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Exchange rate determination: The role of factor price rigidities and nontradeables

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Abstract

This paper introduces factor (labor) markets into the intertemporal monetary model of Obstfeld and Rogoff and combines this richer market structure with a new utility-independent representation of nontradeables. This allows us to explore the international monetary transmission mechanism for factor price (wage) rigidities under different degrees of macroeconomic openness. Factor price rigidities imply similar properties for the international transmission mechanism as domestic producer price rigidities. Nontradeables give raise to interesting new effects under asymmetric monetary shocks: They create short-run PPP deviations, increase exchange rate volatility relative to price level volatility and reduce (positive) consumption and (negative) output comovements.

Keywords: Monetary transmission; Factor price rigidities; Nontradeables

JEL classification: F3; F4

1. Introduction

This paper investigates the role of factor price (wage) rigidities and nontradeables for the international monetary transmission mechanism. Our work builds on the dynamic two-country model of Obstfeld and Rogoff (1995a), which we generalize in three respects. First, we introduce factor markets (similar to

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Blanchard and Kiyotaki, 1987) and assume that nominal rigidities originate in sticky factor prices (wages).[1] Historically, nominal factor price (or wage) rigidities have played a central role in theories of monetary non-neutrality. Recently, Christiano et al. (1997) have pointed out that firm profits decrease after a monetary contraction and that this observation is unexplained by a combination of sticky product prices and a flexible factor (labor) market. Our model with sticky factor prices (wages) correctly predicts procyclical firm profits. The international transmission mechanism is shown to be similar if we assume factor price rigidities instead of product price rigidities. Second, Obstfeld and Rogoff assume nominal price rigidities for the domestic products, while the foreign market price for the same product is flexible and determined by the law of one price. We assume destination-specific flexible price setting in local currency and do not assume international product arbitrage. Given identical constant elasticities in all markets, we recover the law of one price for tradeables as a consequence of optimal monopolistic price setting. However, nontradeables in the consumer price index produce large short-run and small long-run purchasing power parity (PPP) deviations. Third, we provide an integrated approach for the treatment of nontradeables. Obstfeld and Rogoff assume that tradeables and nontradeables enter consumer utility separately. This utility-based distinction between tradeables and nontradeables renders an analysis of the role of economic openness difficult. By contrast, the symmetric utility treatment of both product types in our model allows for a more meaningful comparative statics with respect to the degree of macroeconomic openness.

Nontradeables modify the international transmission mechanism in three different ways. An unanticipated home money expansion, given predetermined factor prices in a monopolistic factor market, increases home aggregate demand. The domestic demand expansion does not fully account for the money supply expansion and a price level increase is needed to clear the market for real balances. Constant demand elasticities tie domestic product prices to a fixed mark-up over nominally rigid factor prices. Only import prices can contribute to a short-run price level increase as foreign exporters pass through any exchange rate depreciation to the home market. More nontradeables reduce the impact of import prices on the domestic price level. The domestic money market equilibrium therefore requires a larger home depreciation and more import price inflation to compensate for fewer tradeables in the consumer price index. Nontradeables therefore create an *exchange rate magnification effect* for any given gap between relative money supply and relative consumption. This effect can explain why the volatility of the exchange rate is high relative to the volatility of the relative price levels (Chari et

[1]Since Obstfeld and Rogoff merge households and producers, the role of factor price (wage) rigidities cannot be addressed.

al. (1997)).[2] Second, more nontradeables imply that a domestic demand expansion is concentrated on domestic products. We call this the *home product consumption bias,* which reduces international demand spillovers. The home product consumption bias tends to reduce the (positive) consumption comovement and the (negative) output comovement. Third, nontradeables change the optimal intertemporal consumption behavior. Net foreign assets accumulation allows domestic consumers to smooth income effects of the domestic expansion into a higher permanent consumption level. But short-run PPP deviations due to nontradeables imply also differential real returns for domestic and foreign investors on any foreign asset. Slow domestic price inflation following the initial home depreciation decreases future real returns and motivates domestic dissaving through a short-run consumption expansion. The *differential real return effect* increases aggregate consumption at home relative to aggregate consumption abroad. The adopted 'money in the utility' framework ties the money demand to aggregate consumption. Differential real returns will therefore contribute to the money market equilibrium and counterbalance the exchange rate magnification effect.

The Obstfeld–Rogoff framework has inspired a wave of new research on general equilibrium models with nominal rigidities. Here we highlight only two contributions and refer the reader to a first survey on the 'new open economy macroeconomics' by Lane (1999). Betts and Devereux (1996) study the case in which the law of one price applies only to a subset of traded goods, while other foreign product prices are sticky in terms of the local currency.[3] They show that local currency stickiness of product prices magnifies exchange rate volatility. Like the exchange rate magnification effect in our model, the exchange rate movements overcompensates for a reduced pass-through to the aggregate relative price level. A further extension of the Obstfeld–Rogoff can be found in Tille (1998) who allows the substitutability between goods produced in different countries to differ from the substitutability between goods produced in the same country. He finds that a lower substitutability across countries raises the volatility of the exchange rate and can lead to a 'beggar-thyself' effect where a country can be adversely affected by its own monetary expansion.

The following Section presents the two-country model. Section 3 solves for the symmetric equilibrium with fully flexible product and factor markets. The model is log-linearized in Section 4 under the assumption that factor prices are nominally rigid, whereas consumer product markets have flexible prices. We discuss how nontradeables affect the international transmission mechanism and undertake a calibration of the model. Section 5 concludes.

[2] The authors estimate that the standard deviation of trade-weighted exchange rates is six times larger than the standard deviation of the price levels based on data for the US and seven European countries.

[3] Their distinction between tradeables which are subject to the law of one price and those which are not is *ad hoc*.

2. The Model

The world consists of two countries A and B of identical size, in which households provide production inputs (factors) for a continuum of domestic firms. Each household monopolistically supplies a single factor and firms are monopolistic producers of a single differentiated product. We represent households and their factors by an index $i \in [0, 1]$ on the unit interval. Firms and their products are represented by an index $z \in [0, 1]$ on a second unit interval. Country A is composed of households on the interval $[0, 1/2]$ and country B is composed of the household set $[1/2, 1]$. Similarly, firms with $z \in \mathscr{A} \equiv [0, 1/2]$ are located in country A and firms with $z \in \mathscr{B} \equiv [1/2, 1]$ are located in country B. We assume that an equal share 2η of firms in each country produce nontradeables, which we group in subsets $\mathscr{A}^N \equiv [0, \eta]$ and $\mathscr{B}^N \equiv [1-\eta, 1]$. All remaining products $z \in \mathscr{A}^T \equiv [\eta, 1/2]$ and $z \in \mathscr{B}^T \equiv [1/2, 1-\eta]$ are tradeables. All factors are nontradeable.

Table 1 summarizes the notation for the product prices in the two countries. A tradeable product z is sold at time t for a nominal price $p(z)_t^A$ in country A and a price $p(z)_t^B$ in country B. Factor prices are denoted by $w(i)_t$. The exchange rate E_t as of time t is defined in units of country A currency needed to buy one unit of country B currency.

2.1. Firms

A producer of tradeables chooses local currency prices $p(z)_t^A$, $p(z)_t^B$, and factor inputs $l(i, z)_t$, where $i \in \mathscr{A}$ for a firm in country A and $i \in \mathscr{B}$ for a firm located in country B. Nontradeable producers only choose a domestic market price. A production plan for a firm $z \in \mathscr{A}$ consists of a choice set $\mathscr{F}(z)$ of variables, where

$$z \in \mathscr{A}^T: \quad \mathscr{F}(z)_t = \{p(z)_s^A, \ p(z)_s^B, \ l(i, z)_s, \ i \in \mathscr{A}, \ s \geq t\}$$

$$z \in \mathscr{A}^N: \quad \mathscr{F}(z)_t = \{p(z)_s^A, \ l(i, z)_s, \ i \in \mathscr{A}, \ s \geq t\}.$$

Firms have identical CES production functions with a substitution elasticity $\varphi > 1$. Let $D(t, t) = 1$ and $D(t, s) = [(1 + R_t)\ (1 + R_{t+1}) \ldots (1 + R_{s-1})]^{-1}$ denote the time

Table 1
Price notation

Product origin / Product type	Country A		Country B	
	Nontraded	Traded	Nontraded	Traded
Product index	$z \in \mathscr{A}^N$	$z \in \mathscr{A}^T$	$z \in \mathscr{B}^T$	$z \in \mathscr{B}^N$
Price in country A	$p(z)_t^A$	$p(z)_t^A$	$p(z)_t^A$	
Price in country B		$p(z)_t^B$	$p(z)_t^B$	$p(z)_t^B$

t discount factor for period s under a sequence of nominal interest rates R_t. Under perfect foresight, the maximization problem for a firm $z \in \mathscr{A}$ becomes

$$V(z)_t = \max_{\mathscr{F}(z)_t} \sum_{s=t}^{\infty} D(t,s)\pi(z)_s \tag{1}$$

$$z \in \mathscr{A}^T: \quad \pi(z)_t = p(z)_t^A y(z)_t^A + E_t p(z)_t^B y(z)_t^B - \int_{\mathscr{A}} l(i,z)_t w(i)_t^A \, di$$

$$z \in \mathscr{A}^N: \quad \pi(z)_t = p(z)_t^A y(z)_t^A - \int_{\mathscr{A}} l(i,z)_t w(i)_t^A \, di \tag{2}$$

$$\mathbf{y}(z)_t = \frac{1}{\alpha}\left[\alpha \int_{\mathscr{A}} l(i,z)_t^{\varphi-1/\varphi} \, di\right]^{\varphi/\varphi-1}. \tag{3}$$

Firm profits in Eq. (2) consist of the domestic and foreign market revenue minus the production costs. Tradeable and nontradeable producers have the same production technologies to manufacture an output $\mathbf{y}(z)_t$. We choose a productivity parameter $\alpha = 2$ in Eq. (3) as a convenient normalization to obtain a production function $y = \frac{1}{2}l$ in the symmetric equilibrium. Firms in country B face an analogous choice problem.

