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Macroeconomics of
International Price Discrimination

GIANCARLO CORSETTI

and

LUCA DEDOLA

BADIA FIESOLANA, SAN DOMENICO (FI)

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European University Institute
Badia Fiesolana
I-50016 San Domenico (FI)
Italy

Macroeconomics of International Price Discrimination¹

Giancarlo Corsetti

Luca Dedola

European University Institute and CEPR

Bank of Italy and Ente Einaudi

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Abstract

This paper builds a baseline two-country model of real and monetary transmission in the presence of optimal international price discrimination by firms. Distributing traded goods to consumers requires nontradables, intensive in local labor. Because of distribution services, the price elasticity of demand is country-specific and depends on exchange-rate fluctuations. Hence, within limits dictated by the possibility of arbitrage, profit-maximizing monopolistic firms drive a wedge between prices across countries at both wholesale and retail level. Optimal price discrimination results in a muted response of import and consumer prices to exchange-rate movements. Despite low pass-through, a currency depreciation generally worsens the terms of trade, consistent with the possibility of expenditure-switching effects. We use our model to derive general equilibrium expressions for the exchange-rate pass-through as a function of fundamentals. Conditional pass-through varies depending on whether shocks are real or nominal, transitory or permanent, thus suggesting caution in deriving structural interpretations from average, unconditional estimates of price elasticities.

JEL classification: F3, F4

Keywords: exchange-rate pass-through, deviations from the law of one price, international transmission, distribution services.

1 Introduction

Cross-border price differentials are one of the most apparent manifestations that the world economy remains strikingly segmented along national boundaries. A large body of empirical work weighs in against the proposition that good-market arbitrage is quick and effective in eliminating international price discrepancies for most types of tradable goods and services.¹ Moreover, prices seem to respond only mildly, if at all, to changes in the nominal exchange rate. Exchange rate pass-through, quite low for consumer prices, is far from complete also for international prices.² To the extent that incomplete exchange-rate pass-through is due to destination-specific markup adjustment by firms, this is evidence of market segmentation, that is, ‘pricing-to-market’ (henceforth PTM).³ With PTM, high exchange-rate volatility implies that buyers across national markets face systematically different prices for otherwise identical goods.⁴

This paper develops a general equilibrium model of endogenous incomplete pass-through and PTM building on the presence of distributive trade as a plausible source of the deviations from the law of one price. In our model, upstream firms with monopoly power optimally charge different prices to competitive retailers situated in different locations. What makes the elasticity of demand differ across markets is the need for local-input-intensive distribution services. This way of modelling vertical relationships among firms located in different markets yields several novel results, helping to reconcile theoretical predictions with key stylized facts

¹See Rogoff [1996] for an excellent survey on the evidence on the failure of the law of one price. Although this law also fails to hold within national boundaries, the deviations are much more dramatic at the international level — which has led some researchers to posit a specific ‘border effect’ (i.e. the effect of switching currencies across jurisdictions) on the prices of tradables (see Engel and Rogers [1996]).

²According to the evidence surveyed by Goldberg and Knetter [1997], 1/2 is the median fraction by which exporters to the US offset a dollar appreciation by lowering their export prices.

³Krugman [1987] labeled the phenomenon of exchange-rate-induced price discrimination ‘pricing-to-market’. Overall, the average degree of pricing-to-market found by Marston’s [1990] classic study of Japanese industries is in the neighborhood of 50 percent. Similar findings are in Knetter [1989, 1993] and Gagnon and Knetter [1995].

⁴In his analysis of US exchange rate movements, using both consumer and producer price indices, Engel [1999] finds that a great deal of the amount of deviations from purchasing power parity are due to a failure of the law of one price for internationally traded goods.

of the international economy.⁵

First, deviations from the law of one price at both wholesale and retail levels in our model derive *endogenously* from optimal pricing by monopolistic firms. Whereas most contributions in the literature simply rule out arbitrage in the goods market, we characterize optimal price discrimination under the constraint that prices should not provide opportunities for arbitrage across wholesalers and retailers in different market locations. *Second*, because of optimal cross-border price discrimination, exchange-rate pass-through is incomplete — its degree depending on the type of shocks hitting the economy. We use our model to derive general equilibrium expressions for the exchange-rate pass-through into import and consumer prices, as a function of exchange-rate and price elasticities. By doing so, we emphasize the differential impact of real and monetary shocks on pass-through and the need for identifying the sources of exchange-rate and price variability. *Third*, despite incomplete pass-through, nominal depreciations worsen the terms of trade — consistent with the empirical evidence stressed by Obstfeld and Rogoff [2000] as well as the possibility of expenditure-switching effects. Furthermore, nominal and real exchange rates, positively correlated in equilibrium, are generally more volatile than fundamentals. Because of low equilibrium pass-through, however, large movements in the nominal and real exchange rates translate into small changes in consumption, employment and price levels.

In the tradition of international macroeconomics, distribution services are invoked as a key reason for the failure of Purchasing Power Parity (henceforth PPP).⁶ Dornbusch [1989], for

⁵To enhance comparison with the literature our open economy model with endogenous price discrimination builds on the analytical framework of Corsetti and Pesenti [2001a,b] and Obstfeld and Rogoff [1995, 2000]. The specification of consumption preferences in these models is such that terms-of-trade movements in response to country-specific shocks can be sufficient to generate optimal risk-sharing: introducing Arrow-Debreu securities would not change the equilibrium allocation. This is no longer the case when we allow for distributive trade: no equilibrium with trade in international bonds can lead to optimal risk sharing — not even when nominal rigidities and monopoly power distortions are removed.

⁶Recent literature has explored the role of barriers to trade and transportation costs, but without linking them explicitly to international price discrimination. See Obstfeld and Rogoff [2001] on the role of transportation costs in explaining major puzzles in international finance, and the evidence in Parsley and Wei [2001] on transportation costs and the border effect.

instance, suggests that these services may provide an explanation for his finding that the price of an identical consumption basket is higher in high-income economies than in low-income ones. Overall, distributive trade accounts for an important share of the retail price of consumption goods: for the US, including wholesale and retail services, marketing, advertisement and local transportation, the average distribution margin is as high as 50 percent (see Burstein, Neves and Rebelo [2001]).

In recent years, a number of contributions have included distributive trade in open macro models in order to account for the large differentials in consumer prices.⁷ In our work, we take a step further relative to the existing literature. Namely, we analyze market segmentation resulting from the vertical interaction among monopolistic producers and retailers, and derive its implications for the degree of exchange-rate pass-through into import and consumer prices. We are motivated by the strong evidence of the importance of distribution services in accounting for international price discrimination — such as the one presented by Goldberg and Verboven [2001]. Based on comprehensive and detailed data of automobile prices in five European countries, these authors show that a 1 percent change in the nominal exchange rate induces a 0.46 percent adjustment in the export prices in exporter currency (i.e., equivalent to a 0.54 pass-through coefficient). Of this, between 0.37 and 0.39 percent can be attributed to a change in local costs (i.e., nominal wages in the destination country).⁸

Our approach also differs from recent contributions that view market segmentation *exclusively* as an implication of price rigidities. In such literature, foreign exporters preset consumer prices in local currency.⁹ It has been shown that models following this approach can account

⁷Erceg and Levin [1995], McCallum and Nelson [1999], and Burstein, Neves and Rebelo [2001] assume that distribution requires local inputs, focusing on the case of perfect competition in the goods market.

⁸Goldberg and Verboven [2001] estimate that local costs account for up to 35 per cent of the price of a car, mainly due to distribution services provided by local dealers.

⁹An incomplete list of papers assuming local currency prices includes Betts and Devereux [2000], Chari, Kehoe and McGrattan [2000], Devereux and Engel [2000], and Kollman [1997], among others (see Engel [2002] for a survey of the literature, and Corsetti and Pesenti [2001b] for a generalization of this approach). Early contributions simply assumed that foreign exporters quote prices in local currency. Recent works by Bacchetta and van Wincoop [2000], Corsetti and Pesenti [2002] and Devereux and Engel [2001] analyze the problem of producers who can choose whether to preset prices in domestic currency only or in both domestic and foreign currencies.

for price differences across markets, the border effect, and exchange rate volatility. Yet they can do so only at the cost of predicting that an exchange rate depreciation improve a country's terms of trade — in contrast with the evidence in Obstfeld and Rogoff [2000].¹⁰

The paper is organized as follows. The following section presents the model. Section 3 discusses optimal pricing by monopolistic firms facing country-specific demand elasticities. Section 4 derives general equilibrium implications for the exchange rate pass-through into import and consumer prices. Section 5 presents the novel features of the equilibrium with endogenously segmented markets, analyzing the link between exchange-rate determination and the behavior of relative prices. Section 6 concludes.

2 The economy

The world economy consists of two countries of equal size, H and F . Each country specializes in *one type of tradable good*, produced in a number of varieties or *brands* defined over a continuum of unit mass. Brands of tradable goods are indexed by $h \in [0, 1]$ in the Home country and $f \in [0, 1]$ in the Foreign country. In addition, each country produces an array of *differentiated nontradable goods*, indexed by $n \in [0, 1]$. Nontraded goods are either consumed or used to make intermediate tradable goods h and f available to domestic consumers.

Firms producing tradable and nontradable goods are monopolistic suppliers of one brand of goods only. These firms employ differentiated domestic labor inputs in a continuum of unit mass. Each worker occupies a point in this continuum, and acts as a monopolistic supplier of a differentiated type of labor input to all firms in the domestic economy. Households/workers are indexed by $j \in [0, 1]$ in the Home country and $j^* \in [0, 1]$ in the Foreign country. Firms operating in the distribution sector, by contrast, are assumed to operate under perfect competition.¹¹ They buy tradable goods and distribute them to consumers using nontraded goods as the only input in production.

¹⁰Another approach to modelling price discrimination (clearly complementary to ours) consists of introducing non-constant elasticity preferences — see the recent work by Bergin and Feenstra [2001] on the persistence of real exchange rates following monetary shocks.

¹¹Due to this assumption, we note from the start that the equilibrium allocation studied below would be identical in a vertically integrated economy, where exporters with monopoly power own local retailers.

In our baseline model, we allow for nominal rigidities by assuming that workers and firms agree on the nominal wage rate one period in advance.¹² In what follows, we describe our set up focusing on the Home country, with the understanding that similar expressions also characterize the Foreign economy — whereas variables referred to Foreign firms and households are marked with an asterisk.

Technology Let $Y(h)$ denote total output of a differentiated tradable good h , and $L(h, j)$ the demand for labor input of type j by the producer of good h . By the same token, $Y(n)$ denotes total production of a differentiated nontradable good n , and $L(n, j)$ the corresponding demand for labor input j . The production function of the Home traded and nontraded goods are, respectively:

$$Y_t(h) = Z_{H,t} \left[\int_0^1 L_t(h, j)^{\frac{\phi-1}{\phi}} dj \right]^{\frac{\phi}{\phi-1}}, \quad Y_t(n) = Z_{N,t} \left[\int_0^1 L_t(n, j)^{\frac{\phi-1}{\phi}} dj \right]^{\frac{\phi}{\phi-1}}; \quad (1)$$

where ϕ is the elasticity of substitution among labor inputs, which is the same across sectors, and Z denotes stochastic productivity parameters, which are sector-specific. Similar expressions hold for firms in the Foreign country, whereas the elasticity of substitution is also ϕ , but the productivity shocks are not necessarily symmetric.

Our specification of the distribution sector is in the spirit of the factual remark by Tirole ([1995], page 175) that “production and retailing are complements, and consumers often consume them in fixed proportions”. As in Erceg and Levin [1995] and Burstein, Neves and Rebelo [2001], we thus assume that bringing one unit of traded goods to consumers requires η units of a basket of differentiated nontraded goods

$$\eta = \left[\int_0^1 \eta(n)^{\frac{\theta-1}{\theta}} dn \right]^{\frac{\theta}{\theta-1}}. \quad (2)$$

We note here that the Dixit-Stiglitz index above also applies to the consumption of differentiated nontraded goods, specified in the next subsection. In equilibrium, then, the basket of

¹²Christiano, Eichenbaum and Evans [2001] and Smets and Wouters [2001] are recent structural models providing convincing evidence that wage stickiness is an important determinant of macroeconomic fluctuations. Here we abstract from issues in inflation dynamics that could be analyzed, for instance, by assuming Calvo-style adjustment of prices or wages. See Kollman [1997] and Chari et al. [2000] among others.

nontraded goods required to distribute tradable goods to consumers will have the same composition as the basket of nontradable goods consumed by the representative domestic household.¹³

Preferences Home agent j 's lifetime expected utility \mathcal{U} is defined as:

$$\mathcal{U}_t(j) \equiv E_t \sum_{\tau=t}^{\infty} \beta^{\tau-t} U \left[\ln C_{\tau}(j) + \frac{\chi_{\tau}}{1-\varepsilon} \left(\frac{M_{\tau}(j)}{P_{\tau}} \right)^{1-\varepsilon} - \kappa_{\tau} \ell_{\tau}(j) \right], \quad (3)$$

where $\beta < 1$ is the discount rate and the instantaneous utility is a function of a consumption index $C(j)$, to be defined below, real balances $M(j)/P$, and labor effort $\ell(j)$. Instantaneous utility is state-dependent, as we potentially allow for velocity shocks in the form of a stochastically varying utility of real balances, and shocks to the disutility of labor.

