate, prior to filtering.

In the "Data" Columns, the figures reported in parentheses are standard errors (obtained using Generalized Method of Moments, assuming tenth-order serial correlation in the residuals).

For the empirical *cross-country correlations* reported in the Table, significance levels (two-sided tests) are shown. **, *, †, §: correlation significantly different from zero at 1%, at 5%, at 10%, and at 20% level, respectively.

u: correlation not defined (series with zero variance).

TABLE 4. Alternative Assumptions About Price/Wage Adjustment

| Statistics | Pricing to market: Shocks to M | Pricing to market: Shocks to θ | Pricing to market: Shocks to M&θ | Sticky wages, flexible prices: Shocks to M&θ | Sticky prices, flexible wages: Shocks to M&θ | Data: U.S. | Data: G6 |
|---|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) | (7) |
| **Standard deviations (in %):** | | | | | | | |
| Output | 2.47 | 0.96 | 2.65 | 1.93 | 1.66 | 1.83 | 1.09 |
| Consumption | 1.33 | 0.67 | 1.49 | 1.07 | 0.84 | 2.00 | 0.99 |
| Investment | 11.69 | 3.03 | 12.07 | 7.17 | 6.96 | 7.84 | 4.34 |
| Money | 1.51 | 0.00 | 1.51 | 1.51 | 1.51 | 2.33 | 1.26 |
| Price level | 1.08 | 0.16 | 1.10 | 1.36 | 1.25 | 1.68 | 1.32 |
| Nominal interest rate | 0.31 | 0.06 | 0.32 | 0.24 | 0.15 | 0.45 | 0.33 |
| Nominal exchange rate | 3.76 | 0.81 | 3.84 | 2.73 | 2.67 | 7.33 | |
| Real exchange rate | 3.22 | 0.99 | 3.36 | 1.89 | 1.54 | 6.86 | |
| Nominal dividend | 5.10 | 1.86 | 5.43 | 1.88 | 7.45 | 3.35 | 4.19 |
| Nominal stock return | 2.36 | 0.63 | 2.44 | 1.78 | 1.58 | 8.16 | 7.80 |
| Real stock return | 2.15 | 0.71 | 2.27 | 1.61 | 1.21 | 8.27 | 7.82 |
| **Cross-country correlations:** | | | | | | | |
| Output | 0.40 | 0.51 | 0.42 | 0.29 | 0.33 | 0.61 | |
| Consumption | 0.26 | 0.70 | 0.35 | 0.59 | 0.61 | 0.47 | |
| Investment | 0.26 | 0.22 | 0.26 | 0.39 | 0.47 | 0.53 | |
| Money | 0.20 | u | 0.20 | 0.20 | 0.20 | 0.30 | |
| Price level | 0.18 | 0.36 | 0.18 | 0.17 | 0.15 | 0.64 | |
| Nominal interest rate | 0.25 | -0.42 | 0.23 | 0.13 | 0.33 | 0.57 | |
| Nominal dividend | 0.55 | -0.06 | 0.47 | 0.20 | 0.38 | 0.28 | |
| Nominal stock return | 0.22 | 0.47 | 0.24 | 0.37 | 0.36 | 0.73 | |
| Real stock return | 0.23 | 0.46 | 0.26 | 0.49 | 0.56 | 0.73 | |

Note: Versions of model with alternative wage and price adjustment rules are considered.

Columns (1)-(3): version of model in which producers of intermediate goods engage in "pricing to market" (PTM).

Column (4): version of model with sticky nominal wages ($\mathfrak{D}$=0), flexible prices ($\delta$=.75).

Column (5): sticky prices ($\delta$=.75), flexible nominal wages ($\mathfrak{D}$=0).

The Columns labelled "Shocks to M" ("Shocks to $\theta$") pertain to versions of the model in which just money supply shocks (just technology shocks) are assumed; the Columns labelled "Shocks to M&$\theta$" subject model to money supply and technology shocks simultaneously.

See Table 3 for further information.