2.2. Households

Households have identical preferences, which depend on a consumption index defined as

$$i \in \mathscr{A}: \quad \mathbf{c}(i)_t \equiv \left[\int_{\mathscr{A} \cup \mathscr{B}^T} c(i,z)_t^{\theta-1/\theta} \, dz\right]^{\theta/\theta-1}$$

$$i \in \mathscr{B}: \quad \mathbf{c}(i)_t \equiv \left[\int_{\mathscr{A}^T \cup \mathscr{B}} c(i,z)_t^{\theta-1/\theta} \, dz\right]^{\theta/\theta-1}, \tag{4}$$

where $\theta > 1$. The parameter θ measures the elasticity of demand in the product market.[4] The consumption-based price indices for the two countries are given by[5]

[4]In our model, the traded and nontraded sector do not differ in the degree of competition. For a model with a competitive traded sector and a monopolistic nontraded sector, see Lane (1997).

[5]The price index is defined as the minimal expenditure needed to purchase a unit of consumption $\mathbf{c}(i)_t$. Formally, P_t^A is a function of individual product prices $p(z)_t$ such that

$$P_t^A \, \mathbf{c}(i)_t = \min_{c(i,z)_t} \int_{\mathscr{A} \cup \mathscr{B}^T} p(z)_t c(i,z)_t \, dz \quad \text{s.t.} \quad \mathbf{c}(i)_t = 1.$$

$$P_t^A \equiv \left[\int_{\mathscr{A}} [p(z)_t^A]^{1-\theta} \, \mathrm{d}z + \int_{\mathscr{B}^T} [p(z)_t^A]^{1-\theta} \, \mathrm{d}z \right]^{1/1-\theta}$$

$$P_t^B \equiv \left[\int_{\mathscr{A}^T} [p(z)_t^B]^{1-\theta} \, \mathrm{d}z + \int_{\mathscr{B}} [p(z)_t^B]^{1-\theta} \, \mathrm{d}z \right]^{1/1-\theta}. \tag{5}$$

There is an integrated world capital market in which all households can borrow and lend. However, the only asset traded is a real bond, denominated in units of the consumption index comprising all tradeable products. The bond price follows as

$$P_t^T \equiv \left[\int_{\mathscr{A}^T} [p(z)_t^A]^{1-\theta} \, \mathrm{d}z + \int_{\mathscr{B}^T} [p(z)_t^A]^{1-\theta} \, \mathrm{d}z \right]^{1/1-\theta}.$$

The bond price is P_t^T/E_t in country B currency. Let r_t denote the real interest rate earned on bonds between dates t and $t+1$, while $f_t(i)$ and $m_t(i)$ are the stock of bonds and domestic money held by a household entering date $t+1$. For a household $i \in \mathscr{A}$ with a factor supply $\mathbf{l}(i)_t = \int_{\mathscr{A}} l(i, z)\mathrm{d}z$, we obtain a budget constraint

$$f(i)_t \frac{P_t^T}{P_t^A} + \frac{m(i)_t}{P_t^A} = [1 + r_{t-1}] f(i)_{t-1} \frac{P_t^T}{P_t^A} + \frac{m(i)_{t-1}}{P_t^A} - \mathbf{c}(i)_t + \frac{w(i)_t^A}{P_t^A} \mathbf{l}(i)_t + \frac{\pi(i)_t}{P_t^A} - \tau(i)_t. \tag{6}$$

The budget constraint combines the real money demand $m(i)_t/P_t^A$, consumption $\mathbf{c}(i)_t$, real taxes $\tau(i)_t$ paid to the government, real factor income $w(i)_t^A \mathbf{l}(i)_t/P_t^A$, real capital income $\pi(i)_t/P_t^A$ from domestic equity and the return $1+r_{t-1}$ on bonds.

Households make consumption decisions $c(i, z)_t$, choose money balances $m(i)_t$ and set a factor price $w(i)_t$. A household plan for a household i consists of a set $\mathscr{H}(i)$ of choice variables, where

$$i \in \mathscr{A}: \quad \mathscr{H}(i)_t = \{w(i)_s^A, m(i)_s, c(i, z)_s, z \in \mathscr{A} \cup \mathscr{B}^T, s \geq t\}$$

$$i \in \mathscr{B}: \quad \mathscr{H}(i)_t = \{w(i)_s^B, m(i)_s, c(i, z)_s, z \in \mathscr{A}^T \cup \mathscr{B}, s \geq t\}.$$

Household preferences are defined over the consumption index $\mathbf{c}(i)_t$, real money balances and the effort spent to provide the factor. Households derive utility only from holding domestic currency, not from foreign currency. For a household $i \in \mathscr{A}$ with perfect foresight, the utility maximization problem can be stated as

$$U(i)_t = \max_{\mathscr{H}(i)_t} \sum_{s=t}^{\infty} \beta^{s-t} \left[\log \mathbf{c}(i)_t + \chi \log \left[\frac{m(i)_t}{P_t^A} \right] - \frac{\kappa}{2} \mathbf{l}(i)_t^2 \right], \tag{7}$$

subject to the budget constraint Eq. (6). In Eq. (7), $1 > \beta > 0$, and $\kappa > 0$. A reciprocal maximization problem holds for a household in country B, whose real money balances are given by $m(i)_t / P_t^B$.

2.3. Ownership structure and taxation

The monopolistic market structure yields firm profits. Household income therefore depends on firm ownership. For simplicity, we assume a symmetric ownership structure in which each household owns an equal share of all domestic firms, resulting in a capital income $\pi(i)_t$,[6]

$$i \in \mathscr{A}: \quad \frac{1}{2}\pi(i)_t \equiv \int_{\mathscr{A}} \pi(z)_t \, \mathrm{d}z$$

$$i \in \mathscr{B}: \quad \frac{1}{2}\pi(i)_t \equiv \int_{\mathscr{B}} \pi(z)_t \, \mathrm{d}z.$$

Furthermore, we assume that government spending is zero and the government budget balanced. For an aggregate money supply $\frac{1}{2}M_t^A$ in country A,[7] and a household tax $\tau(i)_t$, the government budget constraint simplifies to

$$\int_{\mathscr{A}} \tau(i)_t \, \mathrm{d}i + \frac{\frac{1}{2}M_t^A - \frac{1}{2}M_{t-1}^A}{P_t^A} = 0, \tag{8}$$

where the second term denotes the seignorage income of the government.[8]

3. The flexible price equilibrium

The following section solves the model for flexible product and factor prices. First, we derive the aggregate consumer demand, the money demand and the factor demand for a given system of product and factor prices. In a second step, optimal monopolistic product and factor prices are deduced from the respective demand functions. A closed form solution is available for the symmetric equilibrium. The

[6] The empirical evidence suggests that international capital diversification is relatively small. Most capital is owned by domestic residents. Complete ownership of domestic assets by domestic residence is an approximation to the home equity bias.

[7] An aggregate variable X is defined in *per capita* terms; that is, $\frac{1}{2}X^A \equiv \int_{\mathscr{A}} x(i) \, \mathrm{d}i$.

[8] The analysis can be extended to fiscal policies without a balanced budget. For such an extension, see Obstfeld and Rogoff (1995b).

symmetric equilibrium provides the benchmark solution around which we log-linearize the model in Section 4.