Households consume all types of (domestically-produced) nontraded goods, and both types of traded goods. So $C_t(n, j)$ is consumption of brand n of Home nontraded good by agent j at time t ; $C_t(h, j)$ and $C_t(f, j)$ are the same agent's consumption of Home brand h and Foreign brand f . For each type of good, we assume that one brand is an imperfect substitute for all other brands, with constant elasticity of substitution $\theta > 1$. Consumption of Home and Foreign goods by Home agent j is defined as:

$$\begin{aligned} C_{H,t}(j) &\equiv \left[\int_0^1 C_t(h, j)^{\frac{\theta-1}{\theta}} dh \right]^{\frac{\theta}{\theta-1}}, & C_{F,t}(j) &\equiv \left[\int_0^1 C_t(f, j)^{\frac{\theta-1}{\theta}} df \right]^{\frac{\theta}{\theta-1}}, \\ C_{N,t}(j) &\equiv \left[\int_0^1 C_t(n, j)^{\frac{\theta-1}{\theta}} dn \right]^{\frac{\theta}{\theta-1}}. \end{aligned}$$

The consumption aggregator of tradable goods and the full consumption basket of individuals j are, respectively:

$$C_{T,t}(j) \equiv 2C_{H,t}(j)^{1/2} C_{F,t}(j)^{1/2} \quad (4)$$

$$C_t(j) \equiv \frac{C_{T,t}(j)^{\gamma} C_{N,t}(j)^{1-\gamma}}{\gamma^{\gamma} (1-\gamma)^{1-\gamma}}. \quad (5)$$

¹³For simplicity, we do not distinguish between nontradable consumption goods, which directly enter the agents' utility, and nontraded distribution services, which are jointly consumed with traded goods. This distinction may however be important in more empirically oriented studies (e.g., see MacDonald and Ricci [2001]). By the same token, we ignore distribution costs incurred in the non-traded good market, as these can be accounted for by varying the level of productivity in the nontradable sector.

As in Corsetti and Pesenti [2001a], the parameters describing consumption preferences are the same in the Home and Foreign country.¹⁴

Price indexes Let $p_t(h)$ and $p_t^*(h)$ denote the *retail* price of brand h expressed in the Home and Foreign currency, respectively. The utility-based price indexes of Home-produced tradables are:

$$P_{H,t} = \left[\int_0^1 [p_t(h)]^{1-\theta} dh \right]^{\frac{1}{1-\theta}}, \quad P_{H,t}^* = \left[\int_0^1 [p_t^*(h)]^{1-\theta} dh \right]^{\frac{1}{1-\theta}}. \quad (6)$$

The price indexes $P_{N,t}$, $P_{N,t}^*$, $P_{F,t}$ and $P_{F,t}^*$, are analogously defined. The utility-based price indexes of tradable and the utility-based CPI are:

$$\begin{aligned} P_{T,t} &= P_{H,t}^{1/2} P_{F,t}^{1/2}, & P_{T,t}^* &= \left(P_{H,t}^* \right)^{1/2} \left(P_{F,t}^* \right)^{1/2} \\ P_t &= P_{T,t}^\gamma P_{N,t}^{1-\gamma}, & P_t^* &= \left(P_{T,t}^* \right)^\gamma \left(P_{N,t}^* \right)^{1-\gamma}. \end{aligned}$$

Household budget constraints and asset markets Home agents hold Home currency M , two international bonds, B_H and B_F , respectively denominated in Home and Foreign currency, and a well-diversified portfolio of domestic equities. They earn labor income $W\ell$ and pay non-distortionary (lump-sum) net taxes T , denominated in Home currency. The individual flow budget constraint for agent j in the Home country is:¹⁵

$$\begin{aligned} M_t(j) + B_{H,t+1}(j) + \mathcal{E}_t B_{F,t+1}(j) &\leq M_{t-1}(j) + (1 + i_t) B_{H,t}(j) \\ &+ (1 + i_t^*) \mathcal{E}_t B_{F,t}(j) + \int_0^1 \Pi(h, j) dh + \int_0^1 \Pi(n, j) dn + \\ W_t(j)\ell_t(j) - T_t(j) - P_{H,t} C_{H,t}(j) - P_{F,t} C_{F,t}(j) - P_{N,t} C_{N,t}(j) & \end{aligned} \quad (7)$$

where \mathcal{E}_t is the nominal exchange rate, expressed as Home currency per unit of Foreign currency; i_t and i_t^* are the nominal yields in Home and Foreign currency, paid at the beginning of period

¹⁴Consistent with the assumption that each country specializes in the production of a single type of traded good, the elasticity of substitution between goods produced in different countries (set equal to one) is below the elasticity of substitution among goods produced in one country ($\theta > 1$).

¹⁵The notation conventions follow Obstfeld and Rogoff [1996, ch.10]. Specifically, $M_t(j)$ denotes agent j 's nominal balances accumulated during period t and carried over into period $t + 1$, while $B_{H,t}(j)$ and $B_{F,t}(j)$ denote agent j 's bonds accumulated during period $t - 1$ and carried over into period t .

t but known at time $t - 1$; and $\int \Pi(h, j)dh + \int \Pi(n, j)dn$ is the agent's share of profits from all firms h and n in the economy.

The international bonds are assumed to be in zero net supply, so that in the aggregate $B_{H,t} = -B_{H,t}^*$ and $B_{F,t} = -B_{F,t}^*$.

Government budget constraint and policy instruments The government budget constraint in the Home country is:

$$\int_0^1 [M_t(j) - M_{t-1}(j)] dj + \int_0^1 T_t(j) dj = 0. \quad (8)$$

We abstract from government spending; seigniorage revenue is rebated to households in a lump-sum fashion. To characterize monetary policy, it is convenient to define a variable μ_t such that

$$\frac{1}{\mu_t} = \beta(1 + i_{t+1})E_t \left(\frac{1}{\mu_{t+1}} \right). \quad (9)$$

Given the time path of μ , there is a corresponding sequence of Home nominal interest rates. We assume that monetary authorities can credibly commit to monetary rules and price level targets, and without loss of generality, affect the stock of Home monetary assets by controlling the short-term rate i_{t+1} : Home monetary easing at time t leading to a lower i_{t+1} is associated with a higher μ_t .¹⁶

3 An optimizing model of pricing-to-market

3.1 Firms' optimization and optimal price discrimination

International price discrimination is a key feature of the international economy captured by our model. In what follows we show that, even if Home and Foreign consumers have identical constant-elasticity preferences for consumption, the need for distribution services intensive in

¹⁶With logarithmic utility, in equilibrium μ_t is equal to nominal spending $P_t C_t$. Note that, solving forward the above equation, the Home monetary stance at any t is a function of current and future expected interest rates, and the expected level of nominal spending in the infinite future, discounted at the rate β . We assume that policy rules are such that the latter term does not diverge asymptotically.

local nontraded goods implies that the elasticity of demand for the h (f) brand at wholesale level be not generally the same across markets. Firms will thus want to charge different prices at Home and in the Foreign country. We will focus our analysis on Home firms — optimal pricing by Foreign firms can be easily derived from it.

Consider first the optimal pricing problem faced by firms producing nontradables for the Home market. The demand for their product is

$$C(n) + \eta(n) = [p_t(n)]^{-\theta} P_{N,t}^\theta \left[C_{N,t} + \eta \left(\int_0^1 C_t(h) dh + \int_0^1 C_t(f) df \right) \right]. \quad (10)$$

It is easy to see that their optimal price will result from charging a constant markup over the unit labor costs:

$$p_t(n) = P_{N,t} = \frac{\theta}{\theta - 1} \frac{W_t}{Z_{N,t}}. \quad (11)$$

Note that nominal wage rigidities do not translate into price rigidities: the price of the non-traded good $p_t(n)$ in fact moves inversely with productivity in the sector.

Now, let $\bar{p}_t(h)$ denote the price of brand h expressed in the Home currency, at *producer* level. With a competitive distribution sector, the consumer price of good h is simply

$$p_t(h) = \bar{p}_t(h) + \eta P_{N,t}. \quad (12)$$

In the case of firms producing tradables, “pricing to market” derives endogenously from the solution to the problem of the Home representative firm in the sector:

$$\text{Max}_{\bar{p}(h), \bar{p}^*(h)} \quad [\bar{p}_t(h) C_t(h) + \mathcal{E}_t \bar{p}_t^*(h) C_t^*(h)] - \frac{W_t}{Z_{H,t}} [C_t(h) + C_t^*(h)] \quad (13)$$

where

$$C_t(h) = \left(\frac{P_{H,t}}{\bar{p}_t(h) + \eta P_{N,t}} \right)^{-\theta} C_{H,t}, \quad C_t^*(h) = \left(\frac{P_{H,t}^*}{\bar{p}_t^*(h) + \eta P_{N,t}^*} \right)^{-\theta} C_{H,t}^*. \quad (14)$$

Making use of (11), the optimal wholesale prices $\bar{p}(h)$ and $\bar{p}^*(h)$ are:

$$\bar{p}_t(h) = \frac{\theta}{\theta - 1} \left(1 + \frac{\eta}{\theta - 1} \frac{Z_{H,t}}{Z_{N,t}} \right) \frac{W_t}{Z_{H,t}}, \quad (15)$$

$$\mathcal{E}_t \bar{p}_t^*(h) = \frac{\theta}{\theta - 1} \left(1 + \frac{\eta}{\theta - 1} \frac{\mathcal{E}_t W_t^*}{W_t} \frac{Z_{H,t}}{Z_{N,t}^*} \right) \frac{W_t}{Z_{H,t}}. \quad (16)$$

Unlike the case of nontraded goods (11), in this case the markups charged by the Home firms include a state-contingent component — in brackets in the above expression — that varies as a function of productivity shocks, monetary innovations (affecting the exchange rate) and relative wages. Let $mk_{H,t}$ and $mk_{H^*,t}$ denote the stage contingent component of markups:

$$mk_{H,t} = 1 + \frac{\eta}{\theta - 1} \frac{Z_{H,t}}{Z_{N,t}}, \quad (17)$$

$$mk_{H^*,t} = 1 + \frac{\eta}{\theta - 1} \frac{\mathcal{E}_t W_t^*}{W_t} \frac{Z_{H,t}}{Z_{N,t}^*}. \quad (18)$$

Since in general $mk_{H,t}$ will not equal to $mk_{H^*,t}$, the optimal wholesale price of tradable goods will not obey the law of one price ($\bar{p}_t(h) \neq \mathcal{E}_t \bar{p}_t^*(h)$). To understand this result, observe that, despite CES preferences, the elasticity of the demand for the Home goods faced by the upstream monopolist will be different at Home and abroad, reflecting any asymmetry in relative productivity and/or relative wages. In the Home market, the price elasticity of the demand for the good h depends on relative productivity across domestic sectors:

$$\xi_{C_t(h), \bar{p}_t(h)} \equiv - \frac{\partial C_t(h)}{\partial \bar{p}_t(h)} \frac{\bar{p}_t(h)}{C_t(h)} = \theta \frac{\bar{p}_t(h)}{\bar{p}_t(h) + \eta P_{N,t}} = \theta \frac{1 + \frac{\eta}{\theta-1} \frac{Z_{H,t}}{Z_{N,t}}}{1 + \eta \frac{\theta}{\theta-1} \frac{Z_{H,t}}{Z_{N,t}}}. \quad (19)$$

In the export market the price elasticity of the demand for the good h depends on productivity shocks at Home and abroad, relative wages and the exchange rate:

$$\xi_{C_t^*(h), \bar{p}_t^*(h)} \equiv - \frac{\partial C_t^*(h)}{\partial \bar{p}_t^*(h)} \frac{\bar{p}_t^*(h)}{C_t^*(h)} = \theta \frac{\bar{p}_t^*(h)}{\bar{p}_t^*(h) + \eta P_{N,t}^*} = \theta \frac{1 + \frac{\eta}{\theta-1} \frac{\mathcal{E}_t W_t^*}{W_t} \frac{Z_{H,t}}{Z_{N,t}^*}}{1 + \eta \frac{\theta}{\theta-1} \frac{\mathcal{E}_t W_t^*}{W_t} \frac{Z_{H,t}}{Z_{N,t}^*}}. \quad (20)$$

Home monopolistic firms take account of the implications of distributive trade on the demand elasticity for their product, and find it optimal to charge different prices to firms distributing in the Home and in the Foreign market.

