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Explaining international comovements of output and asset returns: The role of money and nominal rigidities☆

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Abstract

Output and asset returns are highly positively correlated across the U.S. and the remaining major industrialized countries. Standard business cycle models that assume flexible prices and wages, in the real business cycle (RBC) 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. The structure here generates cross-country correlations of output and 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.

JEL classification: E4; F3; F4

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1. 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 International Macroeconomics 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 capture 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, hence, 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 and other real variables. 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 that country's output, consumption and investment, a fall in its interest rate, as well as a nominal and real depreciation of its currency. *Foreign* output, consumption and investment are likewise predicted to rise (for plausible elasticities of substitution between domestic and foreign goods). Nominal rigidities influence also the response of the economy to productivity shocks: in the nominal rigidities structure considered here, these shocks induce output responses that are much more strongly positively correlated across countries, than predicted responses to productivity shocks generated by standard models with flexible prices and wages.

When money supply and productivity shocks occur simultaneously, the nominal rigidities structure generates, thus, cross-country correlations of output that are markedly higher, and hence closer to the data, than the correlations that obtain when flexible prices and wages are postulated. In that structure, physical investment and equity returns are likewise predicted to be more highly positively correlated across countries (compared to flexible-prices/flexible-wages models). It appears that assuming simultaneous stickiness of prices *and* of wages is helpful for explaining observed international comovements: versions of the model that postulate that prices only are sticky or that only wages are sticky generate lower cross-country correlations than versions with price *and* wage stickiness.

It is also found that the predicted variability of nominal and real exchange rates is higher — and somewhat 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).

The basic Keynesian open economy model with sticky prices developed by Mundell (1968, Chapter 18) predicts a negative response of foreign output to a positive money supply shock at home, when the exchange rate is flexible, 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, productivity shocks induce sizable positive cross-country output correlations.

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). In contrast, standard business cycle models without nominal rigidities fail to generate a sizable response of equity returns to money supply shocks (e.g., Marshall, 1992).

In assuming nominal rigidities, the work here is related to Keynesian open economy models developed during the 1960s and 1970s (see, e.g., Mundell, 1968; Dornbusch, 1976). However, these models lack the explicit micro-foundations regarding the private sector's consumption, investment and production decisions that characterize the dynamic-optimizing approach adopted here. The paper builds on 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., there is no physical capital in their model. For plausible parameter values, that model predicts strong *negative* international transmission of money shocks.[1] In contrast to Obstfeld-Rogoff, the paper here assumes physical capital and *multi-period* pricing.[2]

The present structure extends the quantitative small open economy model in Kollmann (1996b) to a two-country world. Methodologically, it builds on much recent work on calibrated DSGE models of *closed* economies with sticky prices or wages (e.g., Hairault and Portier, 1993; Kim, 1996; Yun, 1996; Erceg et al. 1999; Ireland, 1997; Rotemberg and Woodford, 1998).

The failure of standard RBC models to capture key features of international macroeconomic data has also motivated recent work by Betts and Devereux (1998) and by Chari et al. (1998) who present quantitative dynamic-optimizing two-country models with sticky *prices*.[3] In contrast to the paper here, these studies focus mainly on exchange rate dynamics. The present paper also differs from these studies by using a model that assumes sticky *wages* and incomplete international asset markets, by studying model implications for a wider set of variables (i.e. asset returns) and by investigating how nominal rigidities influence the international effects of *productivity* shocks (the studies that were just cited do not consider productivity shocks).

Chari et al. and Kollmann (1996b) find that a high degree of price stickiness has to be postulated to rationalize the high volatility of real exchange rates seen in the data. Using a model without capital and in which prices are set one period in advance, Betts-Devereux argue that 'pricing to market' (PTM) behavior by firms — limited 'pass through' of exchange rate movements into prices, due to local currency price setting — matters greatly for international comovements. In their model, output is highly *negatively* correlated across countries, unless all (or close to 100% of) firms use PTM; when *all* firms use PTM, then the cross-country output correlation is unity. By contrast, the structure here (with capital and multiperiod pricing), generates sizable cross-country correlations, irrespective of whether full exchange rate pass through or PTM is assumed (empirical estimates of the incidence of PTM behavior vary widely, by country and industrial sector; see, e.g., Hooper and Marquez, 1995).

Section 2 of the paper outlines the model. Section 3 discusses empirical regularities about international business cycles. Section 4 presents simulation results. Section 5 concludes.

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[1] Hau's (1998) version of the Obstfeld–Rogoff framework that assumes nominal *wage* rigidity (wages that are set one period in advance), rather than price rigidities in goods markets, likewise predicts strong negative international transmission of money supply shocks.

[2] 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 here yields richer dynamics.

[3] The basic structure in the present paper was developed before I became aware of Betts-Devereux and Chari et al. (see Kollmann, 1993,1996b) — the present work is, thus, an independent and complementary analysis.

2. The model

A world with two countries, called Home and Foreign, is considered. In each country there are firms, a representative household and a government that issues a national currency.

The following description focuses on the Home country. The Foreign country is a mirror image of the Home country (preferences and technologies are symmetric across the two countries). Foreign variables are denoted by an asterisk.

2.1. Household preferences

The preferences of the Home household are described by

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

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

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

$$U(C, \mathscr{M}/P, L) = (1-\Psi)^{-1}\{[C^\sigma + \kappa(\mathscr{M}/P)^\Gamma]^{1/\sigma}\}^{1-\Psi} - L, \tag{2}$$

where Ψ, σ, Γ and κ are parameters.[4]

2.2. Technologies, firms and the structure of goods markets

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; the final good can be consumed or used as an investment good. In contrast, there is monopolistic competition in the markets for intermediate goods — each intermediate good is produced by a single firm. Producers of

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

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. Firms are price takers in the markets for their inputs.

2.2.1. Final good production

The Home final good is produced using the aggregate technology

$$Q_t = \{(1-\alpha)^{1/\vartheta} \cdot D_t^{(\vartheta-1)/\vartheta} + \alpha^{1/\vartheta} \cdot Z_t^{(\vartheta-1)/\vartheta}\}^{\vartheta/(\vartheta-1)} \quad \text{with } 0 < \alpha < 1,\ \vartheta > 0. \tag{3}$$

Q_t is Home final good output, while D_t and Z_t are indexes of domestically produced and of imported intermediate goods, respectively (the parameter ϑ is the elasticity of substitution between D_t and Z_t):

$$D_t = \left\{\int_0^1 d_t(s)^{(\nu-1)/\nu}\right\}^{\nu/(\nu-1)} \quad \text{and} \quad Z_t = \left\{\int_0^1 z_t(s)^{(\nu-1)/\nu}\right\}^{\nu/(\nu-1)}$$

with $\nu > 1$.

$d_t(s)$ and $z_t(s)$ denote, respectively, the quantities of the Home produced and of the Foreign intermediate good of type s that are used in Home final good production. Let $\mathscr{pd}_t(s)$ and $\mathscr{pz}_t(s)$ denote the prices of these two types of goods, in terms of Home currency. Throughout the paper, all prices are expressed in the buyer's currency. Cost minimization conditions for Home final good producers can be written as

$$d_t(s) = D_t \cdot (\mathscr{pd}_t(s)/\mathscr{PD}_t)^{-\nu}, \quad z_t(s) = Z_t \cdot (\mathscr{pz}_t(s)/\mathscr{PZ}_t)^{-\nu} \tag{4}$$

and

$$D_t = (1-\alpha) \cdot (\mathscr{PD}_t/P_t)^{-\vartheta} \cdot Q_t, \quad Z_t = \alpha \cdot (\mathscr{PZ}_t/P_t)^{-\vartheta} \cdot Q_t, \tag{5}$$

with

$$\mathscr{PD}_t \equiv \left\{\int_0^1 (\mathscr{pd}_t(s))^{1-\nu}\, \mathrm{d}s\right\}^{1/(1-\nu)}, \quad \mathscr{PZ}_t \equiv \left\{\int_0^1 (\mathscr{pz}_t(s))^{1-\nu}\, \mathrm{d}s\right\}^{1/(1-\nu)}, \tag{6}$$

and

$$P_t \equiv \{(1-\alpha)\mathscr{PD}_t^{1-\vartheta} + \alpha\mathscr{PZ}_t^{1-\vartheta}\}^{1/(1-\vartheta)}. \tag{7}$$

Perfect competition in the final good market implies that the date t price of the Home final good equals P_t (the right-hand side of (7) is the marginal cost of producing the final good).[5]

2.2.2. Intermediate goods producers

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

$$y_t(s) = \theta_t(\mathscr{K}_t(s))^{\psi}(\mathscr{L}_t(s))^{1-\psi}, \quad 0 < \psi < 1 \tag{8}$$

at date t, where $y_t(s)$ is the firm's output. θ_t is an exogenous productivity parameter (productivity is identical for all Home intermediate goods producers). $\mathscr{K}_t(s)$ is the physical capital stock used by the firm at date t, while $\mathscr{L}_t(s)$ is an index of the different type of labor used by the firm: $\mathscr{L}_t(s) = \{\int_0^1 \ell_t(h;s)^{(\gamma-1)/\gamma}\,\mathrm{d}h\}^{\gamma/(\gamma-1)}$, with $\gamma > 1$, where $\ell_t(h;s)$ represents the quantity of type h labor used by the firm at date t.