3.1. Product, money and factor demand

The individual product and money demand follows directly from the utility function Eq. (7). The optimal factor demand of a firm depends on the value of its output. For an exporting firm $z \in \mathscr{A}^T$, we define the value of one unit of output as the maximum of domestic and foreign unit revenue; that is $q(z)_t^A \equiv \max\left[p(z)_t^A, E_t p(z)_t^B\right]$. For households and firms in country A, the first-order conditions follow as

$$\mathbf{c}_{t+1}(i)\frac{P_{t+1}^A}{P_{t+1}^T} = \beta(1+r_t)\mathbf{c}_t(i)\frac{P_t^A}{P_t^T} \tag{9}$$

$$i \in \mathscr{A}, z \in \mathscr{A}: \quad c(i,z)_t = \left[\frac{p(z)_t^A}{P_t^A}\right]^{-\theta}\mathbf{c}(i)_t$$

$$i \in \mathscr{A}, z \in \mathscr{B}^T: \quad c(i,z)_t = \left[\frac{p(z)_t^B}{P_t^A}\right]^{-\theta}\mathbf{c}(i)_t \tag{10}$$

$$i \in \mathscr{A}: \quad \frac{m(i)_t}{P_t^A} = \chi\mathbf{c}(i)_t\frac{(1+r_t)P_{t+1}^T}{(1+r_t)P_{t+1}^T - P_t^T} \tag{11}$$

$$i \in \mathscr{A}, z \in \mathscr{A}: \quad l(i,z)_t = \left[\frac{w(i)_t^A}{q(z)_t^A}\right]^{-\varphi} 2\mathbf{y}(z)_t. \tag{12}$$

Eq. (9) is a standard Euler equation, which describes optimal intertemporal consumption allocation between two periods. The optimal intratemporal disaggregate consumption is captured in Eq. (10) for domestic and foreign products, respectively. Product demand depends on the local prices $p(z)_t^A$ and $p(z)_t^B$ for domestic and foreign products relative to the domestic price index P_t^A. The parameter θ characterizes the price elasticity of demand. The real money demand Eq. (11) increases in the consumption index $\mathbf{c}(i)_t$. The money in the utility formulation of the money demand ties the real money demand to the consumption level. Eq. (12) states that optimal factor demand $l(i, z)_t$ of firm z for the household factor i is proportional to the total product demand $\mathbf{y}(z)_t$ and has a constant elasticity φ with respect to the factor price $w(i)_t$. Analogous relationships hold for country B.

The demand $\mathbf{y}(z)_t$ for product z, the aggregate real money demand $\int_{\mathscr{A}} m(i)_t^A \, \mathrm{d}i / P_t^A$ and the demand $\mathbf{l}(i)_t = \int_{\mathscr{A}} l(i, z) \, \mathrm{d}z$ for the factor of household i follow directly as

$$z \in \mathscr{A}^T: \quad \mathbf{y}(z)_t = \left[\frac{p(z)_t^A}{P_t^A}\right]^{-\theta} \int_{\mathscr{A}} \mathbf{c}(i)_t \,\mathrm{d}i + \left[\frac{p(z)_t^B}{P_t^B}\right]^{-\theta} \int_{\mathscr{B}} \mathbf{c}(i)_t \,\mathrm{d}i$$

$$z \in \mathscr{A}^N: \quad \mathbf{y}(z)_t = \left[\frac{p(z)_t^A}{P_t^A}\right]^{-\theta} \int_{\mathscr{A}} \mathbf{c}(i)_t \,\mathrm{d}i \tag{13}$$

$$\frac{1}{P_t^A} \int_{\mathscr{A}} m(i)_t^A \,\mathrm{d}i = \int_{\mathscr{A}} \chi\, \mathbf{c}(i)_t \frac{(1+r_t)P_{t+1}^T}{(1+r_t)P_{t+1}^T - P_t^T} \,\mathrm{d}i \tag{14}$$

$$i \in \mathscr{A}: \quad \mathbf{l}(i)_t = \int_{\mathscr{A}} \left[\frac{w(i)_t^A}{q(z)_t^A}\right]^{-\varphi} 2\mathbf{y}(z)_t \,\mathrm{d}z. \tag{15}$$

The product demand for the internationally traded good increases in the aggregate consumption in both countries. The price elasticities of factor and product demand are the same as the individual demand functions.

3.2. Monopolistic product and factor prices

Next, we solve for the system of monopolistic factor and product prices. To obtain the first-order conditions for the factor prices, we substitute the aggregate labor demand in Eq. (15) into the household budget constraint Eq. (6). By differentiating the utility function with respect to $w(i)_t$ we obtain first-order conditions Eq. (17) for the factor prices.

To determine the first-order conditions for the product prices, recall that all households are identical. This allows us to restrict our attention to identical domestic factor prices $w(i)_t^A = W_t^A$ for $i \in \mathscr{A}$ and $w(i)_t^B = W_t^B$ for $i \in \mathscr{B}$. The CES production technology then requires that firms use all domestic factors in equal proportions. We thus obtain a linear production function $\mathbf{y}(z)_t = \frac{1}{2} l(i, z) = \mathbf{l}(i)_t$. Maximizing the firm value is equivalent to maximizing firm profits in each period. For an exporting firm $z \in \mathscr{A}^T$, we get

$$\pi(z)_t = \max_{\{p(z)_t^A, p(z)_t^B\}} \left\{\left[p(z)_t^A - W_t^A\right] y(z)_t^A + \left[E_t p(z)_t^B - W_t^A\right] y_t^B(z)\right\}. \tag{16}$$

The linear production function allows us to treat the determination of the optimal domestic and foreign price as separate problems. We can substitute the domestic and foreign demand component from Eq. (13) into Eq. (16) and maximize its first and second term with respect to $p(z)_t^A$ and $p(z)_t^B$. For both tradeable and nontradeable producers, we obtain first-order conditions Eq. (18).

$$i \in \mathscr{A}: \quad \frac{w(i)_t^A}{\mathbf{c}(i)_t P_t^A} = \frac{\varphi}{\varphi - 1} \kappa \mathbf{l}(i)_t$$

$$i \in \mathscr{B}: \quad \frac{w(i)^B}{\mathbf{c}(i)_t P_t^B} = \frac{\varphi}{\varphi - 1} \kappa \mathbf{l}(i)_t \tag{17}$$

$$z \in \mathscr{A}^N: \quad \frac{\theta}{\theta - 1} W_t^A = p(z)_t^A$$

$$z \in \mathscr{A}^T: \quad \frac{\theta}{\theta - 1} W_t^A = p(z)_t^A = E_t p(z)_t^B$$

$$z \in \mathscr{B}^T: \quad \frac{\theta}{\theta - 1} W_t^B = p(z)_t^B = \frac{p(z)_t^A}{E_t}$$

$$z \in \mathscr{B}^N: \quad \frac{\theta}{\theta - 1} W_t^B = p(z)_t^B. \tag{18}$$

The term $\kappa \mathbf{l}(i)_t$ on the right-hand side of Eq. (17) characterizes the marginal disutility of additional factor supply and the left-hand side gives the marginal utility of the consumption that additional factor supply buys at real factor prices $w(i)_t^A / P_t^A$. Both terms differ by the mark-up $\varphi/(\varphi - 1)$ on real factor prices charged by households for their market power over production inputs. The term $\theta/(\theta - 1)$ in Eq. (18) describes the firms' monopolistic price mark-up over the unit production cost W_t. Firms set their foreign market price to preserve the same profit margin in both markets. Tradeable producers in country A respond to a depreciation of country A's currency with a proportional price decrease of their foreign market price $p(z)_t^B$ in country B. The first-order conditions in Eq. (18) show that the law of one price holds. We note that constant and identical product demand elasticities for the domestic and foreign market are essential for the result. Deviations from the constant elasticity framework change the respective mark-ups and can explain incomplete exchange rate pass-through (Feenstra et al., 1996).

3.3. The symmetric equilibrium

The symmetric model setup with identical production technologies, identical household preferences and symmetric ownership distribution allows us to restrict attention to the symmetric equilibrium with identical household and firm behavior within a country. Aggregate variables (expressed in *per capita* terms) are capitalized and steady state values of the symmetric equilibrium are marked by overbars; that is

$$i \in \mathscr{A}: \quad c(i,z)_t = \overline{C}^A, \mathbf{l}(i)_t = \overline{L}^A, m(i)_t = \overline{M}^A, f(i)_t = \overline{F}^A$$

$$i \in \mathscr{B}: \quad c(i,z)_t = \overline{C}^B, \mathbf{l}(i)_t = \overline{L}^B, m(i)_t = \overline{M}^B, f(i)_t = \overline{F}^B$$

$$z \in \mathscr{A}^N: \quad \mathbf{y}(z)_t = \overline{Y}_N^A$$

$$z \in \mathscr{A}^T: \quad \mathbf{y}(z)_t = \overline{Y}_T^A = 2\overline{Y}_N^A$$

$$z \in \mathscr{B}^T: \quad \mathbf{y}(z)_t = \overline{Y}_T^B = 2\overline{Y}_N^B$$

$$z \in \mathscr{B}^N: \quad \mathbf{y}(z)_t = \overline{Y}_N^B.$$

For a constant consumption in steady state, the real interest rate is tied down by the consumption Euler condition Eq. (9) as

$$\bar{r} = \frac{1-\beta}{\beta}.$$

The total aggregate output per household $\mathbf{Y}^A$ is distinguished by bold print and defined as

$$\frac{1}{2}\overline{\mathbf{Y}}^A \equiv \int_{\mathscr{A}} \mathbf{y}(z)\,\mathrm{d}z = \left(\frac{1}{2} - \eta\right)\overline{Y}_T^A + \eta\overline{Y}_N^A.$$

Under a symmetric ownership structure, the average capital income of a household follows as ($j = A, B$)

$$\overline{\Pi}^j = \frac{1}{\theta - 1}\overline{W}^j\overline{\mathbf{Y}}^j = \frac{1}{\theta}\bar{p}^j\overline{\mathbf{Y}}^j$$

and the household budget constraint implies

$$\overline{P}^j\overline{\mathbf{c}}^j = \overline{W}^j\overline{L}^j + \overline{\Pi}^j + \bar{r}\overline{F}^j\overline{P}^T = \bar{p}^j\overline{\mathbf{Y}}^j + \bar{r}\overline{F}^j\overline{P}^T. \tag{19}$$