It is worth stressing three properties of the above elasticities. First, the price elasticity of export demand is non linear in the exchange rate: a relatively appreciated Home currency (a low \mathcal{E}_t) corresponds to a relatively large price elasticity. Second, such elasticity is increasing in the wholesale price — as shown by the literature on international trade, this is a sufficient condition for incomplete exchange-rate pass-through (we will discuss this topic in detail below).¹⁷

¹⁷As far as the elasticity of substitution between the tradable good and the nontradable bundle in the retailer distribution technology is less than 1, the producer's price elasticity will be increasing in $\bar{p}^*(h)$.

Third, let $\delta_t(h)$ ($\delta_t^*(h)$) denote the distribution margin, i.e., the share of distributive trade in the consumer price of the good h in the Home (Foreign) market. The above expressions can then be written as follows

$$\begin{aligned}\xi_{C_t(h), \bar{p}_t(h)} &= \theta \left(1 - \frac{\eta P_{N,t}}{p_t(h)} \right) = \theta (1 - \delta_t(h)), \\ \xi_{C_t^*(h), \bar{p}_t^*(h)} &= \theta \left(1 - \frac{\eta P_{N,t}^*}{p_t^*(h)} \right) = \theta (1 - \delta_t^*(h)).\end{aligned}$$

The elasticities of consumption to the wholesale prices are monotonic functions of the distribution margins. In either market, the higher the distribution margin, the lower the price elasticity. Note that when $\eta = 0$, $\delta = 0$ and the above expressions are equal to the constant θ .

3.2 The role of arbitrage across national markets

Most open macro models accounting for deviations from the law of one price simply rule out arbitrage in the goods market by assumption. In our framework, we can actually say something about the role of arbitrage as a constraint on firms' pricing decisions. Specifically, we can analyze firms' optimal pricing decisions allowing for the possibility of arbitrage across wholesale and retail markets.¹⁸

In the previous section we have derived (15) and (16) under the assumption that no agents in the economy could arbitrage across market location. In this section, we study the extent to which arbitrage in the goods market may prevent optimal price discrimination between domestic and foreign dealers. Consider the consumer price of the good h in both markets, calculated adding the distribution costs (ηP_N and $\eta^* P_N^*$) to the optimal producer prices above:

$$p_t(h) = \frac{\theta}{\theta - 1} \left(1 + \eta \frac{\theta}{\theta - 1} \frac{Z_{H,t}}{Z_{N,t}} \right) \frac{W_t}{Z_{H,t}}, \quad (21)$$

$$\mathcal{E}_t p_t^*(h) = \frac{\theta}{\theta - 1} \left(1 + \eta \frac{\theta}{\theta - 1} \frac{\mathcal{E}_t W_t^*}{W_t} \frac{Z_{H,t}}{Z_{N,t}^*} \right) \frac{W_t}{Z_{H,t}}. \quad (22)$$

¹⁸We are assuming that markets can be segmented along national lines. In our model this could be easily justified with a system of selective and exclusive distribution, in which the manufacturer can choose dealers and restrain them from reselling to anyone but end-users. We observe here that regulation 123/85 of the European Commission has allowed these practices in the European Union to some extent (see Goldberg and Verboven [2001] for the implications of the Regulation in the European car market).

If the representative Home firm set the wholesale price in the Foreign country above the consumer price of its own good in the Home country, firms distributing good h in the Foreign country would find it profitable to buy it from Home retailers rather than in the wholesale market. This implies that optimal price discrimination is possible only as long as the following no-arbitrage conditions are verified:

$$\begin{aligned}\mathcal{E}_t p_t^*(h) &= \mathcal{E}_t \left(\bar{p}_t^*(h) + \eta P_{N,t}^* \right) \geq \bar{p}_t(h) \\ p_t(h) &= \bar{p}_t(h) + \eta P_{N,t} \geq \mathcal{E}_t \bar{p}_t^*(h).\end{aligned}$$

Using optimal prices, these conditions can be synthetically written as:

$$\frac{1}{\theta} \leq \frac{\mathcal{E}_t W_t^*}{W_t} \frac{Z_{N,t}}{Z_{N,t}^*} \leq \theta. \quad (23)$$

According to this expression, for given relative nominal marginal costs in the nontraded goods sector, a large depreciation of the nominal exchange rate could reduce the Home consumer price of h in Foreign currency below the optimal export price $\bar{p}_t^*(h)$ — violating the second inequality above. In that case, arbitrage in the goods market would force firms to set the domestic price and the foreign wholesale price equal to each other: $p_t(h) = \mathcal{E}_t \bar{p}_t^*(h)$. By the same token, a large appreciation of the exchange rate could reduce the foreign retail price of h in the Home currency below the wholesale price at Home. In this case, ruling out arbitrage requires firms to set $\bar{p}_t(h) = \mathcal{E}_t p_t^*(h)$.

Leaving the characterization of optimal pricing subject to the no-arbitrage condition (23) to the Appendix, we provide an intuitive account of our main results. Suppose that to rule out arbitrage Home firms must set: $p_t(h) = \mathcal{E}_t \bar{p}_t^*(h)$. Relative to the optimal prices (15) and (16), Home firms will now raise $\bar{p}_t(h)$ above (15) while lowering $\bar{p}_t^*(h)$ below (16). As the two prices cannot be set independently, the drop in the markup in the foreign market is partly offset by a higher markup at home. Note that, when the no-arbitrage condition is binding, *wholesale* prices will be different in the Home and Foreign markets: with $\eta > 0$, the law of one price cannot hold.

It is easy to verify that, holding (23), it can never be profitable to buy good h at the Home (Foreign) retail price and sell it at the Foreign (Home) retail price after paying local distribution costs. We note here that, to the extent that domestic households need local distribution services

even if they buy tradables abroad (i.e., technical assistance), our model endogenously rules out consumers' arbitrage across retail markets.

In concluding this section, it is appropriate to discuss briefly our assumption of perfect competition in the distribution sector. Allowing for monopoly power in the retail sector would imply double marginalization at consumer prices. In our setup, however, monopolistic retailers face a constant-elasticity demand, so that their markup over marginal cost would be constant (the right hand side of (12) would be multiplied by the constant $\frac{\theta}{\theta-1}$). Thus, double marginalization would influence the level of consumer prices (both (21) and (22) would be multiplied by $\frac{\theta}{\theta-1}$), but not their wholesale counterpart (15) and (16). For this reason, the equilibrium response of prices to nominal and real shocks would not be substantially different from what we obtain in our model, built on the simplest benchmark specification of monopolistic wholesale suppliers and competitive distributors.

4 Endogenous pass-through and deviations from the law of one price

The empirical evidence on pass-through unambiguously shows that prices tend to vary far less than one-to-one with exchange rates. Yet the exchange-rate elasticity of prices can hardly be considered a constant parameter, as it may depend on a variety of factors including market structure, price adjustment costs and, most crucially, on the nature of shocks hitting the economy. In this section, we use our model to derive general equilibrium expressions for the exchange-rate pass-through into import prices and consumer prices, as a function of equilibrium exchange-rate and price elasticities. By doing so, we are able to trace the differential impact of real and monetary shocks on pass-through, showing the importance of identifying the source of exchange-rate and price variability.

Since we focus on symmetric equilibria within a country (though not necessarily symmetric across countries), from now on we will write prices with country-specific, rather than firm-specific indexes, e.g., $\bar{P}_{F,t}$ rather $\bar{p}_t(f)$, dropping the indices j and j^* and interpreting all variables in per-capita (or aggregate) terms.

Exchange-rate pass-through in response to nominal and real shocks In addition to explaining price discrimination, the combination of distribution costs and monopoly power has crucial implications for the optimal degree of exchange-rate pass-through. Assume at first that the no-arbitrage condition (23) is satisfied as a strict inequality. By taking the total differential of the analog of (16) for the Home import prices $\bar{P}_{F,t}$, we obtain a general expression for the elasticity of the (producer) price of imports with respect to the exchange rate:

$$\xi_{\bar{P}_{F,t}, \varepsilon_t} \equiv \frac{\partial \bar{P}_{F,t}}{\partial \varepsilon_t} \frac{\varepsilon_t}{\bar{P}_{F,t}} = mk_{F,t}^{-1} \left[1 - \xi_{\varepsilon_t, Z_{F,t}}^{-1} - (mk_{F,t} - 1) \left(\xi_{\varepsilon_t, Z_{N,t}}^{-1} \right) \right], \quad (24)$$

where in analogy to (18), $mk_{F,t} \equiv \left(1 + \frac{\eta}{\theta - 1} \frac{W_t}{\varepsilon_t} \frac{Z_{F,t}}{Z_{N,t}} \right)$.¹⁹

This expression makes clear that the exchange-rate pass-through critically hinges on the nature of the shocks hitting the economy, for in general equilibrium each shock will result in a different impact on the nominal exchange rate and thus on the elasticities appearing in (24). Consider first the effect of monetary policy shocks, so that obviously $\xi_{\varepsilon_t, Z_{F,t}}^{-1} = \xi_{\varepsilon_t, Z_{N,t}}^{-1} = 0$. The exchange-rate pass-through into import prices will be equal to $mk_{F,t}^{-1}$, the inverse of the contingent component of the markup charged by Foreign producers to local distributors. Since $mk_{F,t}^{-1} < 1$, pass-through will be less than complete. For instance, with a state contingent markup of 25 percent, a one percent exchange-rate depreciation conditional on a domestic monetary shock would result in a 0.8 percent increase in import prices, i.e., in a 80 percent pass-through. Moreover, pass-through will be decreasing in any variable that raises the equilibrium markup charged by Foreign firms in the Home market — including a higher degree of monopoly power (a lower θ), or a larger distribution margin (a larger η).²⁰ Similarly, it will be smaller in

¹⁹For simplicity, in (24) we write out (the inverse of) elasticities with the implicit convention that they are zero if the corresponding shock does not materialize in the economy.

²⁰Clearly, these results would not hold in the absence of nominal rigidities. To see this, we rewrite (24) as

$$\xi_{\bar{P}_{F,t}, \varepsilon_t} \equiv mk_{F,t}^{-1} \left[\begin{array}{c} \left(1 + \xi_{W_t^*, \varepsilon_t} - \xi_{\varepsilon_t, Z_{F,t}}^{-1} \right) + \\ (mk_{F,t} - 1) \left(\xi_{W_t, \varepsilon_t} - \xi_{\varepsilon_t, Z_{N,t}}^{-1} \right) \end{array} \right],$$

With wage contracts $\xi_{W_t, \varepsilon_t} = \xi_{W_t^*, \varepsilon_t} = 0$. Without wage contracts, nominal shocks would not alter relative wages (the exchange rate and the wage rate would move in the same direction). In this case, following a domestic (foreign) expansionary shock to μ_t (μ_t), $\xi_{W_t, \varepsilon_t} = \xi_{W_t, \mu_t} = 1$ (0) and $\xi_{W_t^*, \varepsilon_t} = 0$ (-1). It is easy to see that exchange rate pass-through will be either complete or zero, depending on the origin of the monetary

case of a currency appreciation (a smaller \mathcal{E}_t), higher in case of depreciation. Monetary shocks thus may induce asymmetries in the exchange rate elasticity $\xi_{\overline{P}_{F,t},\mathcal{E}_t}$.