Let R_t and $w_t(h)$ be the Home nominal rental rate of capital and the Home nominal wage for type h labor, respectively, at date t. The cost function of a Home intermediate good producer is

$$\mathfrak{G}_t(y) \equiv \operatorname*{Min}_{\mathscr{K},\,\ell(h)} R_t\mathscr{K} + \int_0^1 w_t(h)\ell(h)\,\mathrm{d}h$$

$$\text{s.t. } y = \theta_t\mathscr{K}^{\psi}\left\{\int_0^1 \ell(h)^{(\gamma-1)/\gamma}\,\mathrm{d}h\right\}^{(\gamma/(\gamma-1))(1-\psi)}.$$

Cost minimization implies

$$\ell_t(h;s) = \mathscr{L}_t(s)[w_t(h)/W_t]^{-\gamma} \quad \text{and} \quad \mathscr{L}_t(s) = ((1-\psi)/\psi)R_t\mathscr{K}_t(s)/W_t, \tag{9}$$

where

$$W_t \equiv \left\{\int_0^1 w_t(h)^{1-\gamma}\,\mathrm{d}h\right\}^{1/(1-\gamma)} \tag{10}$$

is an aggregate wage index.[6]

As the production function exhibits constant returns to scale, $\mathfrak{G}_t(y) = y \cdot \mathfrak{G}'_t$ holds, where $\mathfrak{G}'_t$ is the firm's marginal cost function:

$$\mathfrak{G}'_t = (1/\theta_t)(R_t)^{\psi}(W_t)^{1-\psi}\psi^{-\psi}(1-\psi)^{-(1-\psi)}. \tag{11}$$

[5] $\mathscr{P}\mathscr{D}_t$ and $\mathscr{P}\mathscr{Z}_t$ are price indices that represent the minimal expenditure, in Home currency, needed to purchase one unit of the composite inputs D_t and Z_t, respectively ((4) implies that $\mathscr{P}\mathscr{D}_t \cdot D_t = \int \mathscr{p}d_t(s) \cdot d_t(s)\,\mathrm{d}s$ and $\mathscr{P}\mathscr{Z}_t \cdot Z_t = \int \mathscr{p}z_t(s) \cdot z_t(s)\,\mathrm{d}s$).

[6] W_t represents the minimal expenditure, in Home currency, needed to purchase one unit of the composite labor input $\mathscr{L}$ in period t.

The demand function of the Home producer of intermediate good s in its domestic market is given in (4). The firm faces the following demand function in its export market:

$$z_t^*(s) = Z_t^* \cdot (\mathscr{pz}_t^*(s)/\mathscr{PZ}_t^*)^{-\nu}, \tag{12}$$

where $\mathscr{pz}_t^*(s)$ is the firm's export price, in terms of Foreign currency, and $\mathscr{PZ}_t^* \equiv \{\int(\mathscr{pz}_t^*(s))^{1-\nu} \mathrm{d}s\}^{1/(1-\nu)}$.[7] The firm's output equals the demand for its good:

$$y_t(s) = d_t(s) + z_t^*(s). \tag{13}$$

At t, the profit of the producer of Home intermediate good s is, thus

$$\mathscr{pd}_t(s)d_t(s) + e_t\mathscr{pz}_t^*(s)z_t^*(s) - \mathfrak{G}_t' \cdot (d_t(s) + z_t^*(s)),$$

where e_t is the nominal exchange rate between the two countries, defined as the Home currency price of one unit of Foreign currency.

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.

$$\mathscr{pz}_t^*(s) = \mathscr{pd}_t(s)/e_t, \tag{14}$$

which implies

$$\mathscr{PZ}_t^* = \mathscr{PD}_t/e_t. \tag{15}$$

These equations and the demand functions for intermediate goods derived above imply that the nominal profit of the producer of Home intermediate good s can be expressed as the following function of its Home currency price, $\mathscr{pd}_t(s)$:

$$\pi_t(\mathscr{pd}_t(s)) \equiv (\mathscr{pd}_t(s) - \mathfrak{G}_t') \cdot (D_t + Z_t^*) \cdot [\mathscr{pd}_t(s)/\mathscr{PD}_t]^{-\nu}.$$

Determination of intermediate goods prices. Prices for intermediate goods are set in a staggered fashion, à la Calvo (1983), in terms of the currency of their producers: producers are not allowed to change these prices, 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 currency of its producer, can be changed in any particular period is $1-\delta$, a constant (as there is a continuum of intermediate goods, $1-\delta$ represents also the fraction of all prices, in producer currency, that are changed each period; furthermore, the average time between price changes is $1/(1-\delta)$).

[7] The Foreign final good technology is analogous to (3), i.e. $Q_t^* = \{(1-\alpha)^{1/\vartheta}(D_t^*)^{(\vartheta-1)/\vartheta} + \alpha^{1/\vartheta}(Z_t^*)^{(\vartheta-1)/\vartheta}\}^{\vartheta/(\vartheta-1)}$, $D_t^* = \{\int_0^1 d_t^*(s)^{(\nu-1)/\nu}\}^{\nu/(\nu-1)}$, $Z_t^* = \{\int_0^1 z_t^*(s)^{(\nu-1)/\nu}\}^{\nu/(\nu-1)}$, where $d_t^*(s)$ is the quantity of the Foreign produced intermediate input of type s that is used in Foreign final good production.

Consider a Home intermediate good producer that is "allowed" at date t to set a new Home currency price for its good and let $\mathscr{pd}_{t,t}$ denote this new price. With probability $\delta^{\tau}, \mathscr{pd}_{t,t}$ is still in effect at date $t+\tau$. Hence, the firm sets $\mathscr{pd}_{t,t}$ at

$$\mathscr{pd}_{t,t} = \text{Arg}\ \underset{\mathscr{pd}}{\text{Max}} \sum_{\tau=0}^{\tau=\infty} \delta^{\tau} E_t\{\rho_{t,t+\tau}\pi_{t+\tau}(\mathscr{pd})/P_{t+\tau}\}, \tag{16}$$

where $\rho_{t,t+\tau}$ is the pricing kernel used by the firm at date t to value random date $t+\tau$ pay-offs (that are expressed in units of the Home final good). As discussed below, it is assumed that Home firms are owned by that country's representative household; hence, it is assumed that $\rho_{t,t+\tau}$ equals the intertemporal marginal rate of substitution in consumption of the Home household:

$$\rho_{t,t+\tau} = \beta^{\tau} \cdot U_{C,t+\tau}/U_{C,t}, \tag{17}$$

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

The solution of the maximization problem in (16) is[8]

$$\mathscr{pd}_{t,t} = (v/(v-1))\left\{\sum_{\tau=0}^{\tau=\infty} \delta^{\tau} E_t\{\Xi_{t,t+\tau}\mathfrak{G}'_{t+\tau}\}\right\}\Bigg/\left\{\sum_{\tau=0}^{\tau=\infty} \delta^{\tau} E_t \Xi_{t,t+\tau}\right\}, \tag{18}$$

where

$$\Xi_{t,t+\tau} \equiv \rho_{t,t+\tau} \cdot (1/P_{t+\tau}) \cdot (D_{t+\tau} + Z^{*}_{t+\tau}) \cdot (\mathscr{PD}_{t+\tau})^{v}. \tag{19}$$

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 (13)). In other words, firms with predetermined prices (prices that were set in previous periods) have an infinitely elastic output supply schedule.[9]

At date t, a fraction $(1-\delta)\delta^{\tau}$ of Home producers of intermediate goods are posting Home currency prices that were set $\tau \geq 0$ periods ago. The definition of the price index $\mathscr{PD}_t$ (see (6)) implies, hence, that the law of motion of $\mathscr{PD}_t$ is

$$(\mathscr{PD}_t)^{1-v} = \delta(\mathscr{PD}_{t-1})^{1-v} + (1-\delta)(\mathscr{pd}_{t,t})^{1-v}. \tag{20}$$

[8] Very similar expressions are derived by Yun (1996, p. 352) who also studies a dynamic general equilibrium model with price setting à la Calvo.

[9] This assumption is standard in models with price rigidities (e.g., Mankiw, 1997, Chapter 8)). (18) implies that, up to a certainty equivalent approximation, the price $\mathscr{pd}_{t,t}$ equals a weighted average of current and expected future marginal production costs, multiplied by a constant mark up factor, $v/(v-1) > 1$. When prices are fully flexible ($\delta = 0$), then (18) implies that the price $\mathscr{pd}_{t,t}$ is set at the current marginal cost, multiplied by $v/(v-1)$. When prices are sticky ($\delta > 0$), then $\mathscr{pd}_{t,t}$ depends on *future* marginal costs as well. As long as $\mathscr{pd}_{t,t}$ exceeds the firm's marginal (= average) cost, it is not in its interest to ration its customers.