A closed form solution for the symmetric steady state exists for the special case of zero net foreign assets. Following Obstfeld and Rogoff (1995a), we denote this particular steady state by zero subscripts. For $\overline{F}_0^A = \overline{F}_0^B = 0$, the steady state levels of aggregate output, consumption and factor supply have the following closed form solution:[9]

$$\overline{\mathbf{Y}}_0^A = \overline{\mathbf{Y}}_0^B = (1-\eta)\overline{C}_0^A = (1-\eta)\overline{C}_0^B = \overline{L}_0^A = \overline{L}_0^B = \left[\frac{(\varphi-1)(\theta-1)}{\varphi\theta\kappa}\right]^{1/2}, \tag{20}$$

where $\theta > 1$ and $\varphi > 1$. The aggregate output level is influenced by the elasticity of substitution in the product and factor markets. Higher substitutability in either market (φ, θ larger) enhances the output as lower price mark-ups increases the product and factor demand. Aggregate output does not depend on the share 2η of nontradeables since we assume identical demand elasticities for tradeables and nontradeables and the same production technology for both sectors. Household utility and the consumption index $\overline{\mathbf{c}(i)} = (1-\eta)^{1/\theta - 1}\overline{\mathbf{Y}}_0$ increase in the per-

[9] Combining Eqs. (17)–(19) gives:

$$\frac{\theta-1}{\theta} = \frac{\overline{W}_0^j}{\bar{p}_0^j} = \frac{\varphi}{\varphi-1}\kappa\overline{L}_0\frac{\overline{P}_0^j\overline{\mathbf{c}}_0^j}{\bar{p}_0^j} = \frac{\varphi}{(\varphi-1)}\kappa\overline{L}_0\overline{\mathbf{Y}}_0^j = \frac{\varphi}{(\varphi-1)}\kappa\left[\overline{\mathbf{Y}}_0^j\right]^2.$$

centage of tradeables. It is straightforward to solve for the equilibrium prices and the exchange rate level by substituting Eq. (20) into Eq. (14):

$$\bar{P}_0^A = \frac{\bar{p}_0^A}{(1-\eta)^{1/\theta-1}} = \frac{1-\beta}{(1-\eta)^{1/\theta-1}\chi\bar{\mathbf{Y}}_0^A}\bar{M}_0^A$$

$$\bar{P}_0^B = \frac{\bar{p}_0^B}{(1-\eta)^{1/\theta-1}} = \frac{1-\beta}{(1-\eta)^{1/\theta-1}\chi\bar{\mathbf{Y}}_0^B}\bar{M}_0^B$$

$$\bar{E}_0 = \frac{\bar{M}_0^A}{\bar{M}_0^B}.$$

The symmetric equilibrium for monopolistic factor and product markets derived here corresponds to a similar result obtained by Blanchard and Kiyotaki (1987) in a static closed economy framework.

4. The log-linearized model

We can now log-linearize the model around the symmetric steady state derived in Section 3.3. The short-run equilibrium has to account for nominal factor price (wage) rigidities, which can be explained by institutional features of the labor market.[10] Product prices are flexible for both the domestic and foreign market.

The linear approximation of the model has to distinguish between the short-run adjustment to policy changes with nominal factor price rigidities, and the long-run dynamics, where factor price flexibility is the appropriate benchmark. Similar to Obstfeld and Rogoff (1995a), we denote short-run deviations from the steady state by hats; thus for any variable, $\hat{X} \equiv \mathrm{d}X/X_0$. By contrast, long-run deviations from the benchmark value $\bar{X}_0$ are denoted by $\hat{\bar{X}} \equiv \mathrm{d}\bar{X}/\bar{X}_0$. To further simplify notation, we represent country differences in any variable by $\Delta X \equiv X^A - X^B$.

4.1. Short-run equilibrium conditions

With preset nominal factor prices, the factor supply is demand determined. Households choose factor prices above their marginal disutility of factor supply and meet any additional demand. Their first-order conditions Eq. (17) for the optimal factor price do not hold for an unanticipated demand shock.

We first examine the optimal product prices charged by the monopolistic firms under rigid factor prices. Eq. (18) states that firms charge a constant mark-up over

[10] Wage rigidities have been rationalized as implicit contracts (Azariadis and Stiglitz, 1983; Rosen, 1985), by efficiency wage models (Yellen, 1984; Stiglitz, 1986) or insider–outsider models (Lindbeck and Snower, 1987). For a survey, see Haley (1990).

their nominal factor prices for both the domestic nominal price and the foreign price in domestic currency. Monopolistic firms facing a constant elasticity of foreign and domestic demand pass through the entire exchange rate change to their foreign market price. This implies an exchange rate change expressed in Eq. (23).

$$\begin{aligned} z \in \mathscr{A}^N &: \quad \hat{p}(z)^A = 0 \\ z \in \mathscr{A}^T &: \quad \hat{p}(z)^A = 0 \wedge \hat{p}(z)^B = -\hat{E} \\ z \in \mathscr{B}^T &: \quad \hat{p}(z)^B = 0 \wedge \hat{p}(z)^A = \hat{E} \\ z \in \mathscr{B}^N &: \quad \hat{p}(z)^B = 0 \end{aligned} \tag{21}$$

$$\begin{aligned} (1-\eta)\hat{P}^A &= \eta\hat{p}(\mathscr{A}^N)^A + (\tfrac{1}{2}-\eta)\hat{p}(\mathscr{A}^T)^A + (\tfrac{1}{2}-\eta)\hat{p}(\mathscr{B}^T)^A \\ (1-\eta)\hat{P}^B &= (\tfrac{1}{2}-\eta)\hat{p}(\mathscr{A}^T)^B + (\tfrac{1}{2}-\eta)\hat{p}(\mathscr{B}^T)^B + \eta\hat{p}(\mathscr{B}^N)^B \\ \Delta\hat{P} \equiv \hat{P}^A - \hat{P}^B &= \frac{1-2\eta}{1-\eta}\hat{E}. \end{aligned} \tag{23}$$

PPP holds only for the special case where all products are tradeable ($\eta = 0$). Nontradeables reduce the relative price level impact of exchange rate changes. We can define the term $\hat{E}(1-2\eta)/(1-\eta)$ as the *effective exchange rate change*. For a lower percentage of tradeables, a larger nominal exchange rate change is needed to induce the same relative aggregate price change. Moreover, we can define economic openness as

$$\text{openness} \equiv \frac{\text{Exports}}{\text{GDP}} = \frac{\left(\frac{1}{2}-\eta\right)\frac{1}{2}\bar{Y}_T}{\eta\bar{Y}_N + \left(\frac{1}{2}-\eta\right)\bar{Y}_T} = \frac{\frac{1}{2}-\eta}{1-\eta}.$$

This implies that the short-run exchange rate change is inversely related to the openness for any given short-run relative price change, that is

$$\hat{E} = \frac{\Delta\hat{P}}{2\times\text{openness}}.$$

Limited economic openness can therefore explain the high volatility of the exchange rate relative to price level volatility as reported by Chari et al. (1997). This volatility ratio should decrease in the openness of the economy.

Log-linearizing the aggregate demand Eqs. (13)–(15) and taking country differences yields

$$\Delta\hat{\mathbf{Y}} = \frac{\theta}{1-\eta}\frac{1-2\eta}{1-\eta}\hat{E} + \frac{\eta}{1-\eta}\Delta\hat{C} \tag{24}$$

$$\Delta\hat{L} = \Delta\hat{\mathbf{Y}} \tag{25}$$

$$\Delta\hat{M} - \Delta\hat{P} = \Delta\hat{C} - \frac{\beta}{1-\beta}\left(\hat{\bar{E}} - \hat{E}\right). \tag{26}$$

The aggregate intertemporal budget constraint Eq. (6) combined with the government constraint Eq. (8) under symmetric taxation gives

$$\left[f^{j}_{t}(i) - f^{j}_{t-1}(i)\right]\frac{P^{T}_{t}}{P^{j}_{t}} = r_{t-1} f^{j}_{t-1}(i)\frac{P^{T}_{t}}{P^{j}_{t}} + \frac{\theta}{\theta-1}\frac{w(i)^{j}_{t}\mathbf{l}^{j}_{t}(i)}{P^{j}_{t}} - \mathbf{c}^{j}_{t}(i). \tag{27}$$

For $\frac{1}{2}F^{j}_{0} \equiv \int_{\mathscr{A}} f^{j}_{0}(i)\ \mathrm{d}i$ and $f^{j}_{0}(i) = 0$, we obtain the following linear approximation for the country differences in the net foreign asset position:

$$\frac{2\mathrm{d}\bar{F}^{A}_{0}\bar{P}^{T}_{0}}{\bar{\mathbf{Y}}_{0}\bar{p}^{A}_{0}} = -\frac{2\mathrm{d}\bar{F}^{B}_{0}\bar{P}^{T}_{0}}{\bar{\mathbf{Y}}_{0}\bar{p}^{A}_{0}} = \Delta\hat{L} - \Delta\hat{P} - \Delta\hat{C}. \tag{28}$$

Eq. (24) characterizes the expenditure switching. In a world where all consumer goods are traded ($\eta = 0$), the relative demand change $\Delta\hat{\mathbf{Y}} = \theta\hat{E}$ depends only on the exchange rate and the elasticity of product substitution θ determines the scale of the expenditure switching. For nontradeables, both the effective exchange rate change $\hat{E}(1-2\eta)/(1-\eta)$ and the relative consumption change $\Delta\hat{C}$ govern the expenditure switching. Nontradeables introduce a *home product consumption bias* so that a relative demand expansion is concentrated on domestic products. The role of the nominal exchange rate for expenditure switching is reduced as $(1-2\eta)/(1-\eta)^2 \leq 1$.