What about the degree of pass-through resulting from productivity shocks? It is apparent from (24) that shocks to $Z_{H,t}$ and $Z_{N,t}^*$ will result in the same equilibrium pass-through as monetary shocks, $mk_{F,t}^{-1}$, for the term in brackets will be equal to 1 in these cases as well. Conversely, the exchange-rate pass-through due to shocks to $Z_{F,t}$ and $Z_{N,t}$ will generally be different from $mk_{F,t}^{-1}$, depending on the equilibrium response of the exchange rate to these shocks — i.e., on the exchange-rate elasticities $\xi_{\mathcal{E}_t,Z_{F,t}}$ and $\xi_{\mathcal{E}_t,Z_{N,t}}$. Observe that these elasticities can have either sign. Thus, while pass-through will be equal to $mk_{F,t}^{-1}$ in response to monetary shocks, $Z_{H,t}$ and $Z_{N,t}^*$, it can be higher or lower than $mk_{F,t}^{-1}$ in the presence of shocks to domestic nontradables $Z_{N,t}$, and foreign tradables $Z_{F,t}$. But the stronger the response of the nominal exchange rate \mathcal{E}_t to productivity shocks (i.e., the lower $\xi_{\mathcal{E}_t,Z_{F,t}}^{-1}$ and $\xi_{\mathcal{E}_t,Z_{N,t}}^{-1}$), the closer the exchange-rate pass-through to $mk_{F,t}^{-1}$.

It is worth stressing that the implications of real shocks for incomplete pass-through are in general independent of nominal rigidities. Even if all prices and wages were fully flexible, firms may still choose to discriminate prices optimally in response to productivity differentials across sectors, as well as wage differentials arising from country-specific shocks to labor supply.

Finally, allowing for arbitrage between the retail and the wholesale markets cannot but reinforce our results. In the previous section we have shown that, when the exchange-rate depreciation is large enough, Home firms will set the foreign wholesale price equal to the domestic consumer price. To the extent that shocks cause Home firms to raise the Home price of their goods, the degree of pass-through will clearly be even lower than that implicit in (16).

Muted effects on consumer prices The presence of distribution costs further reduces the exchange-rate pass-through into prices at *consumer* level. Consider the exchange-rate elasticity of the Foreign good retail prices in the Home market:

$$\xi_{P_{F,t},\mathcal{E}_t} = (1 - \delta_{F,t}) \xi_{\overline{P}_{F,t},\mathcal{E}_t} - \delta_{F,t} \xi_{\mathcal{E}_t,Z_{N,t}}^{-1}, \quad (25)$$

shock. For instance, a Home shock that raises all prices in domestic currency and depreciates the exchange rate proportionally will also result in higher import prices.

where

$$1 - \delta_{F,t} \equiv 1 - \eta \frac{P_{N,t}}{P_{F,t}} = \frac{1 + \frac{\eta}{\theta-1} \frac{W_t}{\varepsilon_t W_t^*} \frac{Z_{F,t}}{Z_{N,t}}}{1 + \eta \frac{\theta}{\theta-1} \frac{W_t}{\varepsilon_t W_t^*} \frac{Z_{F,t}}{Z_{N,t}}}.$$

For any given exchange-rate pass-through $\xi_{\overline{P}_{F,t}, \varepsilon_t}$, a larger distribution margin $\delta_{F,t}$ translates into smaller movements of consumer prices $\xi_{P_{F,t}, \varepsilon_t}$. In the case of shocks to Home nontradables causing $\xi_{\varepsilon_t, Z_{N,t}} > 0$, the above elasticity is reduced further, as it also reflects falling prices in the distribution sector operating in the Home market.

Note that the elasticity $\xi_{P_{F,t}, \varepsilon_t}$ in (25) is less than one even if the exchange-rate pass-through into import prices is complete. Indeed, some contributions (such as Burstein et al. [2001]) build models assuming the law of one price at wholesale level (and thus $\xi_{\overline{P}_{F,t}, \varepsilon_t} = 1$) in response to any kind of shocks, and attribute imperfect pass-through into consumer prices exclusively to the direct effect of distribution.

The elasticity of the consumer price index to the exchange rate is:

$$\begin{aligned} \xi_{P_t, \varepsilon_t} &= \frac{\gamma}{2} (\xi_{P_{F,t}, \varepsilon_t} + \xi_{P_{H,t}, \varepsilon_t}) + \gamma \xi_{P_{N,t}, \varepsilon_t} \\ &= \frac{\gamma}{2} \left[mk_{F,t}^{-1} (1 - \delta_{F,t}) \left(1 - \xi_{\varepsilon_t, Z_{F,t}}^{-1} \right) - mk_{H,t}^{-1} (1 - \delta_{H,t}) \xi_{\varepsilon_t, Z_{H,t}}^{-1} \right] + \\ &\quad - \left\{ 1 - \frac{\gamma}{2} \left[(1 - \delta_{H,t}) mk_{H,t}^{-1} + (1 - \delta_{F,t}) mk_{F,t}^{-1} \right] \right\} \xi_{\varepsilon_t, Z_{N,t}}^{-1} \end{aligned} \quad (26)$$

The CPI response to exchange rate fluctuations crucially depends on three factors: (i) openness, namely the share of imports in consumption $\frac{\gamma}{2}$ (in turn depending on the share of tradables in consumption γ , and the share of imports in tradables, $\frac{1}{2}$); (ii) the size of markup $mk_{H,t}^{-1}$ and $mk_{F,t}^{-1}$; (iii) the size of the distribution margins $\delta_{H,t}$ and $\delta_{F,t}$.²¹

However, an assessment of (conditional and unconditional) movements in the CPI associated to exchange-rate fluctuations in general equilibrium is by no means trivial. Shocks may move consumer prices differently, even in opposite direction, with respect to the exchange rate and import prices. This suggests caution in deriving structural interpretations from average, unconditional estimates of price elasticities, say, as indicators of ‘exchange rate disconnect’, or in using them to draw conclusions about the inflationary consequences of particular episodes of exchange-rate variability.

²¹Most contributions in the recent open-economy literature focus on either (i), e.g. Obstfeld and Rogoff [2000], or (ii), e.g. LCP, setting (iii) to zero. Burstein et al. [2001] focus on (i) and (iii) but abstract from (ii).

However, an assessment of the general equilibrium conditional and unconditional movements in the CPI associated with exchange-rate fluctuations is by no means trivial, as some shocks may move domestic prices by more and even in the opposite direction with respect to the exchange rate.

This suggests caution in carrying out inference on the effects of exchange-rate movements based on empirical views of the unconditional CPI elasticity to exchange-rate movements.

Failure of the law of one price Consider the definition of the real exchange rate:

$$\frac{\mathcal{E}_t P_t^*}{P_t} = \left(\frac{\mathcal{E}_t P_{T,t}^*}{P_{T,t}} \right) \left(\frac{P_{N,t}^* P_{T,t}}{P_{T,t}^* P_{N,t}} \right)^{1-\gamma} = \left[\left(\frac{\mathcal{E}_t P_{H,t}^*}{P_{H,t}} \right) \left(\frac{\mathcal{E}_t P_{F,t}^*}{P_{F,t}} \right) \right]^{\frac{1}{2}} \left(\frac{P_{N,t}^* P_{T,t}}{P_{T,t}^* P_{N,t}} \right)^{1-\gamma}. \quad (27)$$

In our model, movements in the real exchange rate are due both to differences in prices (in the same currency) of traded goods across countries and to movements of the relative price of tradables in terms of nontradables.²² This is in sharp contrast with models adopting a similar specification, but not allowing for distributive trade. By setting $\eta = 0$, in fact, there would be no deviation from the law of one price (henceforth LOOP). The first term on the right-hand side of the above definition would be constant, and the variability of the real exchange rate would only depend on the variability of the relative price of nontradables within each country — a prediction that is inconsistent with the findings for the US real exchange rate in Engel [1999].

To illustrate this point, take the total differential of $\frac{\mathcal{E}_t P_{F,t}^*}{P_{F,t}}$ — denoting relative LOOP deviations in foreign tradables, so as to obtain:

$$\frac{\partial \frac{\mathcal{E}_t P_{F,t}^*}{P_{F,t}}}{\partial \mathcal{E}_t} \frac{\mathcal{E}_t}{\frac{\mathcal{E}_t P_{F,t}^*}{P_{F,t}}} = 1 - \xi_{P_{F,t}, \mathcal{E}_t} + \xi_{P_{F,t}^*, \mathcal{E}_t}$$

Making use of (24) and (25), and noting that

$$\xi_{P_{F,t}, \mathcal{E}_t} = -\frac{1 - \delta_{F,t}^*}{mk_{F,t}^*} \xi_{\mathcal{E}_t, Z_{F,t}}^{-1} - \delta_{F,t}^* \xi_{\mathcal{E}_t, Z_{N,t}}^{-1}$$

²²Since tradables have equal shares in Home and Foreign consumption baskets, terms of trade movements do not impinge on the real exchange rate.

we can also write

$$\begin{aligned} \frac{\partial \frac{\mathcal{E}_t P_{F,t}^*}{P_{F,t}}}{\partial \mathcal{E}_t} \frac{\mathcal{E}_t}{\frac{\mathcal{E}_t P_{F,t}^*}{P_{F,t}}} &= 1 - (1 - \delta_{F,t}) mk_{F,t}^{-1} - \left(\frac{1 - \delta_{F,t}^*}{mk_{F,t}^*} - \frac{1 - \delta_{F,t}}{mk_{F,t}} \right) \xi_{\mathcal{E}_t, Z_{F,t}}^{-1} \\ &+ \left(\delta_{F,t} + \frac{(1 - \delta_{F,t})(mk_{F,t} - 1)}{mk_{F,t}} \right) \xi_{\mathcal{E}_t, Z_{N,t}}^{-1} - \delta_{F,t}^* \xi_{\mathcal{E}_t, Z_{N,t}^*}^{-1}, \end{aligned}$$

Clearly, with $\eta = 0$, $\delta = 0$ and $mk = 1$ for all goods, and the right hand side of the above expression will be equal to zero: there will be no deviations from the law of one price. With $\eta > 0$, instead, the relative deviation from LOOP conditional on nominal shocks will be equal to $1 - \xi_{P_{F,t}, \mathcal{E}_t}$, which is the complement to one of the exchange-rate pass-through into the consumer price of imports. Relative to the case of nominal shocks, LOOP deviations conditional on productivity shocks can be lower (for shocks to $Z_{N,t}^*$), roughly the same (for shocks to $Z_{F,t}$ and $Z_{H,t}$), or larger (for shocks to $Z_{N,t}$).

Having set the stage for a general equilibrium analysis of price discrimination and pass-through, we are now ready to characterize the equilibrium solution of our model, and discuss its main predictions and properties. To this we turn next.

5 Exchange rates and prices in general equilibrium

5.1 Characterizing the model solution

The world equilibrium is characterized as follows. Given the stochastic processes driving monetary stances (μ_t and μ_t^*) and the shocks to productivity and preferences (all the Z 's, χ_t , χ_t^* , κ_t , and κ_t^*), and given the initial holdings of bonds ($B_{H,0}$ and $B_{F,0}$) and money (M_0 and M_0^*), for $t \geq 0$ the equilibrium (symmetric across firms) is a set of processes for the nominal exchange rate \mathcal{E}_t , the Home allocations and prices (l_t , $C_{H,t}$, $C_{F,t}$, $C_{N,t}$, M_{t+1} , $B_{H,t+1}$, $B_{F,t+1}$, $\bar{P}_{H,t}$, $\bar{P}_{H,t}^*$, $P_{N,t}$ and W_t) and their Foreign counterparts (l_t^* , $C_{H,t}^*$, $C_{F,t}^*$, $C_{N,t}^*$, M_{t+1}^* , $B_{H,t+1}^*$, $B_{F,t+1}^*$, $\bar{P}_{F,t}$, $\bar{P}_{F,t}^*$, $P_{N,t}^*$ and W_t^*) that (a) satisfy the Home and Foreign consumers' optimality conditions, (b) maximize firms profits, (c) satisfy the market clearing conditions for each asset and each good, in all the markets where it is traded, and (d) satisfy the resource constraints.