2.2.3. The demand and supply of physical capital

Eqs. (4), (8), (9), and (12)–(15) imply that the total *demand* for physical capital, by Home intermediate good firms can be expressed as

$$\mathscr{K}_t \equiv \int_0^1 \mathscr{K}_t(s)\,\mathrm{d}s = (D_t + Z_t^*)(\overline{\mathscr{PD}}_t/\mathscr{PD}_t)^{-\nu}\theta_t^{-1}\{\psi(1-\psi)^{-1}W_t/R_t\}^{1-\psi}, \tag{21}$$

where $\overline{\mathscr{PD}}_t \equiv \{\int \not{p}d_t(s)^{-\nu}\,\mathrm{d}s\}^{-1/\nu}$ is a price index that evolves according to

$$(\overline{\mathscr{PD}}_t)^{-\nu} = \delta(\overline{\mathscr{PD}}_{t-1})^{-\nu} + (1-\delta)(\not{p}d_{t,t})^{-\nu}. \tag{22}$$

The *supply* of physical capital, in the Home country, reflects investment decisions made by capital rental firms (who rent capital to that country's intermediate goods producers). The law of motion of the stock of Home physical capital is

$$K_{t+1} + \phi(K_{t+1}, K_t) = K_t(1-d) + I_t, \tag{23}$$

where I_t, gross investment, denotes what quantity of the Home final good is required to change the capital stock from K_t to K_{t+1}. $0 < d < 1$ 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} and K_t:

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

Home capital rental firms maximize

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

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

$$1 = \beta E_t\{\rho_{t,t+1}[R_{t+1}/P_{t+1} + 1 - d + \phi_{2,t+1}]/[1 + \phi_{1,t}]\}, \tag{25}$$

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

2.3. Asset markets, household consumption and investment decisions

The Home representative household can hold the following assets: (i) Home money; (ii) a stock that represents a claim to the aggregate cash flow of all Home producers of intermediate goods and of all Home capital rental firms;

(iii) risk-free nominal one-period bonds denominated in Home currency and in Foreign currency.[10] Given this set of assets, the period t budget constraint of the Home household is

$$\begin{aligned} &\mathscr{M}_{t+1} + A_{t+1} + e_t B_{t+1} + \sigma_t S_{t+1} + P_t C_t \\ &\quad = \mathscr{M}_t + T_t + A_t(1 + r_t) + e_t B_t(1 + r_t^*) + \sigma_{t-1} S_t(1 + rs_t) \\ &\qquad + \int_0^1 \int_0^1 w_t(h) \ell_t(h; s)\, \mathrm{d}s\, \mathrm{d}h, \end{aligned} \tag{26}$$

$$\text{with} \quad (1 + rs_t) \equiv (\sigma_t + \Pi_t + R_t K_t - P_t I_t)/\sigma_{t-1}, \tag{27}$$

where $\Pi_t \equiv \int_0^1 \pi_t(\wp d_t(s))\mathrm{d}s = \mathscr{P}\mathscr{D}_t \cdot (D_t + Z_t^*) - R_t K_t - \int_0^1\int_0^1 w_t(h)\ell_t(h;s)\,\mathrm{d}h\,\mathrm{d}s$ represents total profits of Home intermediate good producers. A_t and B_t are, respectively, the (net) stocks of Home currency bonds and of Foreign currency bonds that are held by the Home household, at the beginning of period t (end of period $t - 1$). r_t and r_t^* are the nominal interest rates on these two types of bonds. σ_t is the nominal price (ex-dividend) of one equity share, in period t, while S_t is the number of equity shares held by the household, at the end of period $t - 1$. $(1 + rs_t)$ is the nominal gross return on Home equity, between periods $t - 1$ and t ($\Pi_t + R_t K_t - P_t I_t$ is the total cash flow generated by all Home firms). T_t is a government cash transfer. The last term on the right-hand side of (26) is the household's total wage income.

The Home household seeks to maximize her expected life-time utility (1) subject to the restriction that the budget constraint (26) holds in all periods and for all states of the world. Ruling out Ponzi games, the following equations are first-order conditions of this decision problem:

$$1 = (1 + r_{t+1})\beta E_t\{(U_{C,t+1}/U_{C,t})(P_t/P_{t+1})\}, \tag{28}$$

$$1 = (1 + r_{t+1}^*)\beta E_t\{(U_{C,t+1}/U_{C,t})(P_t/P_{t+1})(e_{t+1}/e_t)\}, \tag{29}$$

$$1 = \beta E_t\{(U_{C,t+1}/U_{C,t})(P_t/P_{t+1})(1 + rs_{t+1})\}, \tag{30}$$

$$\kappa(\Gamma/\sigma)E_t\{U_{C,t+1}(C_{t+1})^{1-\sigma}(\mathscr{M}_{t+1}/P_{t+1})^{\Gamma-1}/P_{t+1}\} = r_{t+1}E_t\{U_{C,t+1}/P_{t+1}\}. \tag{31}$$

[10] The household's international 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 (1995,1996a,1998) compares models in which bonds only are traded internationally to models that also allow for international trade in state-contingent assets — it is found that the former models capture key international business cycle stylized facts better.

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

2.4. Wage determination

Overlapping nominal wage contracts of random duration are assumed. The household acts as a wage setter, subject to the constraint that the wage rate for labor of a given type can only be changed when she receives a random "wage-change signal" (for labor of that type). The probability that the wage rate for labor of a given type can be changed in any particular period is $1-\mathfrak{D}$, a constant. Assume that the Home household is "allowed" at date t to set a new wage rate for type h labor and let $w_{t,t}(h)$ denote this new wage rate. With probability $\mathfrak{D}^{\tau}$, $w_{t,t}(h)$ is still in effect at date $t+\tau$. The household sets the wage $w_{t,t}(h)$ that maximizes her expected lifetime utility subject to her budget constraint (26), to the demand schedule for type h labor shown below and subject to the wage adjustment pattern that was just described (it is assumed that the household meets the demand for type h labor at the wage $w_{t,t}(h)$ until the next wage-change signal is received). The demand schedule for type h labor is (from (9)):

$$\ell_t(w_t(h)) \equiv \int_0^1 \ell_t(h,s)\,\mathrm{d}s = ((1-\psi)/\psi)\cdot(w_t(h))^{-\gamma}R_t\mathscr{K}_t(W_t)^{\gamma-1},$$

where $\mathscr{K}_t \equiv \int_0^1 \mathscr{K}_t(s)\,\mathrm{d}s$. Assume that when setting $w_{t,t}(h)$ the household takes the current and future *average* wage (W) and other aggregate variables as given.[11] Then $w_{t,t}(h)$ has to satisfy the following first-order condition

$$\sum_{\tau=0}^{\tau=\infty}(\beta\mathfrak{D})^{\tau}E_t\{U_{C,t+\tau}\cdot\partial[w_{t,t}(h)\cdot\ell_{t+\tau}(w_{t,t}(h))/P_{t+\tau}]/\partial w_{t,t}(h)\}$$
$$= -\sum_{\tau=0}^{\tau=\infty}(\beta\mathfrak{D})^{\tau}E_t\{U_{L,t+\tau}\cdot\partial\ell_{t+\tau}(w_{t,t}(h))/\partial w_{t,t}(h)\} \tag{32}$$

$$\Rightarrow w_{t,t} = w_{t,t}(h)$$
$$= (\gamma/(\gamma-1))\sum_{\tau=0}^{\tau=\infty}(\beta\mathfrak{D})^{\tau}E_t\chi_{t+\tau}\Big/\sum_{\tau=0}^{\tau=\infty}(\beta\mathfrak{D})^{\tau}E_t\{U_{C,t+\tau}\cdot\chi_{t+\tau}/P_{t+\tau}\}, \tag{33}$$

[11] A note available from the author considers a variant of the model with a continuum of households, where each household monopolistically provides a *single* type of labor. In that structure, an individual household's wage setting decisions have no effect on economywide variables. The wage equation (33) below holds in that structure and the dynamics of aggregate variables is likewise unchanged (compared to the model in the text), provided there is full consumption risk-sharing among domestic households (which is the case when complete financial markets exist *within* each country).

where $U_{L,t+\tau} = -1$ is the marginal disutility of labor effort and

$$\chi_{t+\tau} \equiv ((1-\psi/\psi)R_{t+\tau}\mathscr{K}_{t+\tau}(W_{t+\tau})^{-1/\gamma}.\text{ [12]} \tag{34}$$

For a fraction $(1-\mathfrak{D})\mathfrak{D}^{\tau}$ of labor types, the wage rate in effect at date t was set in period $t-\tau$. Hence, the law of motion of the aggregate wage index is (from (10)):[13]

$$(W_t)^{1-\gamma} = \mathfrak{D}(W_{t-1})^{1-\gamma} + (1-\mathfrak{D})(w_{t,t})^{1-\gamma}. \tag{35}$$

2.5. Government

Each country's government prints the local currency. Let M_t be the Home 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:

$$M_{t+1} = M_t + T_t. \tag{36}$$

The money supply is exogenous (the government makes no attempt to influence the exchange rate, i.e. the exchange rate floats freely).

2.6. Market clearing conditions

Supply equals demand in labor markets and in the markets for intermediate goods as, by assumption, the household always meets the demand for her labor services and as producers of intermediate goods likewise always meet the demand that they face.

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[12] The left-hand side of (32) represents the effect on the household's expected life-time utility of the change in the stream of labor *income* that results from a variation in $w_{t,t}(h)$, while the right-hand side shows the effect on life-time utility of the ensuing change in current and future labor *effort*. Intuitively, these two expressions have to be equal, at an interior solution of the household's decision problem. Note that (33) implies that the same wage is set for all labor types for which a wage change occurs at t.

[13] N.B. When the wage rate is fully flexible ($\mathfrak{D} = 0$), and the own-wage elasticity of labor demand is infinite ($\gamma = \infty$), then (33), (35) imply $W_t/P_t = 1/U_{C,t}$, 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 $1/U_{C,t}$, as the marginal utility of leisure equals unity, for the utility function assumed here).

Market clearing for the Home final good requires:

$$Q_t = C_t + I_t. \tag{37}$$

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

$$M_t = \mathscr{M}_t, \tag{38}$$

where M_t and $\mathscr{M}_t$ are the Home money supply, and the desired money balances of the Home household, respectively.

Governments do not issue bonds. Market clearing in bond markets requires, thus:

$$A_t + A_t^* = 0 \quad \text{and} \quad B_t + B_t^* = 0, \tag{39}$$

where A_t^*, B_t^* are the Foreign household's stock of Home currency bonds and her stock of Foreign currency bonds, respectively.

Market clearing in the Home rental market for physical capital requires

$$K_t = \mathscr{K}_t, \tag{40}$$

where K_t is the aggregate Home capital stock, while $\mathscr{K}_t$ is total demand for capital, by Home intermediate good producers (see (21)).