TABLE 5. Versions of Nominal Rigidities Structure with Endogenous Money:
$\Delta\ln(M^i_{t+1}) = 0.3\ \Delta\ln(M^i_t) + f\ \Delta\ln(P^i_t) + g\ \Delta\ln(Y^i_t) + \hbar^i\ \Delta\ln(e^{i,j}_t) + \zeta^i_t,\ i=1,2$

| Statistics | $f=-.63$, $g=\hbar^1=\hbar^2=0$ Shocks to | | $g=-.70$, $f=\hbar^1=\hbar^2=0$ Shocks to | | $\hbar^2=-.1$, $f=g=\hbar^1=0$ Shocks to M&θ | | Data | |
|---|---|---|---|---|---|---|---|---|
| | M | M&θ | M | M&θ | i=1 | i=2 | U.S. | G6 |
| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) |
| **Standard deviations (in %):** | | | | | | | | |
| Output | 1.90 | 2.19 | 0.94 | 1.05 | 2.68 | 2.39 | 1.83 | 1.09 |
| Consumption | 0.92 | 1.17 | 0.45 | 0.60 | 1.38 | 1.27 | 2.00 | 0.99 |
| Investment | 8.19 | 8.88 | 3.90 | 4.04 | 11.10 | 9.96 | 7.84 | 4.34 |
| Money | 1.05 | 1.05 | 0.90 | 1.00 | 1.51 | 1.33 | 2.33 | 1.26 |
| Price level | 0.65 | 0.66 | 0.82 | 0.96 | 1.12 | 1.00 | 1.68 | 1.32 |
| Nominal interest rate | 0.34 | 0.35 | 0.09 | 0.11 | 0.25 | 0.28 | 0.45 | 0.33 |
| Nominal exchange rate | 2.12 | 2.26 | 1.63 | 1.64 | 2.69 | | 7.33 | |
| Real exchange rate | 1.48 | 1.72 | 0.92 | 0.99 | 1.89 | | 6.86 | |
| Nominal dividend | 3.90 | 4.25 | 2.08 | 3.56 | 5.55 | 5.11 | 3.35 | 4.19 |
| Nominal stock return | 1.73 | 1.88 | 0.82 | 0.83 | 2.29 | 2.03 | 8.16 | 7.80 |
| Real stock return | 1.55 | 1.74 | 0.64 | 0.70 | 2.04 | 1.85 | 8.27 | 7.82 |
| **Cross-country correlations:** | | | | | | | | |
| Output | 0.53 | 0.53 | 0.29 | 0.34 | 0.58 | | 0.61 | |
| Consumption | 0.68 | 0.73 | 0.51 | 0.67 | 0.75 | | 0.47 | |
| Investment | 0.66 | 0.64 | 0.47 | 0.46 | 0.69 | | 0.53 | |
| Money | 0.32 | 0.32 | 0.18 | 0.25 | 0.38 | | 0.30 | |
| Price level | 0.10 | 0.11 | 0.18 | 0.28 | 0.28 | | 0.64 | |
| Nominal interest rate | 0.76 | 0.74 | -0.01 | 0.07 | 0.77 | | 0.57 | |
| Nominal dividend | 0.64 | 0.49 | 0.42 | 0.32 | 0.57 | | 0.28 | |
| Nominal stock return | 0.56 | 0.58 | 0.31 | 0.32 | 0.62 | | 0.73 | |
| Real stock return | 0.71 | 0.72 | 0.54 | 0.54 | 0.75 | | 0.73 | |

Note: Versions of the sticky prices and sticky wages model are considered that assume endogenous money supplies.

Columns (1),(2) assume that money supplies in both countries respond to the inflation rate.

Columns (3),(4) assume that money supplies in both countries respond to output growth rate.

Columns (5),(6) assume that *country 2* money supply responds to the bilateral exchange rate; because of asymmetry between countries, predicted statistics (for this case) are reported for each of the two countries; Column (5): country 1 (i=1); Column (6): country 2 (i=2).

The Columns labelled "Shocks to M" pertain to versions of the model in which just money supply shocks are assumed; the Columns labelled "Shocks to M&θ" subject model to money supply and technology shocks simultaneously.

See Table 3 for further information.

## Description of data

In what follows, "MEI" refers to the OECD publication Main Economic Indicators, Historical Statistics 1960-1996; "IFS" refers to the IMF publication International Financial Statistics (various issues).