Table 1: Equilibrium characterization

$$W_t = \frac{\phi}{\phi - 1} \frac{E_{t-1} \kappa_t \ell_t}{E_{t-1} \left(\frac{\ell_t}{\mu_t} \right)} \quad (28)$$

$$W_t^* = \frac{\phi}{\phi - 1} \frac{E_{t-1} \kappa_t^* \ell_t^*}{E_{t-1} \left(\frac{\ell_t^*}{\mu_t^*} \right)} \quad (29)$$

$$\mathcal{E}_t = \frac{\mu_t}{\mu_t^*} \frac{E_t \left(\frac{\mathcal{E}_{t+1}}{\mu_{t+1}} \right)}{E_t \left(\frac{1}{\mu_{t+1}^*} \right)} = \frac{\mu_t}{\mu_t^*} \frac{E_t (\mathcal{E}_{t+1} \mu_{t+1}^*)}{E_t (\mu_{t+1})} \quad (30)$$

$$\bar{A}_t = -\mathcal{E}_t \bar{A}_t^* \quad (31)$$

$$E_t \left\{ \frac{\beta \mu_t}{\mu_{t+1}} \bar{A}_{t+1} \right\} = \bar{A}_t - \frac{\gamma}{2} \left[\mu_t \frac{1 + \frac{\eta}{\theta-1} \frac{Z_{F,t}}{Z_{N,t}}}{1 + \frac{\eta\theta}{\theta-1} \frac{Z_{F,t}}{Z_{N,t}}} - \mathcal{E}_t \mu_t^* \frac{1 + \frac{\eta}{\theta-1} \frac{\mathcal{E}_t W_t^*}{W_t} \frac{Z_{H,t}}{Z_{N,t}^*}}{1 + \frac{\eta\theta}{\theta-1} \frac{\mathcal{E}_t W_t^*}{W_t} \frac{Z_{H,t}}{Z_{N,t}^*}} \right] \quad (32)$$

$$\ell_t = \frac{\theta-1}{\theta} \frac{\mu_t}{W_t} \left[1 + \frac{\frac{\gamma}{2} \mathcal{E}_t \mu_t^* / \mu_t}{1 + \frac{\eta\theta}{\theta-1} \frac{\mathcal{E}_t W_t^*}{W_t} \frac{Z_{H,t}}{Z_{N,t}^*}} + \frac{\frac{\gamma}{2} \eta}{\frac{\eta\theta}{\theta-1} + \frac{\mathcal{E}_t W_t^*}{W_t} \frac{Z_{N,t}}{Z_{F,t}}} - \frac{\gamma}{2} \frac{1 + \eta \frac{\theta+1}{\theta-1} \frac{Z_{H,t}}{Z_{N,t}}}{1 + \frac{\eta\theta}{\theta-1} \frac{Z_{H,t}}{Z_{N,t}}} \right] \quad (33)$$

$$\ell_t^* = \frac{\theta-1}{\theta} \frac{\mu_t^*}{W_t^*} \left[1 + \frac{\frac{\gamma}{2} \mu_t / \mathcal{E}_t \mu_t^*}{1 + \frac{\eta\theta}{\theta-1} \frac{W_t}{\mathcal{E}_t W_t^*} \frac{Z_{F,t}}{Z_{N,t}}} + \frac{\frac{\gamma}{2} \eta}{\frac{\eta\theta}{\theta-1} + \frac{W_t}{\mathcal{E}_t W_t^*} \frac{Z_{N,t}^*}{Z_{H,t}}} - \frac{\gamma}{2} \frac{1 + \eta \frac{\theta+1}{\theta-1} \frac{Z_{F,t}}{Z_{N,t}^*}}{1 + \frac{\eta\theta}{\theta-1} \frac{Z_{F,t}}{Z_{N,t}^*}} \right] \quad (34)$$

$$C_t = \frac{\theta-1}{\theta} \frac{\mu_t}{W_t} (Z_{N,t}) \left(\frac{Z_{N,t}}{Z_{H,t}} + \frac{\eta\theta}{\theta-1} \right)^{-\frac{\gamma}{2}} \left(\frac{Z_{N,t}}{Z_{F,t}} \frac{\mathcal{E}_t W_t^*}{W_t} + \frac{\eta\theta}{\theta-1} \right)^{-\frac{\gamma}{2}} \quad (35)$$

$$C_t^* = \frac{\theta-1}{\theta} \frac{\mu_t^*}{W_t^*} (Z_{N,t}^*) \left(\frac{Z_{N,t}^*}{Z_{F,t}} + \frac{\eta\theta}{\theta-1} \right)^{-\frac{\gamma}{2}} \left(\frac{Z_{N,t}^*}{Z_{H,t}} \frac{W_t}{\mathcal{E}_t W_t^*} + \frac{\eta\theta}{\theta-1} \right)^{-\frac{\gamma}{2}} \quad (36)$$

Table 1 presents a subset of equilibrium conditions that completely characterize the model. In the table, \bar{A}_{t+1} denotes Home non-monetary wealth at the beginning of time $t + 1$, i.e.,

$$\bar{A}_{t+1} \equiv (1 + i_{t+1}) B_{H,t+1} + (1 + i_{t+1}^*) \mathcal{E}_{t+1} B_{F,t+1}; \quad (37)$$

\bar{A}^* is similarly defined. Equations (30) state the risk-adjusted uncovered interest parity condition, where we have used the fact that in equilibrium $\mu_t = P_t C_t$ and $\mu_t^* = P_t^* C_t^*$. Equation (31) is the bond market-clearing equation, while (32) is the current account. These three equations simultaneously determine the nominal exchange rate and external borrowing. Employment and consumption in both countries (corresponding to the expressions (33), (35), (34) and (36)) can then be derived as a function of exogenous shocks, wages and the nominal exchange rate. In each country, the nominal wage rate (28) (or (29)) is preset given the joint distribution of employment, κ (or κ^*) and domestic monetary shocks.

In the Appendix, we show that our economy can have multiple non-stochastic steady states, for (perhaps too) large values of the distribution margin. Specifically, we show that the steady state can be characterized by either one or three equilibrium allocations. In the latter case, identical fundamentals may correspond to vastly different equilibrium values for the exchange rate and the terms of trade — although the cross-border differences in the price level, consumption and employment would be small. In this paper we abstract from steady state multiplicity by restricting parameters' values to the region where the equilibrium is unique — and leave a detail analysis of this issue to future research.

It is useful to note here that, despite nominal wage rigidities, in our economy there exists a simple monetary rule that can sustain a flex-price, flex-wage allocation — obtained from Table 1 by evaluating the optimal wage rates (28) and (29) without the expectation operator. Let μ and μ^* be determined as follows

$$\mu_t = \frac{\Gamma_t}{\kappa_t}, \quad \mu_t^* = \frac{\Gamma_t^*}{\kappa_t^*} \quad (38)$$

where Γ_t and Γ_t^* are deterministic functions of time (therefore uniquely pinned down at time $t - 1$), scaling the level of wages in the economy. Following the above rules monetary authorities tightens in those states of the world when the disutility of working is higher. As monetary policy in either country completely stabilizes the marginal disutility of working, according to (28) and

(29) workers will find it optimal to set a nominal wage equal to $\Gamma_t\phi/(\phi-1)$ and $\Gamma_t^*\phi/(\phi-1)$. It is easy to check that this is exactly the flexible wage that would result when (38) is implemented. It follows that the above monetary rules support the flexible-wage allocation.²³

5.2 Equilibrium with distribution services

Distribution services play a key role in differentiating our results relative to competing models, and improve the overall performance of our specification in accounting for key stylized facts of the international economy. We have already noted above that they are responsible for generating deviations from the law of one price and incomplete pass-through. In what follows we stress some additional distinctive features of our specification.

For our purposes, it is analytically convenient to focus first on the extreme case of financial autarky. Under this assumption, the exchange rate is implicitly determined by the balanced trade condition ($\mathcal{E}_t\bar{P}_{H,t}^*C_{H,t}^* = \bar{P}_{F,t}C_{F,t}$) as a non-linear function of relative monetary policy stance μ/μ^* and relative productivity:

$$\mathcal{E}_t\mu_t^* \frac{1 + \frac{\eta}{\theta-1} \frac{\mathcal{E}_t W_t^* Z_{H,t}}{W_t Z_{N,t}^*}}{1 + \frac{\eta\theta}{\theta-1} \frac{\mathcal{E}_t W_t^* Z_{H,t}}{W_t Z_{N,t}^*}} = \mu_t \frac{\mathcal{E}_t + \frac{\eta}{\theta-1} \frac{W_t Z_{F,t}}{W_t^* Z_{N,t}}}{\mathcal{E}_t + \frac{\eta\theta}{\theta-1} \frac{W_t Z_{F,t}}{W_t^* Z_{N,t}}}. \quad (39)$$

which can be written more synthetically as follows

$$\mathcal{E}_t = \frac{\mu_t (1 - \delta_{F,t})}{\mu_t^* (1 - \delta_{H,t}^*)}. \quad (40)$$

The exchange rate depends not only on relative monetary stance, but also on the share of foreign producers in Home import prices, relative to the share of domestic exporters in import prices abroad.

It can be easily shown that in the presence of a full set of contingent nominal bonds, i.e., claims to receiving one unit of currency in each state of nature, the exchange rate is $\mathcal{E}_t = \frac{\mu_t}{\mu_t^*}$.

²³This result shows that market segmentation due to distributive trade does not prevent the possibility that monetary policy rules may sustain the allocation without nominal rigidities. As shown by Corsetti and Pesenti [2001b], however, this is impossible when market segmentation and incomplete pass-through can be attributed to ‘local currency pricing’ or price adjustment costs in local currency. Because of inefficient risk sharing, however, the flex-wage allocation will in general not be Pareto efficient.

Notably, this is also the solution when markets are incomplete but we consider the limiting case $\eta \rightarrow 0$:

$$\lim_{\eta \rightarrow 0} \mathcal{E}_t = \frac{\mu_t}{\mu_t^*}. \quad (41)$$

when our specification becomes similar to Corsetti and Pesenti [2001a], Obstfeld and Rogoff [2000] and Devereux and Engel [2000]. So, if we assume either that markets are complete, or that there are no distribution costs, the exchange rate in our specification would move in proportion to relative monetary stances, with two crucial consequences. First, \mathcal{E}_t would respond to real shocks in the economy only through endogenous changes in the relative monetary policy stance μ_t/μ_t^* , and not directly. Second, the volatility of the nominal exchange rate would coincide with that of nominal shocks — so that the model could not generate any excess volatility.

Our specification with distributive trade, instead, has important implications for international price volatility. In our model the Home demand for imports can be written as:

$$C_{F,t} = \frac{\gamma}{2} \frac{\mu_t}{P_{F,t}} = \frac{\gamma}{2} \frac{\mu_t}{\bar{P}_{F,t} + \eta P_{N,t}},$$

hence the elasticity of the imports demand with respect to the wholesale price $\bar{P}_{F,t}$ is decreasing in the distribution margin in the Home market for the Foreign good, $\delta_{F,t}$:

$$\xi_{C_{F,t}, \bar{P}_{F,t}} \equiv - \frac{\partial C_{F,t}}{\partial \bar{P}_{F,t}} \frac{\bar{P}_{F,t}}{C_{F,t}} = \frac{\bar{P}_{F,t}}{\bar{P}_{F,t} + \eta P_{N,t}} = 1 - \delta_{F,t},$$

By the definition of $\delta_{F,t}$, this expression is decreasing in η , and equal to 1 for $\eta = 0$. Distribution services thus reduce the price elasticity of imports demand, below what is implied by Cobb-Douglas preferences. But by lowering the price elasticity of imports, distributive trade induces larger price movements for any given quantity change not only under financial autarky but also with incomplete markets.²⁴

5.3 The international transmission mechanism

In this subsection, we will show that the exchange rate in our economy tends to move more than the underlying economic fundamentals, and its movements pass through into prices only

²⁴For an analysis of these issues in a quantitative framework see Corsetti, Dedola and Leduc [2002].

partially. Second, notwithstanding incomplete pass-through and deviations from LOOP, nominal depreciations tend to worsen the terms of trade. Finally, nominal and real exchange rates are positively correlated in equilibrium and thus the volatility of the former is inherited by the latter.

To derive these results, in this subsection we keep our early assumption of financial autarky — so that, as shown above, the exchange rate is given by (40). Under this assumption, we linearize the model around a symmetric steady state with $Z_H = Z_F = Z_T$, $Z_N^* = Z_N$ and equal wage levels $\frac{\phi}{\phi-1}\kappa\mu$ across countries. In the next subsection, we will show that the results derived under financial autarky carry through to an economy with international trade in a nominal bond.

Exchange-rate volatility and pass-through Consider the response of the nominal exchange rate to monetary policy shocks, in the form of unexpected changes in the ratio of μ to μ^* . The response of the nominal exchange rate (given nominal wages) is

$$\widehat{\mathcal{E}}_t = \frac{mk_T}{mk_T - 2\delta} (\widehat{\mu}_t - \widehat{\mu}_t^*), \quad (42)$$

where mk_T and δ denote the symmetric steady values of (17) and of the distribution margin, respectively. Under mild conditions on the relative size of markups and distribution margins,²⁵ the coefficient multiplying the relative monetary shock in the above equation is always positive and larger than one — i.e., a Home monetary expansion leads to more than a proportional currency depreciation.²⁶

In response to real productivity shocks, the exchange rate jumps to its new equilibrium

²⁵Note that when $mk_T - 2\delta > 0$, the conditions for the existence of multiple steady states derived in the appendix do not hold.