Market clearing in the Home stock market requires that the demand for equity shares by the Home household equals the supply of shares. Normalizing the supply of shares to unity, the market clearing condition in the Home stock market is, thus:

$$S_t = 1. \tag{41}$$

2.7. Solution method

Given exogenous processes for productivity and the money supply in the two countries $\{\theta_t, M_t, \theta_t^*, M_t^*\}_{t=0}^{t=\infty}$, and given $K_0, A_0, B_0, r_0, r_0^*, W_{-1}$, $\mathscr{PD}_{-1}$, $\overline{\mathscr{PD}}_{-1}, K_0^*$, $W_{-1}^*, \mathscr{PD}_{-1}^*, \overline{\mathscr{PD}}_{-1}^*$, Eqs. (3), (5), (7), (11), (15), (17)–(31), (33)–(41) and the corresponding conditions for the Foreign country determine the endogenous aggregate variables $\{Q_t, C_t, D_t, Z_t, P_t, pd_{t,t}$, $\mathscr{PD}_t, \mathscr{PZ}_t, \overline{\mathscr{PD}}_t, w_{t,t}$, $W_t, R_t, K_{t+1}, I_t, r_{t+1}, rs_t, \sigma_t, Q_t^*, C_t^*, D_t^*, Z_t^*, P_t^*, pd_{t,t}^*, \mathscr{PD}_t^*, \mathscr{PZ}_t^*, \overline{\mathscr{PD}}_t^*, w_{t,t}^*, W_t^*$, $R_t^*, K_{t+1}^*, I_t^*, r_{t+1}^*, rs_t^*, \sigma_t^*, e_t\}_{t=0}^{t=\infty}$.

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.

2.8. Parameter values

2.8.1. Preference, technology and price and wage adjustment parameters

The coefficient of relative risk aversion is set at $\Psi = 2$. 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). The subjective discount factor 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%, a value that corresponds roughly to the long run average return on capital).

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

$$\kappa(\Gamma/\sigma)(\mathscr{M}_{t+1}/P_{t+1})^{\Gamma-1} = r_{t+1}(C_{t+1})^{\sigma-1} + \upsilon_{t+1},$$

where υ_{t+1} is a forecast error ($E_t \upsilon_{t+1} = 0$). Hence, the elasticities of money demand with respect to consumption and with respect to the domestic nominal interest rate are given by $\varepsilon_c \equiv (\sigma - 1)/(\Gamma - 1)$ and $\varepsilon_r \equiv 1/(\Gamma - 1)$, respectively. The simulations assume $\varepsilon_c = 0.20$ and $\varepsilon_r = -0.01$, which pins down the preference parameters σ and Γ (see (2)): $\sigma = -19$, $\Gamma = -99$. These values of ε_c and ε_r are in the range of estimates of the transactions elasticity and interest rate elasticity of money demand that are reported in econometric studies on money demand in the U.S. and in the remaining G7 countries (e.g., McCallum, 1989; Goldfeld and Sichel, 1990; Fair, 1987).[14]

The preference parameter κ (see (2)) is set in such a way that the steady state consumption velocity (ratio of nominal consumption expenditure to the money stock) equals unity.[15]

[14] 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 and other macroeconomic variables (empirically, long-run money demand elasticities are higher than short-run elasticities — e.g., estimation results presented by McCallum (1989) suggest that the long run elasticity of money demand with respect to the transactions proxy is approximately 0.50). The key result discussed below — that nominal rigidities raise cross-country correlations of real economic activity and of returns — is robust to changes in money demand elasticities.

[15] The 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, during the post-Bretton Woods era; e.g., in the U.S. that velocity was 0.93 in 1994).

ϑ, a country's elasticity of substitution between (composite) Home and Foreign intermediate goods, in final good production, equals the price elasticity of its import demand function (see (5)). For the G7 countries, the vast majority of estimates of price elasticities of international trade range between 0 and 1.5; see, e.g., Hooper and Marquez's (1995, Table 4.1) recent survey of the relevant empirical literature (a similar picture emerges from Goldstein and Khan's (1985) survey). Estimates for the U.S. are typically larger than those for the remaining G7 countries. The medians of the price elasticities reported by Hooper and Marquez for the U.S., Japan, the U.K., Canada and Germany are 1.05, 0.76, 0.44, 1.00 and 0.55, respectively. The simulations consider a baseline case in which ϑ is set at $\vartheta = 1$.[16,17] A sensitivity analysis is conducted, around that value.

The technology parameter α (see (3)) determines the ratio of the value of imports to GDP. 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.[18]

[16] The baseline case assumes thus a Cobb-Douglas final good technology, $Q_t = (D_t/(1-\alpha))^{1-\alpha}(Z_t/\alpha)^{\alpha}$, and a final good price given by $P_t = \mathscr{P}\mathscr{D}_t^{1-\alpha}\mathscr{P}\mathscr{Z}_t^{\alpha}$ (these expressions correspond to the limits of (3) and (7), for $\vartheta \to 1$).

[17] An older literature survey by Stern et al. (1976) reports "best guess" estimate of price elasticities of U.S. imports and exports that exceed unity (1.66 and 1.41, respectively). However, as representative estimates of ϑ for other large G7 countries are below unity, it seems reasonable to use $\vartheta = 1$, as a baseline value.

The assumption in the model that the elasticity of substitution is identical across countries is made for simplicity of exposition only. It appears that, in a variant of the model in which Home and Foreign elasticities, denoted ϑ and ϑ^*, are allowed to differ, predictions for the variables discussed below (cross-country correlations of output etc.; see Tables 2 and 3) hinge on the *mean* elasticity $(\vartheta + \vartheta^*)/2$: combinations of ϑ and ϑ^* for which $(\vartheta + \vartheta^*)/2$ is identical, are observationally equivalent, in this sense. Computing a weighted average (using the GDP weights reported in the Data Appendix) of ϑ for Japan, the U.K., Canada and Germany, and then taking the arithmetic mean of this weighted average and of the estimate for the U.S. yields an elasticity of 0.85, when the above estimates based on Marquez et al. are used. The same procedure yields a *mean* elasticity of 1.20, when the "best guess" estimates of Stern et al. are used.

The estimates that were just discussed pertain to *long-run* trade elasticities. Estimates of short-run elasticities are clearly below unity, for each of the G7 countries (e.g., Goldstein and Khan, 1985; Marquez et al., 1998). As the emphasis of the present paper is on high-frequency movements in output and other macroeconomic variables, this too militates in favor of using a conservative value for ϑ.

[18] Denoting Home nominal GDP by $\mathscr{Y}$, we have: $\mathscr{Y}_t = P_t \cdot (C_t + I_t) + \mathscr{P}\mathscr{D}_t Z_t^* - \mathscr{P}\mathscr{Z}_t Z_t$, according to standard National Accounts definitions. The value of the final good sector's output equals its total cost (as that sector is competitive): $P_t Q_t = \mathscr{P}\mathscr{D}_t D_t + \mathscr{P}\mathscr{Z}_t Z_t$ (N.B. $Q_t = C_t + I_t$). Thus, $\mathscr{Y}_t = \mathscr{P}\mathscr{D}_t \cdot (D_t + Z_t^*)$: a country's GDP equals the value of its intermediate goods output (N.B. the model assumes that a country's entire labor force and its entire capital stock are used in that country's intermediate goods sector; hence, a country's entire value added (GDP) is generated in that sector). As described above, the model is linearized around a symmetric deterministic steady state. In such a steady state, net exports are zero ($0 = \mathscr{P}\mathscr{D} \cdot Z^* - \mathscr{P}\mathscr{Z} \cdot Z$), and imported inputs account for a fraction α of the final good sector's cost ($\mathscr{P}\mathscr{D} \cdot Z = \alpha P \cdot Q$), which implies that, in such a steady state, the ratio of imports to GDP equals α.

In steady state, the markup factor of price over marginal cost in the production of intermediate goods is $v/(v-1)$ (v is the own-price elasticity of the demand curve faced by an intermediate good producer; see (4)). $v/(v-1) = 1.2$ is assumed, consistent with estimates of mark ups (in U.S. manufacturing) reported in Basu and Fernald (1993).[19]

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 in GDP is $(1-\psi)(v-1)/v$, where ψ is the elasticity of the production function of intermediate goods with respect to capital (see (8)). Hence, ψ is set at $\psi = 0.208$.

Aggregate data indicate a capital depreciation rate of roughly 2.5% per quarter and, hence, $d = 0.025$ is assumed. The capital adjustment cost parameter Φ (see (24)) is set at $\Phi = 8$, in order to match the observation that the standard deviation of investment is approximately 4 times as large as that of output, in the U.S. and in the G6 (for lower values of Φ, investment is excessively volatile, relative to the variability of output).

The simulations consider a baseline case in which the average time between price changes (in producer's 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 δ 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.[20]

2.8.2. *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 period 1973:Q3–1994:Q3.[21] The results show that the growth rate of money is

[19] It appears that the cyclical properties of the *aggregate* price/quantity variables on which the discussions below focus are invariant to the own-wage elasticity of labor demand, γ, and hence no specific value has to be assigned to that parameter (the linearization of the model yields a system of equations in the aggregate variables that does not depend on γ).

[20] Hall and Taylor (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).

[21] See Section 3 and the Appendix for a discussion of the data. Standard Augmented Dickey-Fuller unit root tests 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. Hence, the series can be modeled as a VAR in first differences (see Campbell and Perron 1991, p. 170). The order of the VAR was chosen using the Akaike criterion.