Eq. (25) states that the relative factor demand change $\Delta\hat{L}$ is proportional to the change in the product demand. The relative change in the real money demand $\Delta\hat{M} - \Delta\hat{P}$ is proportional to the relative change in consumption $\Delta\hat{C}$ and depends on the difference between the relative long-run and short-run exchange rate $\Delta\hat{\bar{E}} - \Delta\hat{E}$. Finally, Eq. (28) expresses the foreign asset position $\mathrm{d}\bar{F}^{A}\bar{P}^{T}_{0}$ relative to the value $\bar{\mathbf{Y}}_{0}\bar{p}_{0}$ of aggregate domestic output. Country differences $2\mathrm{d}\bar{F}^{A}_{0}\bar{P}^{T}_{0}/\bar{\mathbf{Y}}_{0}\bar{p}^{A}_{0} = \mathrm{d}\bar{F}^{A}_{0}\bar{P}^{T}_{0}/\bar{\mathbf{Y}}_{0}\bar{p}_{0} - \mathrm{d}\bar{F}^{B}_{0}\bar{P}^{T}_{0}/\bar{\mathbf{Y}}_{0}\bar{p}_{0}$ in the net foreign asset position are equal to the relative real factor income change $\Delta\hat{L} - \Delta\hat{P}$ minus the relative consumption change $\Delta\hat{C}$.

The five short-run conditions Eqs. (23)–(28) contain five short-run variables $\Delta\hat{Y}$, $\Delta\hat{L}$, $\Delta\hat{C}$, $\hat{E}$, $\Delta\hat{P}$ and two long-run variables $\Delta\hat{\bar{P}}$ and $2\mathrm{d}\bar{F}^{A}_{0}\bar{P}^{T}_{0}/\bar{\mathbf{Y}}_{0}\bar{p}^{A}_{0}$. The short-run equilibrium can only be solved in combination with the long-run equilibrium.

4.2. Long-run equilibrium conditions

The important difference to the short-run equilibrium is that households set optimal factor prices according to Eq. (17). Taking into account that the factor prices are flexible in the long run, price changes follow from the first-order conditions Eq. (18) as

$$z \in \mathscr{A}^N: \quad \bar{\hat{p}}(z)^A = \bar{\hat{W}}^A$$

$$z \in \mathscr{A}^T: \quad \bar{\hat{p}}(z)^A = \bar{\hat{W}}^A \wedge \bar{\hat{p}}(z)^B = \bar{\hat{W}}^A - \bar{\hat{E}}$$

$$z \in \mathscr{B}^T: \quad \bar{\hat{p}}(z)^B = \bar{\hat{W}}^B \wedge \bar{\hat{p}}(z)^A = \bar{\hat{W}}^B + \bar{\hat{E}}$$

$$z \in \mathscr{B}^N: \quad \bar{\hat{p}}(z)^B = \bar{\hat{W}}^B \tag{29}$$

$$\Delta\bar{\hat{P}} \equiv \frac{1-2\eta}{1-\eta}\bar{\hat{E}} + \frac{\eta}{1-\eta}\Delta\bar{\hat{W}}. \tag{30}$$

The long-run consumer price changes in Eq. (29) incorporate the factor price changes. Nontradeables imply that the long-run relative price level in Eq. (30) is determined not only by the long-run exchange rate, but also by relative factor price (wage) changes. Relative factor price changes can produce long-run PPP deviations.

Linearizing the aggregate demand Eqs. (13)–(15), the intertemporal budget constraint Eq. (27), and the first-order conditions Eq. (17) yields

$$\Delta\bar{\hat{\mathbf{Y}}} = \frac{\theta}{1-\eta}\frac{1-2\eta}{1-\eta}\bar{\hat{E}} + \frac{\eta}{1-\eta}\Delta\bar{\hat{C}} - \theta\frac{1-2\eta}{(1-\eta)^2}\Delta\bar{\hat{W}} \tag{31}$$

$$\Delta\bar{\hat{L}} = \Delta\bar{\hat{\mathbf{Y}}} \tag{32}$$

$$\Delta\bar{\hat{M}} - \Delta\bar{\hat{P}} = \Delta\bar{\hat{C}} \tag{33}$$

$$\Delta\bar{\hat{C}} = \Delta\bar{\hat{L}} + \Delta\bar{\hat{W}} - \Delta\bar{\hat{P}} + \bar{r}\frac{2\mathrm{d}\bar{F}_0^A\bar{P}_0^T}{\bar{\mathbf{Y}}_0\bar{p}_0^A} \tag{34}$$

$$\Delta\bar{\hat{W}} - \Delta\bar{\hat{P}} - \Delta\bar{\hat{C}} = \Delta\bar{\hat{L}}. \tag{35}$$

If all products are tradeable ($\eta = 0$), long-run expenditure switching in Eq. (31) is determined only by the permanent relative real factor price change $\Delta\bar{\hat{W}} - \bar{\hat{E}} = \Delta\bar{\hat{W}} - \Delta\bar{\hat{P}}$. The linkage between long-run product demand and factor prices is moderated by nontradeables, which alleviates the competitive disadvantage of a relative factor price change $\Delta\bar{\hat{W}}$. This moderation of long-run expenditure switching due to nontradeables is captured by the term $(1-2\eta)/(1-\eta)^2 < 1$, which decreases in the percentage of nontradeables. A model with only tradeables will tend to overstate the expenditure switching resulting from any given long-run real wage change.

The permanent relative money demand in Eq. (33) is determined by the relative long-run consumption changes $\Delta\bar{\hat{C}}$. The intertemporal budget constraint Eq. (34) requires the relative consumption change to be financed by relative changes in the long-run factor supply $\Delta\bar{\hat{L}}$, real factor prices $\Delta\bar{\hat{W}} - \Delta\bar{\hat{P}}$, or returns on net foreign asset $\bar{r}2\mathrm{d}\bar{F}_0^A\bar{P}_0^T/\bar{\mathbf{Y}}_0\bar{p}_0^A$. Eq. (35) states that the relative factor supply change is equal to the relative real factor price changes minus the relative consumption change.

Only the Euler condition Eq. (9) remains to be linearized. Optimal consumption smoothing equalizes short-run and long-run consumption changes and we obtain

$$\Delta\hat{C} = \Delta\bar{\hat{C}} + (\hat{E} - \Delta\hat{P}) - (\bar{\hat{E}} - \Delta\bar{\hat{P}}). \tag{36}$$

The last two term denote the difference of the short-run and long-run real exchange rate depreciation, respectively. A short-run real depreciation in excess of the long-run change increases short-run relative consumption in country A and deceases savings in the form of net foreign assets, which provide a lower return under an appreciating real exchange rate. We refer to this as the *differential return effect* on relative consumption. In the Obstfeld–Rogoff framework this effect disappears as (in the absence of nontradeables) PPP holds at any time.

Both the intertemporal budget constraint embodied in Eq. (34) and the Euler condition Eq. (36) link the short-run and the long-run dynamics. Altogether, we have five short-run conditions Eqs. (23)–(28) and seven long-run conditions Eqs. (30)–(36) for a total of 12 endogenous variables: $\Delta\hat{Y}$, $\Delta\hat{L}$, $\Delta\hat{C}$, $\hat{E}$, $\Delta\hat{P}$, $\Delta\bar{\hat{Y}}$, $\Delta\bar{\hat{L}}$, $\Delta\bar{\hat{C}}$, $\bar{\hat{E}}$, $\Delta\bar{\hat{P}}$, $\Delta\bar{\hat{W}}$ and $2\mathrm{d}\bar{F}_0^A\bar{P}_0^T/\bar{\mathbf{Y}}_0\bar{p}_0^A$.

4.3. Solution to the model: Money shocks

The following section solves the log-linear model for a one-time unanticipated change in the relative money supply in both countries. We assume that the change in the exogenous money supply is permanent, that is[11]

$$\Delta\hat{M} = \Delta\bar{\hat{M}} > 0. \tag{37}$$

Given 12 log-linearized equilibrium conditions for 12 endogenous variables, solving the model is a straightforward exercise. To allow for a better interpretation of the results, we proceed in two steps. We first derive an equilibrium condition which characterizes market clearing in the money market and then characterize a

[11] We follow the classical Dornbusch (1976) exercise. Transitory shocks to the relative money supply can be analyzed in a similar way.

second equilibrium condition which embodies the intertemporal budget constraint and market clearing in the product and factor markets.