²⁶With financial autarky, in the long run the nominal exchange rate moves one-to-one with relative monetary stances. As all prices are ex-ante flexible, money is neutral: relative wages do not respond to anticipated monetary innovations. Interestingly, then, a permanent monetary expansion depreciates on impact the nominal exchange rate *by more than* its long-run value, generating expectations of appreciation in the future. This result however is not comparable to Dornbusch’s overshooting. Without trade in financial assets uncovered interest parity does not hold. Moreover, by definition of μ , permanent shocks to this variable affect neither Home nor Foreign interest rates.

value:

$$\hat{\mathcal{E}}_t = \frac{\eta}{(1-\delta)(mk_T - 2\delta)} \left[\hat{Z}_{N,t} + \hat{Z}_{H,t} - \hat{Z}_{N,t}^* - \hat{Z}_{F,t} \right]. \quad (43)$$

The response to shocks to the traded and the nontraded sector has the same sign: the nominal exchange rate depreciates with any domestic productivity shock and appreciates with any Foreign shock. Intuitively, a positive shock to productivity in the Home tradable sector leads to a nominal depreciation because such shock reduces the wholesale price of the Home goods in the Foreign market. Although the retail price also falls, raising Foreign demand, the value of exports drops: for a given value of Home imports, balanced trade in equilibrium requires a depreciation of the currency (the less elastic the demand for imports, the larger the rate of depreciation). By the same token, a positive productivity shock to the Home nontradable sector reduces unit distribution costs in the Home market, increasing the price elasticity of Home demand for imports: import prices tend to fall. However, because of falling distribution costs, retail prices fall by more, boosting Home import demand. Thus, the exchange rate must depreciate to ensure a zero trade balance. Note that the size of exchange rate movements in response to productivity shocks is amplified when η and θ are relatively high.²⁷

These results shed light on the effects of productivity shocks on exchange-rate pass-through, discussed in the previous section. In particular, note that under financial autarky, the exchange-rate elasticities to shocks to the traded and the nontraded sector are the same, namely $\xi_{\mathcal{E}_t, Z_{H,t}} = \xi_{\mathcal{E}_t, Z_{N,t}} = -\xi_{\mathcal{E}_t, Z_{F,t}} = \frac{\eta}{(1-\delta)(mk_T - 2\delta)}$. Using expression (24), then, it is easy to verify that for a given size of productivity shocks, pass-through into import prices will be higher when the underlying productivity shock hits domestic nontradables, relative to the case when the shock hits Foreign tradables. Interestingly, however, the response of consumer prices to exchange-rate fluctuations can follow different patterns. From (25) it is apparent that for $\delta_{F,t} \geq 0.5$, pass-through at consumer prices will be lower in response to shocks to $Z_{N,t}$, than to shocks to $Z_{F,t}$.

²⁷When the distribution margin is so high that the economy may exhibit multiple equilibria, the response of the exchange rate to nominal and real shocks may change sign even for equilibria that are in a neighborhood of the symmetric steady state. Clearly, for values of the parameters close to those that make the sign switch, the exchange rate becomes extremely volatile.

Finally, looking at (26), the consumer price index will be more insulated from the exchange rate if nominal depreciations are brought about by shocks to (domestic and foreign) tradables, rather than by nominal shocks and shocks to $Z_{N,t}^*$. The overall effect of exchange-rate fluctuations arising from disturbances to $Z_{N,t}$ is ambiguous and will depend on markups and distribution margins across sectors.

The volatility of nominal and real exchange rates Linearizing the real exchange rate around a symmetric steady state, and focusing on nominal shocks only, we obtain:

$$\left(\frac{\widehat{\mathcal{E}_t P_t^*}}{P_t}\right) = \left[1 - \frac{1 - \delta}{mk_T} \gamma\right] \widehat{\mathcal{E}}_t, \quad (44)$$

where $\widehat{\mathcal{E}}_t$ is given by (42). Since $0 < \gamma < 1$, this expression shows that monetary shocks always move nominal and real exchange rates in the same direction. Thus, an unexpected monetary expansion at home will bring about both a nominal and a real depreciation. However, since the coefficient of $\widehat{\mathcal{E}}_t$ in the above expression is less than one, the nominal exchange rate will move by less.

With respect to shocks to tradables the expression for the real exchange rate is the same as (42), while with respect to shocks to nontraded productivity we have:

$$\left(\frac{\widehat{\mathcal{E}_t P_t^*}}{P_t}\right) = \left[1 - \frac{1 - \delta}{mk_T} \gamma\right] (1 + \widehat{\mathcal{E}}_t), \quad (45)$$

where in both cases $\widehat{\mathcal{E}}_t$ is given by (43). We have seen above that, regardless of the sector in which they occur, domestic productivity shocks always depreciate the domestic currency in nominal terms. It is then apparent from the above expressions that they also depreciate it in real terms. Observe that the real depreciation will be attenuated in the case of shocks to $Z_{H,t}$, relative to the case of shocks to $Z_{N,t}$.²⁸

Exchange rate and terms of trade comovements Consider now the link between nominal exchange rate movements and the terms of trade. Linearizing the latter around a symmetric

²⁸This result runs against the Balassa-Samuelson hypothesis that shocks to tradables should appreciate the real exchange rate via an increase in the relative price of nontradables. However, the Balassa-Samuelson hypothesis assumes away any terms-of-trade effect, positing that tradables are perfect substitute across countries.

steady state, we obtain

$$\frac{\widehat{P_{F,t}}}{\mathcal{E}\widehat{P_{H,t}^*}} = \frac{\left(1 - \frac{\eta}{\theta - 1}\right)\widehat{\mathcal{E}}_t + \left(\widehat{Z_{H,t}} - \widehat{Z_{F,t}^*}\right) - \frac{\eta}{\theta - 1}\left(\widehat{Z_{N,t}} - \widehat{Z_{N,t}^*}\right)}{1 + \frac{\eta}{\theta - 1}}, \quad (46)$$

where $\widehat{\mathcal{E}}_t$ is given by either (42) or (43), depending on the nature of the shock. Under mild conditions on the degree of monopoly power and distribution margins, such that $\eta < \theta - 1$, the coefficient of $\widehat{\mathcal{E}}_t$ in the above expression is positive. Hence, monetary shocks induce a positive correlation between the terms of trade and the exchange rate.

The correlation between the terms of trade and the nominal exchange rate is also positive in the presence of real shocks to productivity in the Home tradable sector. As these shocks unambiguously depreciate the Home currency, they worsen the terms of trade both directly (second term on the right-hand side of the expression above) and through their effect on \mathcal{E} . For this reason, it is possible that shocks to the tradable sector cause the terms of trade to be more volatile than \mathcal{E} .

The correlation between \mathcal{E} and the terms of trade is not necessarily positive, however, when the economy is hit by shocks to productivity to the Home nontradable sector. While unambiguously depreciating the Home currency, these shocks also have a positive effect on the terms of trade. This is because, by reducing the cost of distributive trade in the Home market, they raise the price elasticity of the Home demand for Foreign products, and a higher price elasticity tends to lower the optimal price charged by Foreign wholesalers. Therefore, the volatility of the terms of trade in response to shocks to nontradables tends to be lower than the volatility of \mathcal{E} .

5.4 Numerical examples

To complete the analysis of the international transmission mechanism in our model, we now reconsider the analytical results obtained under the extreme assumption of financial autarky, by carrying out a numerical exercise under the assumption that agents can trade international nominal bonds.²⁹ Specifically, we compute the impact effects of nominal and real shocks, de-

²⁹Corsetti, Dedola and Leduc [2002] carry out extensive quantitative analysis of the model, using more general specifications of preferences and technology. Specifically, that paper focuses on the lack of international risk-

fined as a 1 percent deviation from their initial steady state values, allowing for both permanent and temporary disturbances (lasting only one period).³⁰

In our exercise, we assume that in both countries labor is twice as productive in the tradable sector as in the nontradable sector – namely, we set $\frac{Z_T}{Z_N} = 2$. The values of η and θ are set to 0.625 and 6, such that the distribution margin is 50 percent— a number that is not far from available estimates for the US and other OECD countries (see Burstein, Neves and Rebelo [2001]), and the inverse of the steady state value of the state-contingent markup in (17) is 80 percent — in line with the average exchange-rate pass-through into import prices across OECD countries according to Campa and Goldberg [2003]. In turn, this implies plausible industry markups, varying from 20 percent in the nontradable sector to 50 percent in the tradable sector. Tradables and nontradables are given the same weight in consumption, i.e., $\gamma = 0.5$. Using the conditions derived in the appendix, it can be verified that these parameters values ensure a unique steady state.

The results of our exercise are shown in Table 2, which reports, for each (monetary or real) shock, the percentage changes in the nominal exchange rate, the real exchange rate, and the terms of trade; the exchange-rate pass-through into import prices at both producer and consumer levels; and the exchange rate elasticity of the CPI. Qualitatively, the equilibrium response to shocks in the economies with trade in bonds are in line with our analysis in the previous subsection.

Consider first the response of the nominal exchange rate to monetary shocks. As discussed above, when markets are complete or there are no distribution costs, our specification implies that the nominal exchange rate vary one-to-one with the relative monetary stance. With incomplete markets and distribution costs, instead, the nominal and real exchange rate are more volatile than the underlying shock. As shown in the table, a 1 percent *temporary* increase

sharing as exemplified by the negative correlation of relative consumption and the real exchange rate – the so-called Backus and Smith [1993] anomaly.

³⁰When trade in assets is limited to bonds, it is well known that the effects of shocks on the wealth distribution across countries will generate endogenous dynamics (see Obstfeld and Rogoff [1996], Chapter 10). Thus, we solve for the equilibrium path assuming that after the shock the economy evolves under perfect foresight to its new steady state, characterized by a different world distribution of wealth.

in μ — equivalent to a 1 percentage point drop in the short-term nominal interest rate — depreciates \mathcal{E} by 1.5 percent in the bond economy.³¹ Second, consistent with (43), the effects of innovations to Z_H and Z_N on the nominal and real exchange rate have comparable magnitude. Relative to the case of financial autarky, however, in the bond economy temporary productivity shocks have a much smaller impact than permanent shocks, against which bonds provide no insurance. Finally, nominal and real exchange rates are positively correlated. In all but one case (which is a temporary shock to the nontraded goods sector), a nominal depreciation of the Home currency worsens the domestic terms of trade, raising the possibility of expenditure-switching effects from exchange rate movements.

To appreciate fully our results on exchange-rate pass-through (henceforth ERPT) shown in the bottom half of Table 2, recall that the parameterization of the state-contingent markup roughly implies a 80 percent pass-through into import prices conditional on nominal shocks. A first result highlighted in the table is that pass-through is at most as high as 82 percent, corresponding to shocks to tradables; it is lower for any of the other shocks.³²

Reflecting a low degree of pass-through, our model predicts that, overall, domestic prices move much less than international prices. Following a 1 percent nominal depreciation, ERPT onto consumer import prices is at most one half of ERPT on import prices, while CPI inflation never exceeds 0.12 percent. This is remarkable in an economy with flexible prices: the CPI response is even lower than the average estimates of 0.2 reported by Campa and Goldberg [2003] for OECD countries. For instance, in response to an economy-wide permanent shock to productivity the nominal exchange rate depreciates by more than 11.8 percent but inflation in imports and overall CPI is only 4.1 and 0.3 percent, respectively.

However, the general equilibrium effects on the CPI of exchange-rate fluctuations are by no means obvious, since domestic prices can move by more, or in the opposite direction relative

³¹Under financial autarky, the exchange rate would instead depreciate by 5 per cent, as can be seen by making use of (42). There is a large drop in the exchange rate volatility moving from financial autarky to the bond economy. Under financial autarky, all trade has to be *quid pro quo*. Relative to the bond economy, the Home country must thus export more and import less. But higher net exports in equilibrium require larger movements in the terms of trade and in nominal and real exchange rates.

³²Remarkably, this result would obtain also under a systematic monetary policy that replicates the flexible price allocation, as the one in (38).

to the exchange rate. For instance, nominal shocks and shocks to Z_H , whether or not permanent, all imply essentially the same exchange-rate pass-through into import prices, at both producer level (around 80 percent) and consumer level (around 40 percent). Yet, pass-through on CPI ranges between 12 percent and -32 percent! These numerical results question strong interpretations of empirical estimates of average pass-through: as shown by our model, a fall in domestic prices after an exchange rate depreciation is not necessarily a manifestation of a ‘disconnect’ between the exchange rate and prices.