Table 1
VAR fitted to U.S. and G6 money growth rates[b,d]

$$\begin{bmatrix} \Delta\ \ln(M^{US}_{t+1}) \\ \Delta\ \ln(M^{G6}_{t+1}) \end{bmatrix} = \begin{bmatrix} 0.38^{a} & -\ 0.18 \\ (0.10) & (0.14) \\ 0.04 & 0.18^{c} \\ (0.08) & (0.08) \end{bmatrix} \cdot \begin{bmatrix} \Delta\ln(M^{US}_{t}) \\ \Delta\ln(M^{G6}_{t}) \end{bmatrix} + \begin{bmatrix} \xi^{US}_{t} \\ \xi^{G6}_{t} \end{bmatrix}$$

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

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 (significance levels for two-sided tests).
[a]Coefficient significant at 1% level.
[b]Coefficient significant at 5% level.
[c]Coefficient significant at 10% level.
[d]Coefficient significant at 20% level.
Sample period: 1973: Q3–94: Q3.

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:

$$\begin{bmatrix} \Delta\ \ln(M_{t+1}) \\ \Delta\ \ln(M^*_{t+1}) \end{bmatrix} = \begin{bmatrix} 0.3 & 0 \\ 0 & 0.3 \end{bmatrix} \cdot \begin{bmatrix} \Delta\ \ln(M_t) \\ \Delta\ \ln(M^*_t) \end{bmatrix} + \begin{bmatrix} \zeta_t \\ \zeta^*_t \end{bmatrix}, \tag{42}$$

where Δ is the difference operator (i.e. $\Delta \ln(M_{t+1}) \equiv \ln(M_{t+1}) - \ln(M_t)$); ζ_t and ζ^*_t are normal white noises with a standard deviation of 0.009; the correlation between ζ^1_t and ζ^*_t is 0.20.[22]

[22] To simplify the discussion of the results, a symmetric shock process is assumed; the assumed autocorrelation of the money growth rate and the assumed standard deviation of money supply innovations correspond to the mean values of the corresponding statistics for the U.S. and the G6 money series. N.B. as M_{t+1} is the money stock at the end of period t, the money supply innovation in (42) is assumed to belong to the period t information set.

Log productivity is assumed to follow a VAR:

$$\begin{bmatrix}\ln(\theta_t)\\ \ln(\theta_t^*)\end{bmatrix}=\begin{bmatrix}0.906 & 0.088\\ 0.088 & 0.906\end{bmatrix}\cdot\begin{bmatrix}\ln(\theta_{t-1})\\ \ln(\theta_{t-1}^*)\end{bmatrix}+\begin{bmatrix}\xi_t\\ \xi_t^*\end{bmatrix}, \tag{43}$$

where ξ_t and ξ_t^* are normal white noises with a standard deviation of 0.0085. The correlation between ξ_t and ξ_t^* is 0.258. The parameters of this process are taken from Backus et al. (1995), who argue that (43) captures well the time series properties of total factor productivity in the U.S. and in an aggregate of European countries. This time series process for productivity has widely been assumed in the International RBC literature (see Backus et al., 1995). Eq. (43) 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.

3. Stylized facts (Post-Bretton Woods era)

The last Columns of Table 2 (labelled "Data") document the business cycle stylized facts described in Section 1, 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 2 is real GDP, consumption is private non-durables plus services 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 the Appendix. 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.

In the U.S. and the G6, physical investment is more volatile than output, while the price level is roughly as volatile as output (the standard deviations of U.S. and G6 output are 1.83% and 1.09%, respectively). Standard deviations of consumption and 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%).

Output, investment, the price level and the nominal interest rate are highly positively correlated across the U.S. and the G6 (the cross-country correlations

Table 2
Predictions of model without nominal rigidities and of baseline nominal rigidities model. Historical statistics (1973: Q1–94: Q3)

	Model without nominal rigidities			Baseline nominal rigidities model			Data	
	Shocks to			Shocks to				
Statistics	M	θ	M&θ	M	θ	M&θ	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	0.96 (.09)	0.60 (.07)
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)	
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)[a]	
Consumption	0.16	0.52	0.52	0.59	0.79	0.64	0.34 (.10)[a]	
Investment	0.57	− 0.40	− 0.40	0.57	0.43	0.56	0.53 (.13)[a]	
Money	0.20	u	0.20	0.20	u	0.20	0.30 (.12)[b]	
Price level	0.19	− 0.31	0.19	0.10	0.60	0.11	0.64 (.07)[a]	
Nom interest rate	0.19	− 0.99	0.13	0.59	− 0.09	0.57	0.57 (.07)[a]	
Nom stock return	0.20	0.12	0.18	0.44	0.63	0.45	0.73 (.05)[a]	
Real stock return	0.58	0.00	0.00	0.63	0.67	0.63	0.73 (.05)[a]	

Note: (i) The columns numbered (1)–(6) report model predictions. Columns (7)–(8) report empirical statistics. 'Nom' is abbreviation of 'Nominal'.
(ii) 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.
(iii) 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.
(iv) 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).
(v) For the empirical *cross-country correlations* reported in the table, significance levels (two-sided tests) are shown.
[a]Correlation significantly different from zero at 1% level.
[b]Correlation significantly different from zero at 5% level.
u: correlation not defined (series with zero variance).

of these variables are in the 0.50–0.65 range; these cross-correlations are all statistically significant, at the 1% level). The cross-country (U.S.-G6) correlations of consumption and money stocks are somewhat lower (in the range of 0.30). Cross-country correlations of stock returns (around 0.70) are higher than those of output.

4. Model predictions

Theoretical counterparts to the empirical standard deviations and cross-correlations that were just discussed are reported in Columns (1)–(6) of Table 2, as well as in Table 3. Columns (4)–(6) of Table 2 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 δ and $\mathfrak{D}$ are set at $\delta = \mathfrak{D} = 0$). Table 3 considers alternative versions of the nominal rigidities model. In these Tables, the theoretical output variables for the two countries are defined as $Y_t \equiv D_t + Z_t^*$ and $Y_t^* \equiv D_t^* + Z_t$, which corresponds to Home and Foreign real GDP, in the model.[23] Consumption is $C_t(C_t^*)$, the price level is $P_t(P_t^*)$ and the real exchange rate is defined as $e_t \cdot P_t^*/P_t$. The model statistics reported in Tables 2 and 3 pertain to Hodrick and Prescott (1997) filtered variables. Prior to filtering, all variables (with the exception of interest rates and equity returns) were expressed in logs.

In Tables 2 and 3, 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 θ", 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&θ").

4.1. *Structure without nominal rigidities* (*Columns* (*1*)–(*3*), *Table 2*)

Column (1) of Table 2 reports results for the case in which the structure with 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 rate 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 too small, when compared to the data.

[23] As noted in Section 2.8.1., Home *nominal* GDP is $y_t = \mathscr{P}\mathscr{D}_t \cdot (D_t + Z_t^*)$. *Real* GDP, can be computed by dividing y_t by the growth factor of the price index $\mathscr{P}\mathscr{D}_t$, compared to some base period, $t = b$: $y_t/(\mathscr{P}\mathscr{D}_t/\mathscr{P}\mathscr{D}_b) = \mathscr{P}\mathscr{D}_b \cdot (D_t + Z_t^*)$. Normalizing $\mathscr{P}\mathscr{D}_b = 1$ yields $Y_t = D_t + Z_t^*$.

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 2). However, the standard deviations of the price level, the nominal exchange rate and the nominal interest rate induced by technology shocks are much lower than the standard deviations generated by money supply shocks.

Note also that technology shocks induce *negative* cross-country correlations of output and investment, when prices and wages are fully flexible (see detailed discussion of this prediction in Section 4.2.2. below). Interestingly, *money* supply shocks induce sizable positive cross-country correlations of output and investment, 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 and investment 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 2. (The predicted cross-country correlations of equity returns are positive when both types of shocks are used, but markedly smaller than the correlations seen in the data.) These results confirm the widely discussed failure of standard business cycle models with flexible prices and wages to capture the high cross-country correlations of real economic activity seen in the data (e.g, Backus et al., 1995; Baxter, 1995, Schmitt-Grohé, 1998).

4.2. Baseline nominal rigidities model (*Columns* (*4*)–(*6*), *Table 2*)

4.2.1. Money supply shocks

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 money supply shocks generates standard deviations of output and consumption that are roughly consistent with the data (see Column (4) of Table 2). The predicted standard deviations of the nominal and real exchange rate and of the nominal and real equity return (that are induced by money shocks) increase also noticeably, compared to the model without nominal rigidities (standard deviations of these four variables 3.22%, 2.17%, 2.17% and 1.88%, respectively, in the baseline nominal rigidities structure, compared to 1.91%, 0.01%, 0.89% and 0.01%, respectively, without nominal rigidities). Note furthermore that the baseline nominal rigidities structure generates sizable positive cross-country correlations of output, consumption, investment, the interest rate and equity returns, when just money supply shocks are assumed (correlations in the range 0.40–0.65).[24]

[24] The predicted cross-country correlation of the price level (0.10) is noticeably smaller. The model without nominal rigidities generates likewise a relatively small cross-country correlation of the price level.

4.2.1.1. Impulse response functions. Fig. 1 shows impulse response functions that help to understand these predictions. For the baseline nominal rigidities model, the dynamic effects of a one standard deviation (i.e., 0.90%) innovation to the Home money growth rate are presented. Responses of consumption and investment are expressed in units of GDP in the "unshocked" steady state; interest rates and equity returns are shown as differences from steady state returns, while responses of the remaining variables are expressed as relative deviations from the unshocked steady state.[25]

The Home money supply increase induces a rise in the Home price level. However, the price level increases less rapidly than the money supply and, as a result, Home real money balances rise, which helps to understand why the shock induces a persistent reduction in the Home nominal interest rate (see Panel (c), Fig. 1). The expected Home *real* interest rate, in terms of the Home final good, falls likewise, as the expected Home inflation rate rises (real interest rate not shown in figure). This raises Home consumption and investment demand — hence, Home output increases, on impact (see Panel (a)).