First, we consider the short-run and the long-run money demand in Eqs. (26) and (33) and combine them with the Euler condition Eq. (36). It follows that the money market equilibrium requires an instantaneous adjustment of the exchange rate to its long-run level,

$$\hat{E} = \hat{\bar{E}}. \tag{38}$$

Substituting Eq. (23) into Eq. (26), we obtain the equilibrium condition for the money market, which is referred to as the **MM** schedule and given by

$$\frac{1-2\eta}{1-\eta}\hat{E} = \Delta\hat{M} - \Delta\hat{C}. \tag{MM}$$

The **MM** schedule characterizes combinations of relative money and consumption growth that provide a money market equilibrium for a given effective exchange rate change, $\hat{E}(1-2\eta)/(1-\eta)$. The effective exchange rate jumps in step with the one time permanent change in the relative money supply and relative short-run consumption change. Conditional on a given gap between money supply and consumption changes, $\Delta\hat{M} - \Delta\hat{C}$, we need a larger nominal money exchange rate change $\hat{E}$ if there are more nontradeables. We can label this the *exchange rate magnification effect*.

In a second step, we derive the equilibrium condition for the real sector in the two countries. Combining Eqs. (23), (30), (36) and (38), the long-run changes in the relative price and consumption follow as

$$\Delta\hat{\bar{P}} = \Delta\hat{P} + \frac{\eta}{1-\eta}\Delta\hat{\bar{W}} \tag{39}$$

$$\Delta\hat{\bar{C}} = \Delta\hat{C} - \frac{\eta}{1-\eta}\Delta\hat{\bar{W}}. \tag{40}$$

For nontradeables ($\eta > 0$) the price level adjustment is gradual. Only the long-run price level incorporates the long-run factor price change $\Delta\hat{\bar{W}} > 0$. Eq. (40) shows that we obtain relative short-run consumption overshooting. It follows from the sluggish price adjustment which implies a slow real appreciation after a relative monetary expansion. This real appreciation decreases the return on net foreign assets and increases the relative short-run consumption in the expending country. This is again the *differential real return effect,* which disappears if all products become tradeable ($\eta = 0$) and real asset returns are identical across countries. We note that the differential real return effect tends to reduce the comovement of consumption in the two countries.

We can use the short-run budget constraint in Eq. (28) and substitute the short-run equilibrium conditions Eqs. (23)–(25). This characterizes the current account balance as

$$\frac{2\mathrm{d}\bar{F}_0^A \bar{P}_0^T}{\bar{\mathbf{Y}}_0 \bar{p}_0^A} = \frac{\theta - 1 + \eta}{1 - \eta} \frac{1 - 2\eta}{1 - \eta} \hat{E} - \frac{1 - 2\eta}{1 - \eta} \Delta \hat{C}. \tag{41}$$

Moreover, the current account is determined by Eqs. (28) and (35), which implies

$$\frac{2\mathrm{d}\bar{F}_0^A \bar{P}_0^T}{\bar{\mathbf{Y}}_0 \bar{p}_0^A} = -\frac{2}{\bar{r}} \Delta \hat{\bar{L}} = -\frac{2}{\bar{r}} \Delta \hat{\bar{Y}}. \tag{42}$$

Substitution of Eqs. (30)–(32), (35), (39) and (40) allows us to characterize the current account as a function of the terms $\Delta \hat{C}$, $\Delta \hat{\bar{W}}$, $\hat{E}$. Finally, the long-run labor market equilibrium requires that

$$\Delta \hat{C} = k(\eta)\, \Delta \hat{\bar{W}} - (\theta + 1 - \eta) \frac{1 - 2\eta}{1 - \eta} \hat{E}. \tag{43}$$

where we defined a parameter $k(\eta) \equiv (1 + \theta)(1 - \eta) - (\theta - 1)\eta^2/(1 - \eta)$.

Combining Eqs. (41)–(43) we obtain an equilibrium condition referred to as the **GG** schedule

$$\frac{1 - 2\eta}{1 - \eta} \hat{E} = \frac{k(\eta)\left(\frac{\bar{r}}{2} \frac{1 - 2\eta}{1 - \eta} + 1\right) - 1}{k(\eta)\left(\frac{\bar{r}}{2} \frac{\theta - 1 + \eta}{1 - \eta} - 1\right) + 1 + \theta - \eta} \Delta \hat{C}. \tag{GG}$$

The **GG** schedule defines the combinations of exchange rate and relative short-run consumption changes which clear product and factor markets and fulfill the intertemporal budget constraint. It characterizes the exchange rate change needed to finance the short- and long-run relative consumption changes. The positive slope of the **GG** schedule ($\theta > 1$, $\frac{1}{2} \geq \eta \geq 0$) is straightforward to explain. A depreciation of country *A*'s currency increases its product competitiveness and switches demand to country *A*. Higher incomes translates into higher consumption. Moreover the future real appreciation (following the initial depreciation) decreases the real returns on a current account surplus. This effect counteracts the consumption smoothing motive of households and further increases short-run consumption at the expense of long-run consumption.

Fig. 1 provides a graphical illustration of the transmission mechanism. A monetary expansion in country *A* relative to country *B* corresponds to an upward shift in the **MM** schedule to **M′M′**. The relative monetary expansion in country *A* can be accommodated by an increase in the relative consumption or a relative price change given by the effective exchange rate change $\hat{E}(1 - 2\eta)/(1 - \eta)$. The **GG** schedule determines to which degree the demand expansion translates into relative consumption changes or an effective exchange rate depreciation.

The slope of the **GG** schedule also depends on the demand elasticity θ. If international product markets become perfectly competitive ($\theta \to \infty$), the exchange rate effect of a monetary expansion disappears and the monetary supply shock is

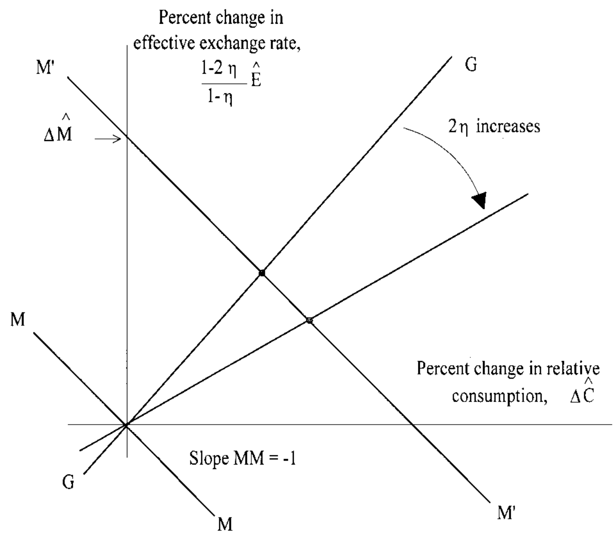

Fig. 1. Money supply shock for different shares of nontradeables.

accommodated entirely by a relative consumption expansion. More product competition implies that a devaluation initiates larger demand switching and a larger relative income effect for the country expanding its money supply. A larger relative income effect allows households a larger consumption expansion.

For the special case of only tradeables ($2\eta = 0$), Fig. 1 simplifies to results in Obstfeld and Rogoff (1995a, p. 641, Fig. 1). In their benchmark model, households are monopolistic producers of consumer products, which have preset domestic nominal prices. The domestic product price rigidities in Obstfeld–Rogoff framework produce the same international transmission effects as factor market rigidities in our model. This equivalence is a consequence of the constant elasticity framework in which factor price rigidities imply domestic product price rigidities. The monopolistic factor markets influence the steady state level of production and consumption, but not those changes that occur as a consequence of the monetary shock.

4.4. The transmission mechanism with nontradeables

Nontradeables introduce three modifications to the international transmission mechanism. First, it rescales the nominal exchange rate $\hat{E}$ on the vertical axes in Fig. 1. An asymmetric unexpected money expansion requires a relative aggregate price change in spite of the demand expansion. Fewer tradeables mean that import price changes have a reduced aggregate price impact measured by the effective exchange rate $\hat{E}(1-2\eta)/(1-\eta)$. Money market clearing with nontradeables therefore implies a higher nominal exchange rate $\hat{E}$ for any given relative consumption change. This corresponds to the *exchange rate magnification effect*.

Second, nontradeables decrease the slope of the **GG** schedule. They increase the *home product consumption bias* and allow for a demand substitution away from appreciating imports. As a consequence, the income effect of a domestic monetary expansion is concentrated in the home country and reflected in a larger relative consumption expansion. Third, the long-run real appreciation (following the initial nominal depreciation) decreases real returns on a current account surplus. More nontradeables increase short-run PPP deviations and larger real return differences translate into a larger relative consumption expansion at the cost of a lower current account surplus. The *differential real return effect* also decreases the slope of the **GG** schedule as represented in Fig. 1. The equilibrium shifts downwards on the **M′M′** schedule towards a lower effective exchange rate change $\hat{E}(1-2\eta)/(1-\eta)$ and a higher relative short-run consumption expansion. A less open economy benefits more from a domestic money expansion than a more open economy (Romer, 1993, Lane, 1997).