Finally, the table documents an interesting relation between ERPT into import prices and the exchange-rate response to economy wide productivity shocks (to Z_H and Z_N combined). Both the rate of currency depreciation and pass-through increase sharply when these shocks are permanent, as opposed to temporary. This result implies that, for any given distribution of shocks, pass-through should be increasing in the size of exchange-rate changes. But a positive correlation between the degree of pass-through and the magnitude of exchange-rate movements is also predicted by models viewing incomplete ERPT as an implication of the presence of menu costs. In fact, given menu costs, one may expect the benefits from changing prices to be increasing in the magnitude of exchange rate movements. In our result, however, price rigidities play no role and incomplete ERPT only reflects optimal price discrimination.

In the numerical exercises summarized by table 2, all percentage changes are measured with respect to a symmetric steady state in which the law of one price holds by assumption. Shocks cause deviations from the law of one price, whose relative size can be read from Table 2 as one minus ERPT. Our model however can also account for deviations from the law of one price in steady state, reflecting asymmetries in fundamentals across countries. For instance, suppose that the productivity level in the tradable sector is 25 percent higher in the Home country than in the Foreign country. With the higher supply of Home tradable goods, in steady state the exchange rate and the terms of trade will be substantially weaker than in the previous example. Most important, because of the implications of productivity differentials on the price elasticity of the demand for Home goods, at wholesale level the Home goods will be 13 percent more expensive in the export market than in the domestic market. At consumer level, the deviation from the law of one price will be as high as 35 percent, larger than the productivity differential.

Table 2: Impact Responses of Selected Variables to Nominal and Real Shocks^a
(Percentage deviations from steady-state values and elasticities)

	<i>Monetary Shock</i>	<i>Shock to Tradables</i>		<i>Shock to Nontradables</i>		<i>Economy-wide Shock</i>	
		Temporary	Permanent	Temporary	Permanent	Temporary	Permanent
Nominal exchange rate	1.5%	0.2%	5.9%	0.2%	5.7%	0.4%	11.8%
Real exchange rate	1.2%	0.2%	4.7%	1.0%	5.3%	1.6%	10.2%
Terms of trade	0.9%	1.0%	4.3%	-0.1%	3.2%	0.9%	7.6%
Producer import price	1.2%	0.2%	4.7%	-0.01%	4.3%	0.2%	9.3%
Consumer import price	0.6%	0.1%	2.4%	-0.5%	1.7%	-0.4%	4.1%
CPI	0.2%	-0.1%	0.5%	-0.8%	-0.2%	-0.8%	0.3%
ERPT ξ :							
Producer import price $\xi_{\bar{P}_{f,t},\mathcal{E}_t}$	0.80	0.81	0.82	-0.06	0.76	0.36	0.78
Consumer import price $\xi_{P_{f,t},\mathcal{E}_t}$	0.40	0.41	0.35	-2.20	0.30	-0.99	0.35
CPI ξ_{P_t,\mathcal{E}_t}	0.12	-0.32	0.08	-3.34	-0.03	-1.87	0.02

^aSee the main text for an explanation of the experiments

6 Conclusions

Many recent contributions to the literature stress the importance of placing international price differentials centerstage in open-macro models. In this paper we have shown that, among alternative ways to do so, modelling vertical relationships among firms located in different markets is a promising strategy, as it brings models more closely into line with the reality of large discrepancies in cross-border prices.

In our model, due to the presence of downstream retailers, upstream firms with monopoly power may face different demand elasticities in national markets even under symmetric, constant elasticity preferences across countries. Thus, these firms will optimally charge different prices to domestic and foreign dealers — within the limits dictated by the possibility of international arbitrage between wholesale and retail markets. As a consequence, the law of one price fails to hold at both producer and consumer levels, independently of nominal rigidities. Secondly, as firms optimally adjust markups in the face of demand fluctuations, the response of prices to exchange rate movements is muted at both producer and consumer levels. In general equilibrium, real and monetary shocks will each have a different impact on exchange rate pass-through. Hence, structural interpretations of estimated elasticities call for identifying the sources of exchange-rate and price variability. Third, our model yields the result that a currency depreciation generally worsens the terms of trade. Thus, despite low pass-through the international transmission of monetary shocks can have expenditure-switching effects. Our specification also implies high exchange-rate volatility relative to fundamentals, whereas large changes in the nominal and real exchange rate are associated with small changes in the real allocation and the consumer price level.

Key to our approach is that distributive trade requires local inputs and thus there are vertical interactions among firms across national boundaries. It is worth stressing that vertical interactions are not exclusively due to distributive trade. Realistically, local inputs can be employed in some final stage of manufacturing of the final product at local level, combined with traded intermediate goods. Encompassing both distributive trade and manufacturing at local level, the share of the consumer prices that can be attributed to local costs may actually become quite high, potentially reinforcing many of the novel results of our analysis.

The model in this paper has been purposely kept simple by means of convenient assumptions. For instance, the elasticity of substitution among individual goods (brands) is the same in all sectors, the elasticity of substitution among types of good is set equal to one, and there is no difference between nontraded goods and distribution services. Relaxing these assumptions is a key step to confront the model more directly with the data.

Most crucially, we have assumed the most basic vertical structure: an upstream monopolist sells its product to a perfectly competitive downstream firm (the retailer). In this case, without distortionary taxation at national level, vertical integration would be completely neutral as regards the equilibrium allocation. An important task for future research is to generalize our setup to richer strategic interactions between upstream and downstream firms (e.g., allowing for non-linear pricing, or nominal rigidities in the goods market), thus bringing more insights from trade and industrial organization theory into the construction of open macro models.

References

- [1] Bacchetta, Philippe, and Eric Van Wincoop [2000]. “A Theory of the Price Denomination of International Trade,” mimeo, Studienzentrum Gerzensee and University of Virginia.
- [2] Backus, David K., and Gregor W. Smith, [1993]. “Consumption and Real Exchange Rates in Dynamic Economies with Non-traded Goods,” *Journal of International Economics* 35, 297-316.
- [3] Bergin, Paul R., and Robert C. Feenstra, [2001]. “Pricing-to-market, Staggered Contracts, and Real Exchange Rate Persistence.” *Journal of International Economics* 54, 333-359.
- [4] Betts, Caroline, and Michael B. Devereux [2000]. “Exchange Rate Dynamics in a Model of Pricing-to-Market.” *Journal of International Economics* 50 (1), February, 215-244.
- [5] Burstein, Ariel T., João Neves, and Sergio Rebelo [2001]. “Distribution Costs and Real Exchange Rate Dynamics During Exchange-Rate-Based Stabilizations.” National Bureau of Economic Research Working Paper no. 7862 and *Journal of Monetary Economics*, forthcoming.
- [6] Campa, Josè Manuel and Linda S. Goldberg [2003]. “Decomposing the Exchange Rate Disconnect Puzzle”, mimeo, Federal Reserve Bank of New York.
- [7] Chari, V.V., Patrick Kehoe, and Ellen McGrattan [2000]. “Can Sticky Prices Generate Volatile and Persistent Real Exchange Rates?” Federal Reserve Bank of Minneapolis Staff Report No.277; *Review of Economic Studies*, forthcoming.
- [8] Christiano, Lawrence J., Martin Eichenbaum and Charles Evans [2001]. “Nominal Rigidities and the Dynamic Effects of a Shock to Monetary Policy”, mimeo, Northwestern University.
- [9] Corsetti G., L. Dedola [2002], “Macroeconomics of International Price Discrimination”, European Central Bank Working Paper No. 176.
- [10] Corsetti G., L. Dedola and S. Leduc [2002]. “International Risk Sharing and the Transmission of Productivity Shocks”, working paper, Federal Reserve Bank of Philadelphia.

- [11] Corsetti, Giancarlo, and Paolo Pesenti [2001a]. “Welfare and Macroeconomic Interdependence.” *Quarterly Journal of Economics*, May.
- [12] Corsetti, Giancarlo, and Paolo Pesenti [2001b]. “International Dimensions of Optimal Monetary Policy.” National Bureau of Economic Research Working Paper no. 8230.
- [13] Corsetti, Giancarlo, and Paolo Pesenti [2002]. “Self-validating optimum currency areas.” National Bureau of Economic Research Working Paper no. 8783.
- [14] Devereux, Michael B., and Charles Engel [2000]. “Monetary Policy in the Open Economy Revisited: Price Setting and Exchange Rate Flexibility.” National Bureau of Economic Research Working Paper No. 7665.
- [15] Devereux, Michael B., and Charles Engel [2001]. “Endogenous currency of price setting in a dynamic open economy model”, mimeo, University of British Columbia and University of Wisconsin, June.
- [16] Dornbusch, R. [1989]. “Real Exchange Rates and Macroeconomics: A Selective Survey,” *Scandinavian Journal of Economics* 91, 401-32.
- [17] Engel, Charles [1999]. “Accounting for Real Exchange Rate Changes,” *Journal of Political Economy* 107, 507-38.
- [18] Engel, Charles [2002]. “Expenditure Switching and Exchange-Rate Policy,” in Ben Bernanke and Kenneth Rogoff (eds.), *NBER Macroeconomics Annual 2002*, Cambridge, MA: MIT Press, forthcoming.
- [19] Engel, Charles, and John H. Rogers [1996]. “How Wide is the Border?” *American Economic Review* 86 (5), December, 1112-1125.
- [20] Erceg, Chris, and Andrew Levin [1995]. “Structures and the Dynamic Behavior of the Real Exchange Rate,” mimeo, Board of Governors of the Federal Reserve System.
- [21] Gagnon, Joseph E., and Michael M. Knetter [1995]. “Markup Adjustment and Exchange Rate Fluctuations: Evidence from Panel Data on Automobile Exports,” *Journal of International Money and Finance* 14, 289-310.

- [22] Goldberg, Pinelopi K., and Michael M. Knetter [1997]. “Goods Prices and Exchange Rates: What Have We Learned?” *Journal of Economic Literature* 35, 1243-1272.
- [23] Goldberg, Pinelopi K., and Frank Verboven [2001]. “The Evolution of Price Dispersion in the European Car Market,” *Review of Economic Studies* 68, 811-48.
- [24] Knetter, Michael M. [1989]. “Price Discrimination by U.S. and German Exporters,” *American Economic Review* 79, 198-210.
- [25] Knetter, Michael M. [1993]. “International Comparisons of Price-to-Market Behavior,” *American Economic Review* 83, 473-86.
- [26] Kollman, Robert [1997]. “The Exchange Rate in a Dynamic-Optimizing Current Account Model with Nominal Rigidities: A Quantitative Investigation.”, IMF working paper 97/7.
- [27] Krugman, Paul [1987]. “Pricing to Market When the Exchange Rate Changes,” in *Real-financial linkages among open economies*, Eds.: Sven W. Arndt and J. David Richardson, Cambridge, MA: MIT Press, 49-70.
- [28] Krugman, Paul [1989]. *Exchange Rate Instability*. Cambridge, MA: MIT Press.
- [29] MacDonald, Ronald, and Luca Ricci, [2001]. “PPP and the Balassa-Samuelson Effect: The Role of the Distribution Sector,” mimeo, University of Strathclyde and IMF, February.
- [30] Marston, Richard [1990]. “Pricing to Market in Japanese Manufacturing,” *Journal of International Economics* 29, 217-36.
- [31] McCallum, Bennett, and Edward Nelson [1999]. “Nominal Income Targeting in an Open Economy Optimizing Model,” *Journal of Monetary Economics* 43 (3), 553-578.
- [32] Obstfeld, Maurice, and Kenneth Rogoff [1995]. “Exchange Rate Dynamics Redux.” *Journal of Political Economy* 103, 624-660.
- [33] Obstfeld, Maurice, and Kenneth Rogoff [1996]. *Foundations of International Macroeconomics*. Cambridge, MA: MIT Press.

- [34] Obstfeld, Maurice, and Kenneth Rogoff [2000]. “New Directions for Stochastic Open Economy Models.” *Journal of International Economics* 50 (1), February, pp.117-153.
- [35] Obstfeld, Maurice, and Kenneth Rogoff [2001]. “The Six Major Puzzles in International Macroeconomics: Is There a Common Cause?” in Ben Bernanke and Kenneth Rogoff (eds.), *NBER Macroeconomics Annual 2000*, Cambridge, MA: MIT Press, forthcoming.
- [36] Parsley, David C., and Shang-Jin Wei [2001]. “Explaining the Border Effect: The Role of Exchange Rate Variability, Shipping Costs and Geography,” *Journal of International Economics*, 55 (1), October, 87-105.
- [37] Rogoff, Kenneth [1996], “The Purchasing Power Parity Puzzle,” *Journal of Economic Literature*, 34 (2), June, 647-68.
- [38] Smets, Frank and Raf Wouters [2001]. “Monetary Policy in a Estimated Stochastic General Equilibrium Model for the Euro Area,” *Journal of the European Economic Association*, forthcoming.
- [39] Tirole, Jean [1995]. *The Theory of Industrial Organization*. Cambridge, MA: MIT Press.