Panel (c) of Fig. 1 shows that, on impact, a 0.9% money supply innovation induces a depreciation of the Home currency by about 2%. In subsequent periods, the exchange rate appreciates and converges to its new long-run level.[26] The long-run effect of the money supply shock is a depreciation of the exchange rate by approximately 1.3% (it appears that the Home money supply and price level rise by roughly 1.3%, 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 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 the Home exchange rate is accompanied by a substantial *real* depreciation (see Panel (c) in Fig. 1), which explains why the predicted standard deviation of the *real* exchange rate increases strongly when nominal rigidities are assumed

[25] For example, the response of the Home interest rate is shown as $r_t - r$, where r is the steady state interest rate, while the responses of Home consumption and output are expressed as $P\cdot(C_t - C)/(\mathscr{PD}\cdot Y)$ and $(Y_t - Y)/Y$, respectively, where C, Y, P, and $\mathscr{PD}$ are consumption, real GDP, the final good price and the GDP deflator, respectively, in the unshocked steady state.

[26] Eqs. (28) and (29) imply that, up to a certainty equivalent approximation, Uncovered Interest Parity holds, in equilibrium: $1 + r_{t+1} \simeq (1 + r^*_{t+1})(E_t e_{t+1}/e_t)$. As discussed above, a positive Home money supply shock induces a persistent reduction in the Home interest rate (the Foreign interest rate falls as well, but by less). Hence, the Home currency *appreciates* in the periods that follow the money supply shock.

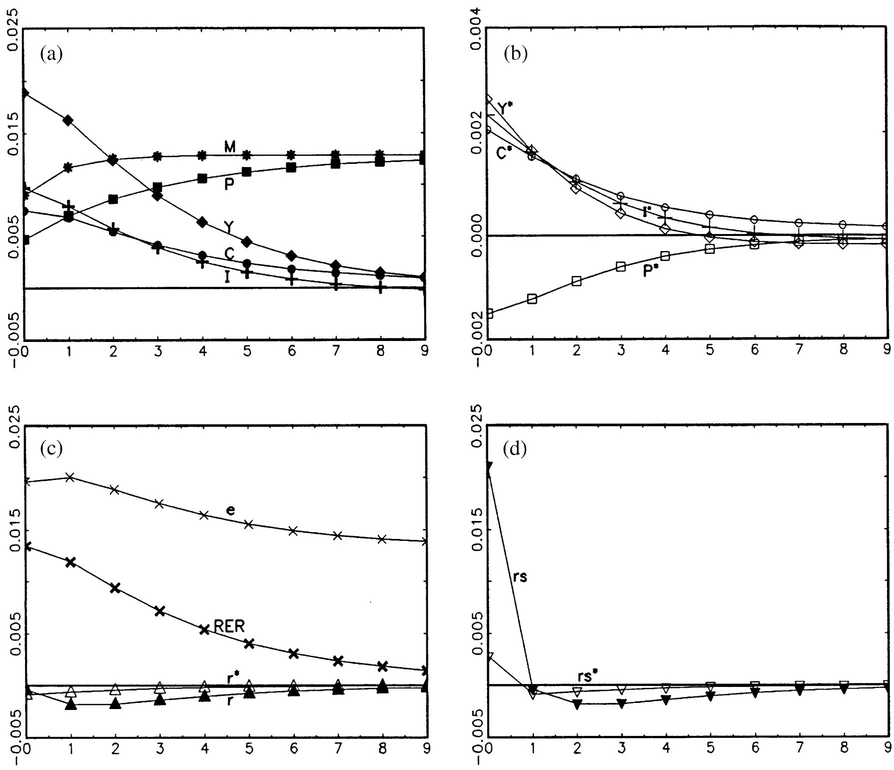

Fig. 1. Baseline nominal rigidities model: shock to Home money supply. (a) Home money, price level, output, consumption, investment; (b) Foreign price level, output consumption, investment; (c) Interest rates, nominal & real exchange rate and (d) Stock returns.

Dynamic responses to 1 standard deviation innovation to growth rate of Home money stock. Interest rate and stock return responses expressed as differences from initial position; consumption and investment responses shown in units of initial real GDP; responses of other variables shown as relative deviations from initial position. Period t responses of money stock, interest rates and stock returns pertain, respectively, to end of period money stock (M_{t+1}), interest rates between t and $t+1$ (r_{t+1}, r^*_{t+1}) and to realized stock returns between $t-1$ and t (rs_t, rs^*_t). Abscissa: Periods after shock.

✻: Home money, M; ×: Nominal exchange rate, e; ✕: Real exchange rate, RER.

Home/Foreign

◆/◇: Output, Y/Y^*; ●/○: Consumption, C/C^*; +/ + : Investment, I/I^*;

▩/□: Price level, P/P^*; ▲/Δ: Nominal interest rate, r/r^*; ▼/▽: Nominal stock ret, rs/rs*.

(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 Fig. 1 shows that, in response to a positive shock to the Home money supply, Foreign output, consumption and investment rise, though by markedly less than Home variables (notice different scale in Panel (b)).[27] The rise in Foreign output is due to the following two mechanisms: (i) the rise in consumption and investment demand in the Home country raises the demand for Foreign intermediate goods. (ii) The depreciation of the Home currency reduces the price of imports (in terms of Foreign currency) purchased by the Foreign country, which lowers the Foreign price level; this raises Foreign real balances and induces a persistent fall in the Foreign interest rate (see Panel (c), Fig. 1), which provides a further positive stimulus to demand for Foreign goods.

In contrast to the model here, the basic Keynesian open economy model developed by Mundell (1968, Chapter 18) predicts a *negative* response of Foreign output, to a Home money supply increase, when the exchange rate is flexible, as the depreciation of the Home currency (triggered by the Home money shock) induces agents to substitute Foreign goods with Home goods.[28] 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.

Note also that as a positive Home money supply innovation induces a persistent reduction in the interest rate and a rise in real economic activity, in both countries, the (nominal and real) stock return is predicted to rise in both countries, on impact (the rise in the Foreign return is markedly smaller than that of the Home return).[29]

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). The predicted positive international transmission effect of money supply shocks is consistent with Kim (1998) who shows, using a VAR methodology, that a loosening of U.S. monetary policy raises output, consumption and investment, in the U.S. *and* in the G6; the foreign (G6) responses are markedly weaker than the own-country effects — as predicted by the theoretical model here.

[27] For example, on impact, Home and Foreign output rise by 1.89% and 0.26%, respectively.

[28] The basic Mundell model stresses this demand-switching effect of exchange rate movements. In more elaborate Keynesian models, positive international transmission effects can occur which are partly comparable to those discussed above (e.g., Turnovsky (1990); Frankel (1988) provides a detailed overview of relevant transmission channels, in those models).

[29] Up to a certainty equivalent approximation, Eqs. (28) and (30) imply that the date t interest rate equals the expected stock return between t and $t+1$: $r_{t+1} \simeq E_t rs_{t+1}$. Given the persistent reduction in interest rates that is induced by a positive money supply shock, this explains the drop in 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).

4.2.2. Baseline model with nominal rigidities: technology shocks

Column (5) of Table 2 reports results for the version of the baseline nominal rigidities model 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 correlations of output and investment are 0.51 and 0.43, respectively, in the baseline nominal rigidities model, when just technology shocks are assumed, compared to correlations of -0.05 and -0.40, respectively, in the structure without nominal rigidities.

For the baseline nominal rigidities model, Fig. 2 shows the effect of a one standard deviation (i.e. 0.85%) innovation to Home productivity. That shock raises Home output, consumption and investment; it also induces a fall in the Home price level, as well as a nominal and real depreciation of the Home currency. In the baseline nominal rigidities model, an increase in Home productivity triggers a *rise* in Foreign output. This is due to the fact that the Home productivity increase raises the wealth of the Home household, which increases Home demand for Foreign intermediate goods. In the structure without nominal rigidities, by contrast, a positive Home productivity shock induces a fall in Foreign output, on impact (impulse responses available from the author).

The intuition for this difference between the two structures is that a positive Home productivity shock induces a *delayed* rise in Foreign productivity, as can be seen in Panel (b) of Fig. 2.[30] The shock raises, thus, the wealth of the Foreign household. On impact, this induces a fall in Foreign labor supply (leisure being a normal good, in the model here). In the structure without nominal rigidities, this induces a fall in Foreign working hours (on impact) and, thus, a fall in Foreign output (see Baxter (1995) for a detailed discussion of the international transmission of productivity shocks, in dynamic trade models without nominal rigidities). This contrasts with the nominal rigidities structure, where hours worked, for labor types with predetermined wage rates, are determined by labor *demand* (the household meets any demand for these labor types, at the predetermined wage rates) — in response to a positive shock to Home productivity, Foreign output falls hence less, in that structure (compared to the case without nominal rigidities), or even rises (as is the case in the baseline nominal rigidities structure) because Foreign producers of intermediate goods face an increased demand for their goods (see discussion above).[31] This explains why

[30] This is due to the VAR time series process followed by productivity: the off-diagonal elements of the matrix of autoregressive coefficients of the VAR are positive (see (43)).

[31] Depending on parameter values, Foreign output may either fall or rise, on impact (in response to a positive shock to Home productivity), in the nominal rigidities structure (a fall occurs, e.g., for large values of the elasticity of substitution between Home and Foreign intermediate goods, ϑ; see discussion below). However, even if Foreign output falls in that structure, it falls *less* than when there are no nominal rigidities.