It is straightforward to combine the two equilibrium schedules and obtain the following solution for the nominal exchange rate change

$$\frac{\hat{E}}{\Delta\hat{M}}=\frac{2(\theta-\eta)(1-\eta)+\bar{r}(1-\eta)k(\eta)}{2(\theta-\eta)(1-\eta)+\bar{r}(\theta-\eta)k(\eta)}<1.$$

The nominal exchange rate change does not exceed the relative permanent money supply change. The intuition for this result is that the *exchange rate magnification effect* in the money market is counterbalanced by relative consumption change induced by the *differential real return effect*. For the money in the utility framework the real money demand is tied to the consumption level. As the consumption expansion gets concentrated in a home country with more nontradeable, the gap between relative money supply and relative consumption change narrows and a smaller effective exchange rate change is needed in the money market.

We emphasize that the *differential real return effect* crucially depends on the validity of the Euler condition Eq. (36) and indirectly on the utility function. If we allow for example for habit formation and require a sluggish consumption adjustment, the *exchange rate magnification effect* would assert its full force and nontradeables generate more volatile exchange rates.

4.5. A model calibration

To discuss the qualitative results in greater detail, we calibrate the model for the discount factor β and the product demand elasticities θ. Our calibration follows the example of Betts and Devereux (1996). Based on an estimation of the consumption elasticity of money demand around unity by Mankiw and Summers (1986), Betts and Devereux suggest a unit money demand elasticity, which corresponds to our log-utility specification. For the estimate of the elasticity θ, we can refer to Rotemberg and Woodford (1992), who argue for an average mark-up of 1.2 according to US data. This implies an elasticity parameter $\theta = 6$. For the discount factor we assume $\beta = 0.94$. Romer (1993) calculates an average export/GDP ratio of 0.32 for the OECD countries during the period 1973–1993, implying $2\eta = 0.52$. For a rather closed economy like the US (export/GDP = 0.12) we may consider a nontradeable share of $2\eta = 0.83$.

Figs. 2–13 show the percentage changes of the different domestic and foreign variables as a function of the percentage of nontradeables. We assume an unexpected positive permanent money supply shock of one percent in country *A*. Country *B* (foreign) variables are distinguished from country *A* (domestic)

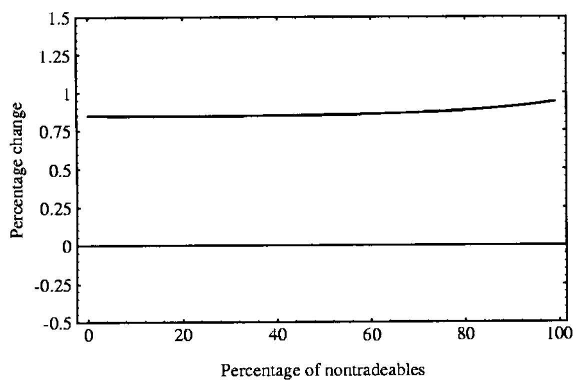

Fig. 2. Short and long-run exchange rate depreciation of a 1% unanticipated permanent money supply expansion in country *A* for different degrees of openness.

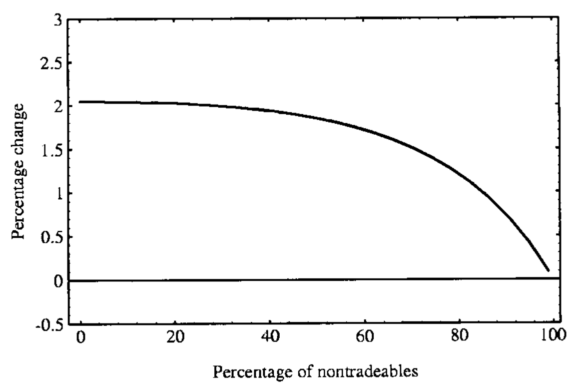

Fig. 3. Current account change of a 1% unanticipated permanent money supply expansion in country *A* for different degrees of openness.

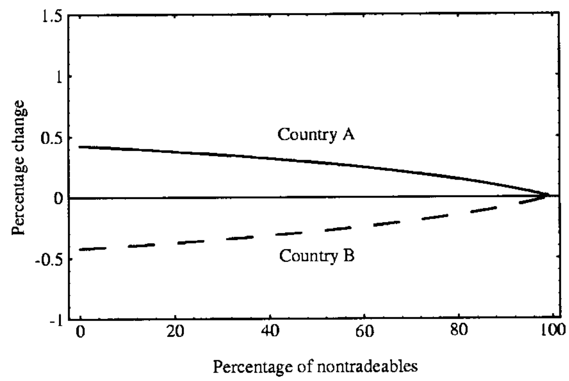

Fig. 4. Short-run price inflation of a 1% unanticipated permanent money supply expansion in country *A* for different degrees of openness.

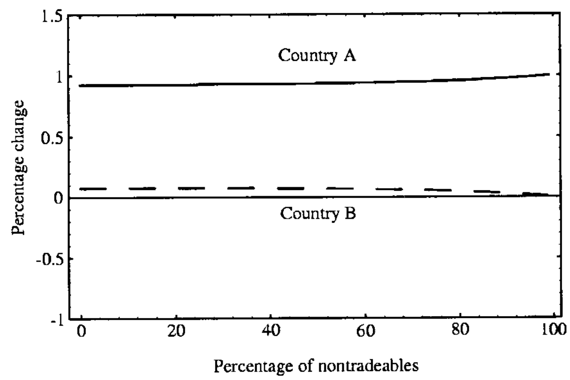

Fig. 5. Long-run price inflation of a 1% unanticipated permanent money supply expansion in country *A* for different degrees of openness.

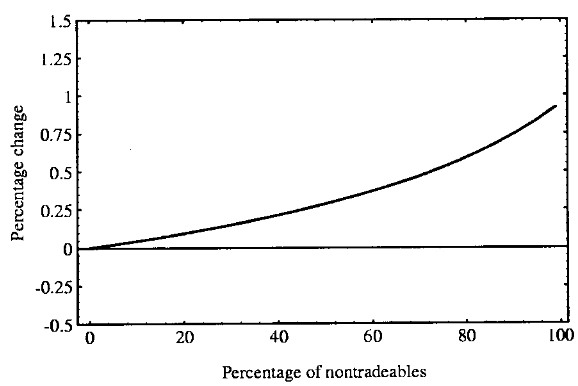

Fig. 6. Short-run real exchange rate depreciation of a 1% unanticipated permanent money supply expansion in country *A* for different degrees of openness.

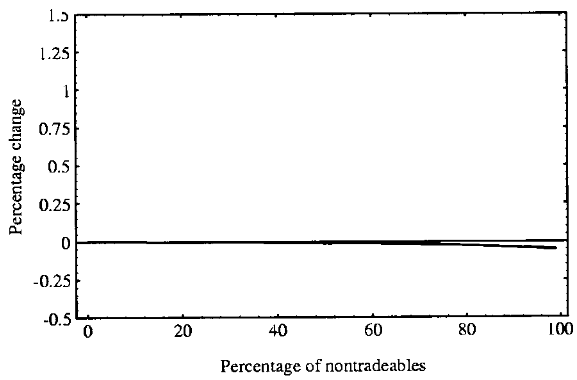

Fig. 7. Long-run real exchange rate depreciation of a 1% unanticipated permanent money supply expansion in country A for different degrees of openness.

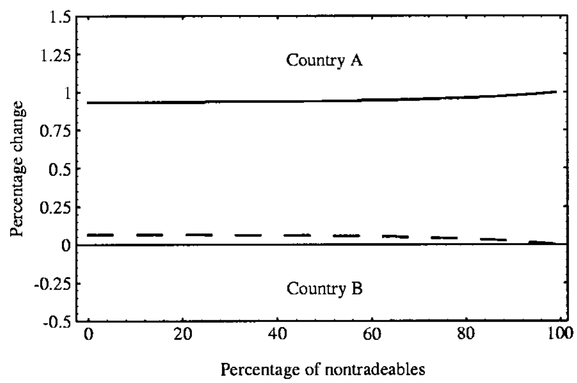

Fig. 8. Long-run nominal wage inflation of a 1% unanticipated permanent money supply expansion in country A for different degrees of openness.

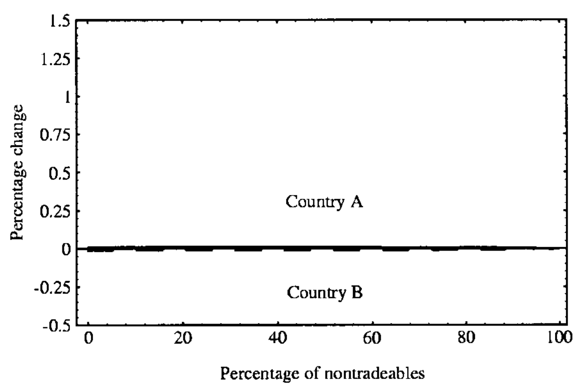

Fig. 9. Long-run real wage inflation of a 1% unanticipated permanent money supply expansion in country A for different degrees of openness.