**Output**--GDP in volume terms, from MEI (for Germany, nominal GNP deflated using domestic CPI, from IFS, was used, as no German GDP volume series available from MEI, for whole sample period).

**Investment**--gross fixed capital formation plus change in stock of inventories (nominal series from IFS were deflated using domestic CPIs).

**Consumption**--private consumption expenditures (nominal series from IFS were deflated using domestic CPIs).

**Price level**--consumer price index (CPI), from IFS.

**Money supply**--narrow money stock (M1) from MEI. For the United Kingdom, the time series on narrow money provided by that data source starts in 1982:Q3. The G6 money supply series for 1982:Q3-1994:Q3 is a geometric weighted average of money supplies in the individual G6 countries, using the weights indicated below. To obtain a G6 money supply series for the whole sample period, the 1982:Q3-1994:Q3 series was multiplicatively spliced together with a geometric weighted average of money supplies in Japan, Germany, France, Italy and Canada during the period 1973:Q1-1983:Q3.

**Nominal interest rate**--short term interest rates from Citibase. U.S.: CD rate (Citibase series FYUSCD); Japan, Germany, France: call money rate (FYJPCM, FYGECM, FYFRCM); U.K.: interest rate on prime bank bills (FYGBBB); Italy: bond yields, credit institutions (FYITBY); Canada: prime corporate paper, 60 days (FYCACP). Interest rates expressed on per quarter basis.

**Nominal exchange rate between U.S. and G6**--a geometric average of bilateral U.S. dollar exchange rates (from IFS).

**Real exchange rate**--constructed using relative consumer price indices.

**Stock return**--quarterly nominal returns series were constructed from Morgan Stanley Capital International (MSCI) stock price indices (dividend reinvested). Real stock returns were constructed by subtracting CPI inflation rates from nominal returns.

**Nominal dividend**--dividend series were constructed from dividend reinvested equity indices and from dividend exclusive indices provided by MSCI. For the U.S. and Canada, the dividend series represents current quarter dividends. For the remaining countries, the dividend series is a 12-month trailing dividend.

**Data frequency and timing issues:** the **output, investment and money supply** series are obtained in quarterly form from the data source. Money supply data provided by OECD MEI measure end of period stocks (accordingly the money stock reported for period t-1 by OECD MEI is used as the empirical counterpart to the variable $M_t$, in the model). The **price** level, **interest rate** and **exchange rate** time series were obtained at a monthly frequency. The empirical analysis uses quarterly averages of these monthly series.
The series for **output, investment, price level** and **money** are provided in seasonally adjusted form by the data sources. The remaining series do not exhibit seasonality. **Interest rate** and **stock returns** are expressed on a per quarter basis. All time series used in the empirical analysis are quarterly.
**Construction of aggregate series for G6:** the G6 aggregate series for output, investment, the price level, the money supply, nominal and real exchange rates and dividends are *geometric* averages of time series for the individual G6 countries. G6 aggregate series for the interest rate and stock returns are *arithmetic* averages of the corresponding series for the individual G6 countries. The following country weights are used--Japan: 0.282; Germany: 0.203; France: 0.177; United Kingdom: 0.144; Britain: 0.120; Canada: 0.070. These weights correspond to the 1980 shares of individual G6 countries in aggregate G6 GDP (to compute these shares, national GPDs were expressed in U.S. dollars, using the 1980 exchange rate between G6 currencies and the U.S. dollar).

## Derivation of wage equation (32)

Eqns. (8)-(9) imply that the total demand for type h labor, in country i, can be expressed as the following function of the wage of that labor type:

$$\bar{\ell}_t^i(w_t^i(h)) \equiv \int_0^1 \ell_t^i(h,s)ds = ((1-\psi)/\psi)\cdot(w_t^i(h))^{1/(\gamma-1)}\cdot R_t^i\cdot\mathcal{K}_t^i\cdot(W_t^i)^{\gamma/(1-\gamma)}, \qquad \text{(A.1)}$$

where $\mathcal{K}_t^i \equiv \int \mathcal{K}_t^i(s)ds$. Assume that at date t a new wage rate, $w_{t,t}^i(h)$, is set for type h labor. At date t, the country i household makes a commitment to provide $\xi_t^i(h)\cdot\bar{\ell}_{t+k}^i(w_{t,t}^i(h))$ hours of type h labor at date t+k (k≥0), if the wage rate $w_{t,t}^i(h)$ is still in effect at t+k, where $\xi_t^i(h)$ is a choice variable that the household sets at date t. The household sets $\xi_t^i(h)$ with the objective of maximizing her expected life-time utility (from the vantage point of period t).