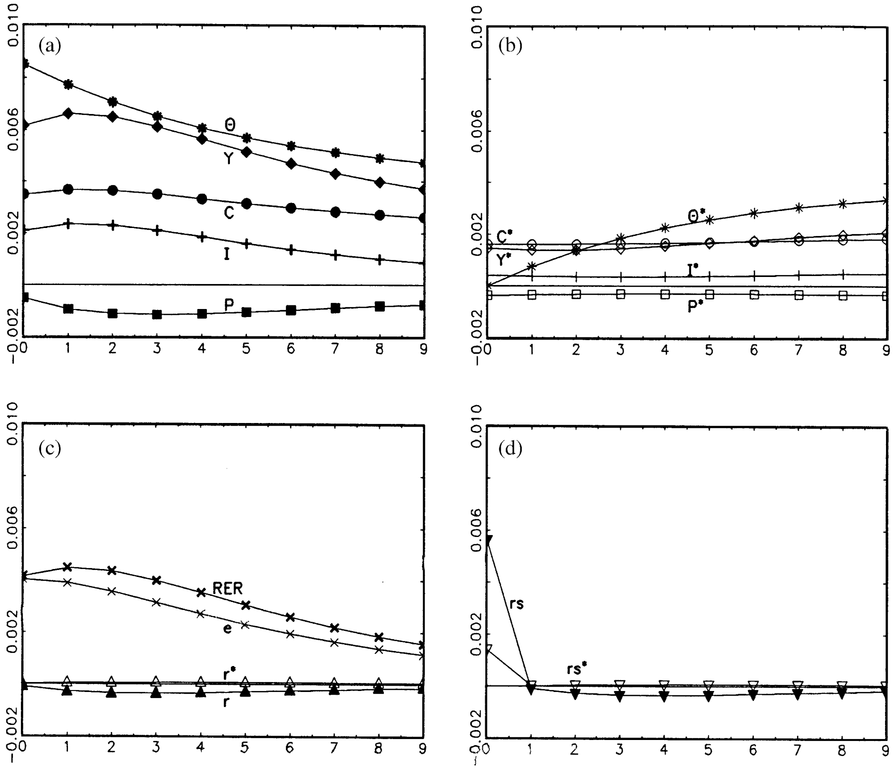

Fig. 2. Baseline nominal rigidities model: shock to Home productivity. (a) Home productivity, price level, output, consumption, investment; (b) Foreign productivity, price level output, consumption, investment; (c) Interest rates, nominal & real exchange rate and (d) Stock returns.

Dynamic responses to 1 standard deviation innovation to Home productivity. Interest rate and stock return responses expressed as differences from initial position; consumption and investment responses shown in units of initial real GDP; responses of other variables shown as relative deviations from initial position. Period t responses of interest rates and stock returns pertain, respectively, to interest rates between t and $t+1$ (r_{t+1}, r^*_{t+1}) and to realized stock returns between $t-1$ and t (rs_t, rs^*_t). Abscissa: Periods after shock.

×: Nominal exchange rate, e; **×**: Real exchange rate, RER.

Home/Foreign

✱/✲: Productivity, θ/θ^*;

◆/◇: Output, Y/Y^*; ●/○: Consumption, C/C^*; **+**/ + : Investment, I/I^*;

▩/□: Price level, P/P^*; ▲/Δ: Nominal interest rate, r/r^*; ▼/▽: Nominal stock ret, rs/rs*.

technology shocks induce cross-country correlations of output that are higher when nominal rigidities are assumed (compared to the case without nominal rigidities).

4.2.3. 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 2) — 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 2). 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 and equity 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.

4.3. Sensitivity analysis

4.3.1. Technology and preference parameters

A parameter that has a particular influence on the predicted cross-country *output* correlation is ϑ, the elasticity of substitution between (composite) Home and Foreign intermediate goods, in final good production: the output correlation is negatively related to ϑ.[32] However, irrespective of the value of ϑ, cross-country output correlations are markedly higher when nominal rigidities are assumed, compared to the case without nominal rigidities. This is documented in Columns (1)–(4) of Table 3, where versions of the model with $\vartheta = 0.2$ and $\vartheta = 2$ are considered (N.B. the baseline model assumes $\vartheta = 1$): when $\vartheta = 0.2$, the predicted cross-country correlation of output is 0.24 when prices and wages are flexible (and money and productivity shocks occur simultaneously) and 0.62 with sticky prices and wages; the corresponding correlations are -0.28 and 0.18, respectively, when $\vartheta = 2$.[33] Interestingly, predicted

[32] Recall that positive shocks to Home money and productivity lead to a depreciation of the Home currency, which induces a substitution effect from Foreign to Home goods; the bigger is ϑ, the stronger is this effect and the lower is, thus, the cross-country output correlation.

[33] In the baseline nominal rigidities structure, Home money supply shocks are positively transmitted to Foreign output, provided $\vartheta \leq 1.99$, i.e. for values of ϑ in the empirically relevant range (cf. Section 2.8.1); when money and productivity shocks occur simultaneously, the baseline nominal rigidities model generates positive cross-country correlations of output if $\vartheta \leq 2.95$.

The model here assumes that elasticities of substitution are the same in both countries. Recall from Section 2.8.1 that if elasticities of substitution differ across countries, then cross-country output correlations hinge on the *mean* of the two countries' elasticities, $(\vartheta + \vartheta^*)/2$. Thus, if $\vartheta^* < 1$ were assumed (motivated, say, by the fact that estimates of ϑ are often below unity, for non-U.S. G7 countries), then $\vartheta > 4.9$ would have to be postulated to overturn the predicted positive cross-country output correlation generated by the nominal rigidities structure. Such large elasticities lack empirical plausibility.

cross-country correlations of *investment* and *returns* (and of the remaining variables in Table 2) are basically insensitive to ϑ — irrespective of the value of ϑ, predicted cross-country correlations of investment and returns are, hence, closer to the empirical correlations, when sticky prices and wages are assumed.

The result that nominal rigidities raise predicted cross-country correlations of output, investment and returns (compared to the case with flexible prices and wages) is also robust to changes in other technology parameters and in preference parameters (a detailed sensitivity analysis is available from the author).

4.3.2. Alternative assumptions about price/wage adjustment

The sensitivity of model predictions to alternative assumptions about the price/wage adjustment mechanism is investigated in Columns (5)–(7) of Table 3. Column (5) considers a version of the nominal rigidities 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. Columns (6) and (7) of Table 3 consider 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 (exceptions to this are Kim, 1996; Erceg et al., 1999). When just prices or just wages are sticky, predicted cross-country correlations of real economic activity and of returns are lower than in the baseline model with sticky prices *and* sticky wages.

4.3.2.1. Pricing to market behavior (*Column* (5), *Table 3*). 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 (14)); as the prices of intermediate goods are assumed to be sticky, in terms of the producer's domestic 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 buyer's currency, is assumed; the average duration

Table 3
Alternative specifications (money and productivity shocks used simultaneously)

Statistics	Substitution elasticity Home vs. Foreign goods $\vartheta = 0.2$ No nom. rig.	Nom. rig.	$\vartheta = 2$ No nom. rig.	Nom. rig.	Alternative assumptions about price/wage setting: Pricing to market	Sticky wages, flex. prices	Sticky prices, flex. wages	Data U.S.	G6
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Standard deviations (in %)									
Output	0.73	2.48	0.97	2.90	2.65	1.93	1.66	1.83	1.09
Consumption	0.56	1.38	0.54	1.34	1.49	1.07	0.84	0.96	0.60
Investment	2.43	10.96	2.37	10.86	12.07	7.17	6.96	7.84	4.34
Money	1.51	1.51	1.51	1.51	1.51	1.51	1.51	2.33	1.26
Price level	1.52	1.12	1.52	1.13	1.10	1.36	1.25	1.68	1.32
Nominal interest rate	0.26	0.28	0.26	0.28	0.32	0.24	0.15	0.45	0.33
Nominal exchange rate	2.02	3.13	2.02	3.15	3.84	2.73	2.67	7.33	
Real exchange rate	0.93	4.16	0.90	2.16	3.36	1.89	1.54	6.86	
Nominal stock return	1.01	2.29	1.00	2.24	2.44	1.78	1.58	8.16	7.80
Real stock return	0.60	2.03	0.56	1.98	2.27	1.61	1.21	8.27	7.82

Cross-country correlations

Output	0.24	0.62	−0.28	0.18	0.42	0.29	0.33	0.61
Consumption	0.45	0.57	0.56	0.66	0.35	0.59	0.61	0.34
Investment	−0.42	0.52	−0.39	0.55	0.26	0.39	0.47	0.53
Money	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.30
Price level	0.19	0.13	0.19	0.10	0.18	0.17	0.15	0.64
Nominal interest rate	0.12	0.52	0.14	0.60	0.23	0.13	0.33	0.57
Nominal stock return	0.17	0.41	0.19	0.47	0.24	0.37	0.36	0.73
Real stock return	−0.06	0.58	0.05	0.65	0.26	0.49	0.56	0.73

Note:

ϑ : elasticity of substitution between Home and Foreign intermediate goods (in final good production).

Columns (1)–(2): for $\vartheta = 0.2$, comparison between structure without nominal rigidities ('No nom. rig'.) and structure with sticky prices and sticky wages ('Nom. rig.').

Columns (3)–(4): same comparison as in (1)–(2), but for $\vartheta = 2$.

Column (5): version of model with 'pricing to market' (PTM) behavior of producers of intermediate goods.

Column (6): version of model with sticky wages ($\mathfrak{D} = 0$), but flexible prices ($\delta = 0.75$).