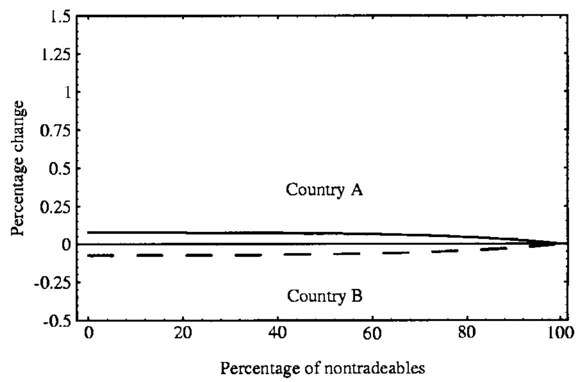

Fig. 10. Short-run consumption change of a 1% unanticipated permanent money supply expansion in country *A* for different degrees of openness.

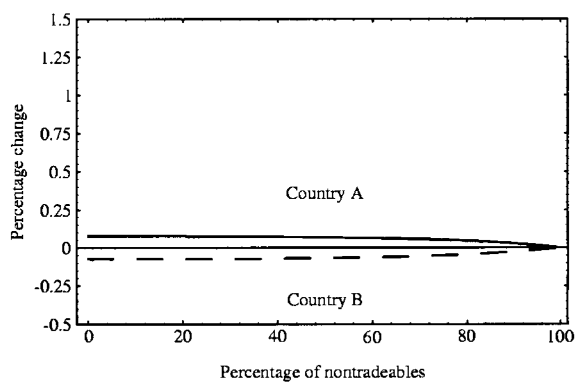

Fig. 11. Long-run consumption change of a 1% unanticipated permanent money supply expansion in country *A* for different degrees of openness.

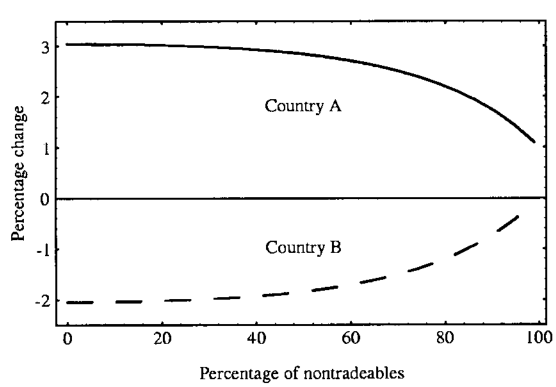

Fig. 12. Short-run output change of a 1% unanticipated permanent money supply expansion in country *A* for different degrees of openness.

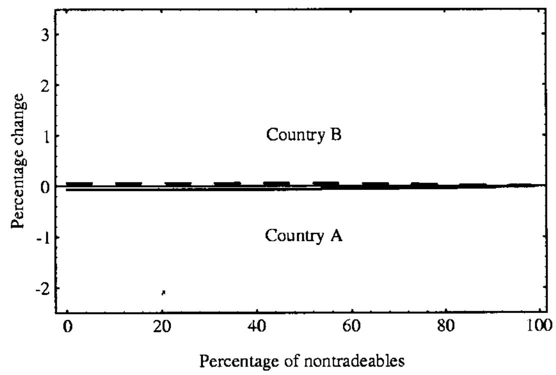

Fig. 13. Long-run output change of a 1% unanticipated permanent money supply expansion in country *A* for different degrees of openness.

variables by a dashed line. Fig. 2 shows the nominal short-run and long-run exchange rate, which is slightly smaller than the relative money supply change. The nominal depreciation improves the competitiveness of domestic exports and allows a current account surplus plotted in Fig. 3. The current account surplus decreases in the percentage of nontradeables.[12] Fig. 4 shows the short-run price level change in the two countries. More nontradeables increase the degree of nominal rigidity as the respective price indices feature fewer tradeable prices. Domestic product prices do not contribute to the price level adjustment as they are tied to the nominally rigid factor prices. The long-run price level changes shown in Fig. 5 are close to the relative money supply shock independent of the percentage of nontradeables. Figs. 6 and 7 plot the short-run and long-run real exchange rate, respectively. Short-run PPP deviations become important as the percentage of nontradeables increases. This implies that real exchange rate volatility should be larger for more closed economies as documented by Hau (1998). However, long-run PPP deviations are small after the factor price (wage) adjustment shown in Fig. 8. Long-run real wage (Fig. 9), long-run consumption (Fig. 11) and long-run output (Fig. 13) are only slightly changed by nontradeables due to the current account effect. More important is the effect on short-run consumption and output shown in Figs. 10 and 12. A higher percentage of nontradeables increases the domestic relative to the foreign consumption expansion. The home product consumption bias implies that the aggregate demand effect of the monetary shock is concentrated on the domestic products. Moreover, different consumption baskets increase the real return differential on net foreign assets and contribute to

[12]The model predicts that the current account balance is procyclical for the country with the monetary shock. This counterfactual result may be explained by our neglect of capital investment. Chari et al. (1997) emphasize that incorporating capital formation tends to produce a countercyclical current account balance.

diverging dissaving behavior. Nontradeables can therefore help to explain the low international consumption correlation (Backus et al., 1992). The domestic output expansion is moderated by a larger share of nontradeables (Fig. 13). The competitive advantage rendered by the home depreciation benefits a smaller tradeable sector.

5. Conclusions

A central issue in international economics is the transmission of asymmetric monetary shocks. This paper inquires whether factor price (wage) rigidities in combination with nontradeables change this transmission mechanism. We extend the Obstfeld–Rogoff framework to a richer market structure with monopolistic factor markets and propose a new utility-independent treatment of nontradeables. For product markets we assume fully flexible local currency prices as our benchmark.

We find that factor price rigidities work very much like rigid domestic producer prices. Under constant demand elasticities, firms aim at constant mark-ups over nominally rigid factor prices. This generates price level rigidities from which only imported tradeables (priced under full exchange rate pass-through) are exempted. The results of Obstfeld and Rogoff therefore generalize to a market structure with factor price rigidities.

Nontradeables on the other hand modify the transmission mechanism in important ways. A larger nontradeable share implies an exchange rate magnification effect as the money market equilibrium relies on a short-run price adjustment carried out by fewer tradeables. This effect helps to explain the observed high volatility of the nominal exchange rate relative to the price level volatility. Nontradeables also reduce the (positive) consumption and (negative) output comovement as the aggregate demand expansion is concentrated on domestic products. Finally we find that short-run PPP deviations due to nontradeables generate differential real returns which reinforce the short-run consumption at the expense of consumption smoothing through a current account surplus.

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References

Azariadis, C., Stiglitz, J.E., 1983. Implicit contracts and fixed prices in equilibria. Quarterly Journal of Economics 93 (Suppl.), 1–22.

Backus, D., Kehoe, P.J., Kyland, F., 1992. International real business cycles. Journal of Political Economy 100, 745–775.

Betts, C.M., Devereux, M.B., 1996. The exchange rate in a model of pricing-to-market. European Economic Review 40, 1007–1021.

Blanchard, O., Kiyotaki, N., 1987. Monopolistic competition and the effects of aggregate demand. American Economics Review 77, 647–666.

Chari, V. V., Kehoe, P.J., McGrattan, E.R., 1997. Monetary shocks and the real exchange rates in sticky price models of the international business cycles, NBER Working Paper No. 5876.

Christiano, L.J., Eichenbaum, M., Evans, C., 1997. Sticky price and limited participation models of money: A comparison. European Economic Review 41, 1201–1249.

Dornbusch, R., 1976. Expectations and exchange rate dynamics. Journal of Political Economy 84, 1161–1176.

Feenstra, R.C., Gagnon, J.E., Knetter, M.M., 1996. Market share and exchange rate pass-through in world automobile trade. Journal of International Economics 40, 187–207.

Haley, J., 1990. Theoretical foundations for sticky wages. Journal of Economic Surveys 4 (2), 115–155.

Hau, H., 1998. Openness and real exchange rate volatility: Theory and evidence, mimeo.

Lane, P.R., 1997. Inflation in open economies. Journal of International Economics 42, 327–347.

Lane, P.R., 1999. The new open economy macroeconomics: A survey, mimeo.

Lindbeck, A., Snower, D.J., 1987. Efficiency wages versus insiders and outsiders. European Economic Review 31, 407–416.

Mankiw, N.G., Summers, L.H., 1986. Money demand and the effect of fiscal policies. Journal of Money, Credit and Banking 18, 415–429.

Obstfeld, M., Rogoff, K., 1995a. Exchange rate redux. Journal of Political Economy 103, 624–660.

Obstfeld, M., Rogoff, K., 1995b. In: Grossman, G., Rogoff, K. (Eds.), Handbook of International Economics, The intertemporal approach to the current account, Vol. 1, Elsevier Scientific Publishers, Amsterdam.

Romer, D., 1993. Openness and inflation: Theory and evidence. Quarterly Journal of Economics 108, 870–903.

Rosen, S., 1985. Implicit contracts: A survey. Journal of Economic Literature 23 (3), 1144–1175.

Rotemberg, J., Woodford, M., 1992. Oligopolistic pricing and the effects of aggregate demand on economic activity. Journal of Political Economy 100, 1153–1207.

Stiglitz, J.E., 1986. Theories of wage rigidities. In: Butkiewicz, J.L. et al. (Ed.), Keynes' Economic Legacy, Praeger Publishers, New York, pp. 153–206, Chapter 4.

Tille, C., 1998. The role of consumption substitutability in the international transmission of shocks, mimeo.

Yellen, J.L., 1984. Efficiency wage models of unemployment. American Economic Review 74, 200–205.