Equation (32) is a first-order condition for this decision problem. To understand (32), note that if the household changes $\xi_t^i(h)$ by an infinitesimal amount $\varepsilon$, then her labor effort at date t+k changes by $\varepsilon\cdot\bar{\ell}_{t+k}^i(w_{t,t}^i(h))$, and her real wage income at t+k changes by $\varepsilon\cdot\bar{\ell}_{t+k}^i(w_{t,t}^i(h))\cdot w_{t,t}^i(h)/P_{t+k}^i$, if the "contract wage" $w_{t,t}^i(h)$, is still valid at t+k. Assume, without loss of generality, that the household adjusts her consumption at t+k by the amount of the change in her real wage income. With probability $\mathcal{D}^k$, $w_{t,t}^i(h)$ is still in effect at date t+k. Hence, the change in the consumer's expected life-time utility level (evaluated at date t) that results from changing $\xi_t^i(h)$ by an amount $\varepsilon$ is:

$$\sum_{k=0}^{k=\infty}(\beta\mathcal{D})^k\, E_t\left(U_{C,t+k}^i\cdot\varepsilon\cdot\bar{\ell}_{t+k}^i(w_{t,t}^i(h))\cdot w_{t,t}^i(h)/P_{t+k}^i\right) + \sum_{k=0}^{k=\infty}(\beta\mathcal{D})^k\, E_t\left(U_{L,t+k}^i\cdot\varepsilon\cdot\bar{\ell}_{t+k}^i(w_{t,t}^i(h))\right), \qquad \text{(A.2)}$$

where $U_{C,t+k}^i$ and $U_{L,t+k}^i$ are the household's marginal utility of consumption and her disutility of labor effort, respectively, at date t+k.

At an interior solution of the household's decision problem, the change in lifetime utility from changing $\xi_t^i(h)$ by $\varepsilon$ has to equal zero. Setting the expression in (A.2) to zero and using $\bar{\ell}_{t+k}^i(w_{t,t}^i(h)) = ((1-\psi)/\psi)\cdot(w_{t,t}^i(h))^{1/(\gamma-1)}\cdot R_{t+k}^i\cdot\mathcal{K}_{t+k}^i\cdot(W_{t+k}^i)^{\gamma/(1-\gamma)}$ (see (A.1) above) yields

(32) in the text (note that $U^i_{L,t+k}=-1$; see (1b)). Let $\mathfrak{I}^i_t$ denote the right-hand side of (32). To justify the focus on situations where (32) holds with equality, note that when $w^i_{t,t}<\mathfrak{I}^i_t$ (i.e. when the expression is negative, for $\varepsilon>0$), then the household sets $\xi^i_t(h)=0$, which cannot be an equilibrium (as $\xi^i_t(h)=1$ has to hold in equilibrium; see (40)). When $w^i_{t,t}>\mathfrak{I}^i_t$, then the household's decision problem is not well defined (the household selects $\xi^i_t(h)=\infty$).

**Econometric method used to estimate policy reaction function**

An instrumental variables approach was used to estimate (46), as the right-hand side variables $P_t^i$, $y_t^i$ and $e_t^{i,j}$ are likely to be correlated with the error term $\zeta_t^i$ (in the model, $P_t^i$, $y_t^i$, $e_t^{i,j}$ respond contemporaneously to monetary policy shocks). Each of the variables $\Delta\ln(P_t^i)$, $\Delta\ln(y_t^i)$, $\Delta\ln(e_t^{j,i})$ was regressed on its own one-period lag, a constant and a linear time trend. The reaction function was estimated by OLS, using fitted values from these first-stage regressions. $\Delta M_t^i$ is predetermined at date t, as $M_t^i$ is the money stock at the end of period t-1, and thus there is no need to use instruments for $\Delta M_t^i$.

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