Column (7): version of model with sticky prices ($\delta = 0.75$), but flexible wages ($\mathfrak{D} = 0$).

This table assumes that the economy is simultaneously subjected to money supply and to technology shocks.

See Table 2 for further information.

between price adjustments is assumed to be 4 periods, in both markets.[34] All other aspects of the model are unchanged, compared to the baseline model. Results for the PTM case are shown in Column (5) of Table 3.

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 returns fall noticeably, when PTM is assumed, but PTM raises the predicted variability of nominal and real exchange rates.[35]

Fig. 3 shows dynamic responses to a one standard deviation (0.90%) innovation to the Home money supply, for the structure with PTM. In that structure, a Home money supply increase induces a much smaller fall in the Foreign price level than in the baseline model, as import prices in the Foreign country are less responsive to exchange rate movements, when PTM is assumed. As a result, the Foreign interest rate falls less than in the baseline nominal rigidities structure, and Foreign consumption, investment and equity returns rise less than in that structure — which helps to understand why these variables are less highly positively correlated across countries, under PTM.[36]

[34] Consider a Home intermediate good producer that gets to reset her export price, in Foreign currency, at date t. Let $\mathscr{pz}^*_{t,t}$ denote that price. Under PTM, $\mathscr{pz}^*_{t,t}$ is set at

$$\mathscr{pz}^*_{t,t} = \operatorname*{Arg\,Max}_{\mathscr{pz}} \sum_{\tau=0}^{\tau=\infty} \delta^\tau E_t\{\rho_{t,t+\tau}\cdot(\mathscr{pz}\cdot e_{t+\tau} - \mathfrak{G}'_{t+\tau})\cdot Z^*_{t+\tau}\cdot(\mathscr{pz}/\mathscr{PZ}^*_{t+\tau})^{-\nu}/P_{t+\tau}\}.$$

A Home intermediate good producer that resets her price in the Home market, at date t, sets the following price, under PTM:

$$\mathscr{pd}_{t,t} = \operatorname*{Arg\,Max}_{\mathscr{pd}} \sum_{\tau=0}^{\tau=\infty} \delta^\tau E_t\{\rho_{t,t+\tau}\cdot(\mathscr{pd} - \mathfrak{G}'_{t+\tau})\cdot D_{t+\tau}\cdot(\mathscr{pd}/\mathscr{PD}_{t+\tau})^{-\nu}/P_{t+\tau}\}.$$

[35] 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 investment and of the real stock return are 3.84%, 0.26 and 0.26, respectively, compared to 3.29%, 0.56 and 0.63, in the baseline model.

[36] The discussion of the baseline nominal rigidities model in Section 4.2.1 has focused on two channels that induce a positive response of Foreign output to a rise in Home money (rise in Home absorption that raises demand for Foreign goods; fall in the Foreign interest rate induced by reduction in Foreign price level) and one *negative* transmission effect (negative substitution effect due to the depreciation of the Home currency). When PTM is assumed, the second of these *positive* international transmission channels is weakened considerably (as the Foreign interest rate falls less, in response to the money supply shock). However, the *negative* substitution 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 nominal exchange rate movements on the relative price between domestic and foreign intermediate goods faced by the buyers of these goods). The net result is that the response of Foreign output changes little, compared to the baseline case, which explains why the predicted cross-country correlation of output is hardly affected by PTM, as discussed above.

The weaker response of the Foreign interest rate (to a Home money supply increase), under PTM, implies also that the Home-Foreign interest rate *differential* ($r_t - r^*_t$) falls more strongly, in response to a positive shock to the Home money supply (see Panel (c), Fig. 3) and, hence, exchange rate overshooting is stronger under PTM. This explains why predicted exchange rate variability increases when PTM is assumed.

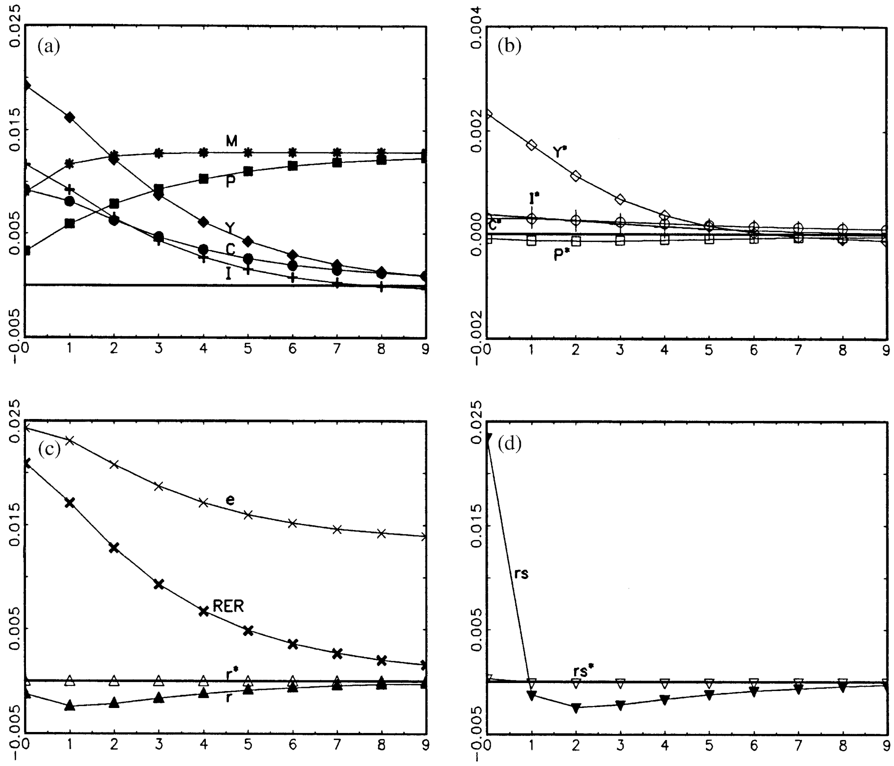

Fig. 3. Version of nominal rigidities model with pricing to market (PTM): shock to Home money supply. (a) Home money, price level, output, consumption, investment; (b) Foreign price level, output, consumption, investment; (c) Interest rates, nominal & real exchange rate and (d) Stock returns.

Dynamic responses to 1 standard deviation innovation to growth rate of Home money stock. Interest rate and stock return responses expressed as differences from initial position; consumption and investment responses shown in units of initial real GDP; responses of other variables shown as relative deviations from initial position. Period t responses of money stock, interest rates and stock returns pertain, respectively, to end of period money stock (M_{t+1}), interest rates between t and $t+1$ (r_{t+1}, r^*_{t+1}) and to realized stock returns between $t-1$ and t (rs_t, rs^*_t). Abscissa: Periods after shock.

$*$: Home money, M; $\times$: Nominal exchange rate, e; **×**: Real exchange rate, RER.

Home/Foreign

◆/◇: Output, Y/Y^*; ●/○: Consumption, C/C^*; +/ + : Investment, I/I^*;

▩/□: Price level, P/P^*; ▲/Δ: Nominal interest rate, r/r^*; ▼/▽: Nominal stock ret, rs/rs*.

4.3.2.2. Versions of model in which prices only or wages only are sticky (*Columns* (*6*)–(*7*), *Table* 3). 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 predicted cross-country correlations of output and asset returns fall, compared to the baseline nominal rigidities structure.[37] Also, the predicted standard deviations of the variables considered here (with the exception of the price level) tend to fall.

5. 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 dynamic-optimizing stochastic general equilibrium model of a two-country world that postulates sticky nominal prices and wages. The structure here 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 with flexible prices and wages.

Appendix. 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 (MEI); for Germany, the MEI output series starts in 1991: Q1; this series was spliced to German GDP, from IFS, for earlier period.

Consumption — private non-durables plus services consumption expenditures, in volume terms (from OECD Quarterly National Accounts).

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

Money supply — narrow money stock, M1 (MEI). The UK money series starts in 1982: Q3. (G6 money series for 1982: Q3–1994: Q3 is geometric weighted average of M1 in each G6 country; that series was spliced to geometric weighted average of M1 in non-UK G6 countries, during prior period).

Price level — consumer price index, CPI (IFS).

Nominal interest rate — short term interest rates from Citibase. U.S.: CD rate (series FYUSCD); Japan, Germany, France: call money rate (FYJPCM,

[37] For example, when only wages are sticky, then the predicted cross-country correlations of output, investment and the real equity return are 0.29, 0.39 and 0.49, respectively (in the case where money supply and technology shocks occur simultaneously), compared to correlations of 0.42, 0.56 and 0.63, respectively, in the baseline structure.

FYGECM, FYFRCM); U.K.: rate on prime bank bills (FYGBBB); Italy: bond yields, credit institutions (FYITBY); Canada: prime corporate paper, 60 days (FYCACP).

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

Real exchange rate — constructed using relative CPIs.

Stock return — Constructed from Morgan Stanley Capital International stock indices. Real stock returns are nominal returns minus CPI inflation rates.

All time series are used in quarterly form. Interest rates and stock returns are expressed on a per quarter basis. Price level, interest rate and exchange rate time series were obtained at a monthly frequency from data sources. Quarterly averages of these series are used. Output, consumption, investment, price level and money series are provided in seasonally adjusted form by the data sources (the remaining series do not exhibit seasonality). The G6 aggregate series for the interest rate and the stock return are *arithmetic* averages of series for the individual G6 countries; G6 aggregates for other variables are *geometric* averages of individual G6 series. Country weights: Japan, 0.28; Germany, 0.20; France, 0.18; United Kingdom, 0.14; Britain, 0.12; Canada, 0.07. These weights are 1980 shares of individual G6 countries's GDP (in U.S. dollars, at 1980 U.S. exchange rates) in total G6 GDP.

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