A Appendix

A.1 Firms' pricing and the no-arbitrage conditions

This section of the Appendix studies the representative firm's problem under the constraint that prices should not provide opportunities for arbitrage. The (arbitrage-constrained) optimal prices by the representative Home firm is the solution to the following profit maximization problem

$$\text{Max}_{\bar{p}(h), \bar{p}^*(h)} \quad [\bar{p}_t(h)C_t(h) + \mathcal{E}_t \bar{p}_t^*(h)C_t^*(h)] - \frac{W_t}{Z_{H,t}} [C_t(h) + C_t^*(h)]$$

s.t.

$$\begin{aligned} C_t(h) + C_t^*(h) &= [\bar{p}_t(h) + \eta P_{N,t}]^{-\theta} P_{H,t}^\theta C_{H,t} + [\bar{p}_t^*(h) + \eta P_{N,t}^*]^{-\theta} (P_{H,t}^*)^\theta C_{H,t}^* \\ \bar{p}_t(h) + \eta P_{N,t} - \mathcal{E}_t \bar{p}_t^*(h) &\geq 0 \\ \mathcal{E}_t (\bar{p}_t^*(h) + \eta P_{N,t}^*) - \bar{p}_t(h) &\geq 0. \end{aligned}$$

The relevant FOC's for $\bar{p}(h)$ and $\bar{p}^*(h)$ (including the complementary slackness conditions and dropping time subscripts) are, respectively:

$$\begin{aligned} [\bar{p}(h) + \eta P_N]^{-\theta} P_H^\theta C_H \left(1 - \theta \frac{\bar{p}(h)}{\bar{p}(h) + \eta P_N} + \theta \frac{W}{Z_H} \frac{1}{\bar{p}(h) + \eta P_N} \right) + \xi_1 &= \xi_2 \\ [\bar{p}^*(h) + \eta P_N^*]^{-\theta} (P_H^*)^\theta C_H^* \left(1 - \theta \frac{\bar{p}^*(h)}{\bar{p}^*(h) + \eta P_N^*} + \theta \frac{W}{Z_H} \frac{1}{\mathcal{E}(\bar{p}^*(h) + \eta P_N^*)} \right) + \xi_2 &= \xi_1 \end{aligned}$$

$$\begin{aligned} \xi_1 [\bar{p}(h) + \eta P_N - \mathcal{E} \bar{p}^*(h)] &= 0, & \bar{p}(h) + \eta P_N - \mathcal{E} \bar{p}^*(h) &\geq 0, & \xi_1 &\geq 0 \\ \xi_2 [\mathcal{E} (\bar{p}^*(h) + \eta P_N^*) - \bar{p}(h)] &= 0, & \mathcal{E} (\bar{p}^*(h) + \eta P_N^*) - \bar{p}(h) &\geq 0, & \xi_2 &\geq 0. \end{aligned}$$

The optimal prices discussed in the main text are derived for the case in which $\xi_1 = \xi_2 = 0$. An important implication of these prices is that, if the Home monopolist can freely discriminate across national markets, the same is true of the Foreign one. Before proceeding further, note that if $\xi_1 \geq 0$, and $\xi_2 \geq 0$, then it must be that $\eta(P_N + \mathcal{E}P_N^*) = 0$, which can be true only for $\eta = 0$. Obviously, as long as distribution costs are strictly positive, the two constraints cannot be binding at the same time.

Thus, we can characterize optimal price-setting when either condition is binding. Without loss of generality set $\xi_1 \geq 0$ and $\xi_2 = 0$, i.e., $\bar{p}(h) + \eta P_N = \mathcal{E}\bar{p}^*(h)$. The relevant FOC's for $\bar{p}(h)$ and complementary slackness conditions are:

$$\frac{P_H^\theta C_H \left(1 - \theta \frac{\bar{p}(h)}{\bar{p}(h) + \eta P_N} + \theta \frac{W}{Z_H} \frac{1}{\bar{p}(h) + \eta P_N}\right)}{[\bar{p}(h) + \eta P_N]^\theta} = -\xi_1 \leq 0,$$

$$\frac{(\mathcal{E}P_N^*)^\theta C_H^* \left(1 - \theta \frac{\bar{p}(h) + \eta P_N}{\bar{p}(h) + \eta(P_N + \mathcal{E}P_N^*)} + \theta \frac{W}{Z_H} \frac{1}{\bar{p}(h) + \eta(P_N + \mathcal{E}P_N^*)}\right)}{[\bar{p}(h) + \eta(P_N + \mathcal{E}P_N^*)]^\theta} = \xi_1 \geq 0.$$

It follows that, under symmetry, the optimal price \bar{P}_H should satisfy

$$\left(1 + \frac{\eta}{\theta - 1} \frac{Z_H}{Z_N}\right) \frac{W}{Z_H} < \bar{P}_H < \left(1 - \eta \frac{Z_H}{Z_N}\right) \frac{W}{Z_H} + \frac{\eta}{\theta - 1} \frac{\mathcal{E}W^*}{Z_N^*},$$

while solving the following quadratic equation:

$$C_H \frac{\theta \left(1 + \frac{\eta}{\theta - 1} \frac{Z_H}{Z_N}\right) \frac{W}{Z_H} - (\theta - 1) \bar{P}_H}{\bar{P}_H + \eta \frac{\theta}{\theta - 1} \frac{W}{Z_N}} +$$

$$C_H^* \frac{\theta \left[\left(\frac{1}{Z_H} - \frac{\eta}{\theta - 1} \frac{1}{Z_N}\right) W + \frac{\eta}{\theta - 1} \frac{\mathcal{E}W^*}{Z_N^*}\right] - (\theta - 1) \bar{P}_H}{\bar{P}_H + \eta \frac{\theta}{\theta - 1} \left(\frac{W}{Z_N} + \frac{\mathcal{E}W^*}{Z_N^*}\right)} = 0.$$

The optimality condition for \bar{P}_F^* mirrors the above expression.

A.2 Steady state characterization and multiplicity

In this section of the appendix, we show that our economy can have either a unique or three steady states, depending on whether the exchange rate elasticity of Home export expenditure is larger or smaller than the exchange rate elasticity of Home import expenditure, both evaluated at the symmetric equilibrium with $\mathcal{E} = 1$ — a condition reminiscent of the Marshall-Lerner condition.

Consider a deterministic steady state in which external wealth is zero, i.e., $B_H = B_F = 0$, so that the trade balance is zero, and all exogenous variables are set equal to constant values, symmetric across countries. The steady state exchange rate is given by (39).

Proposition 1 *If $\frac{\mu^*}{\mu} = 1$, $\frac{Z_F}{Z_N} = \frac{Z_H}{Z_N^*} = \frac{Z_T}{Z_N}$, and $\frac{\kappa}{\kappa^*} = 1$, there always exists a steady state in which $\frac{W}{W^*} = \frac{\kappa\mu}{\kappa^*\mu^*} = 1$, the nominal exchange rate \mathcal{E} is equal to 1, and the consumption and*

labor allocation as determined by equations (33) and (35) are equal across countries. Moreover, when the exchange-rate elasticity of import expenditure is larger than the exchange-rate elasticity of export expenditure in Home currency, both evaluated at the symmetric equilibrium with $\mathcal{E} = 1$

$$\left[\frac{\partial (\bar{P}_F C_F)}{\partial \mathcal{E}} \frac{\mathcal{E}}{\bar{P}_F C_F} \right]_{\mathcal{E}=1} \geq \left[\frac{\partial (\mathcal{E} \bar{P}_H^* C_H^*)}{\partial \mathcal{E}} \frac{\mathcal{E}}{\mathcal{E} \bar{P}_H^* C_H^*} \right]_{\mathcal{E}=1}, \quad (47)$$

there will be two more steady-state equilibria in which $\frac{W}{W^*} = 1$, but the nominal exchange rate is equal to \mathcal{E}_h and \mathcal{E}_l , respectively, where $\mathcal{E}_h > 1$, and $0 < \mathcal{E}_l < 1$. The consumption and labor allocations, as determined by equations (33) and (35), will differ across countries.

As the proof of this proposition is the same as the proof of multiple temporary equilibria in a version of our economy with balanced trade and flexible wages, in what follows we write variables with time subscripts. Since the trade balance is identically equal to zero in equilibrium, the value of Home exports is equal to the value of Home imports:

$$\mathcal{E}_t \bar{P}_{H,t}^* C_{H,t}^* = \bar{P}_{F,t} C_{F,t},$$

that is

$$\mathcal{E}_t \mu_t^* \frac{\bar{P}_{H,t}^*}{P_{H,t}^*} = \frac{\bar{P}_{F,t}}{P_{F,t}} \mu_t,$$

or, using the expressions for $P_{F,t}$, $\bar{P}_{F,t}$, $P_{H,t}^*$ and $\bar{P}_{H,t}^*$:

$$\mathcal{E}_t \mu_t^* \frac{1 + \frac{\eta}{\theta - 1} \frac{\mathcal{E}_t W_t^*}{W_t} \frac{Z_{H,t}}{Z_{N,t}^*}}{1 + \frac{\eta \theta}{\theta - 1} \frac{\mathcal{E}_t W_t^*}{W_t} \frac{Z_{H,t}}{Z_{N,t}^*}} = \mu_t \frac{\mathcal{E}_t + \frac{\eta}{\theta - 1} \frac{W_t}{W_t^*} \frac{Z_{F,t}}{Z_{N,t}}}{\mathcal{E}_t + \frac{\eta \theta}{\theta - 1} \frac{W_t}{W_t^*} \frac{Z_{F,t}}{Z_{N,t}}}.$$

It is straightforward to verify that, for $\frac{\mu_t}{\mu_t^*} = \frac{W_t}{W_t^*} = 1$ and $\frac{Z_{F,t}}{Z_{N,t}} = \frac{Z_{H,t}}{Z_{N,t}^*}$, the equality above is always satisfied for $\mathcal{E}_t = 1$. This establishes the first part of the proposition.

In order to prove the second part, note that both the left-hand side and the right-hand side of the above expression are nonlinear functions of \mathcal{E}_t . For $\mathcal{E}_t = 0$, the left-hand side term of the above expression is equal to zero, but the right-hand side term is positive and equal to $\mu_t \frac{\eta}{\theta - 1} \frac{W_t}{W_t^*} \frac{Z_{F,t}}{Z_{N,t}} > 0$ (i.e., the value of the Home country imports is above the value of its

exports). Second, for $\mathcal{E}_t \rightarrow \infty$, the left-hand side diverges, while the right hand side converges to μ_t (i.e., Home country net exports are surely positive). Therefore, if the function of \mathcal{E}_t defined by the left-hand side expression cuts the function defined by the right-hand side one at $\mathcal{E}_t = 1$ from above — i.e., the derivative of the first function with respect to \mathcal{E}_t is smaller in absolute value than the derivative of the second function both evaluated at $\mathcal{E}_t = 1$, then the equilibrium condition is satisfied by two more values of the nominal exchange rate, \mathcal{E}_l and \mathcal{E}_h , such that $\mathcal{E}_h > 1 > \mathcal{E}_l > 0$. This proves the second part of our proposition.

Finally, the two derivatives of interest are given by the following expressions:

$$\begin{aligned} & \frac{\partial \left[\frac{\mathcal{E}_t \mu_t^*}{1 + \frac{\eta}{\theta - 1} \frac{\mathcal{E}_t W_t^* Z_{H,t}}{W_t Z_{N,t}^*}} \right]}{\partial \mathcal{E}_t} \\ &= \mu_t^* \frac{1 + 2 \frac{\eta}{\theta - 1} \frac{\mathcal{E}_t W_t^* Z_{H,t}}{W_t Z_{N,t}^*} + \theta \left(\frac{\eta}{\theta - 1} \frac{\mathcal{E}_t W_t^* Z_{H,t}}{W_t Z_{N,t}^*} \right)^2}{\left(1 + \frac{\eta \theta}{\theta - 1} \frac{\mathcal{E}_t W_t^* Z_{H,t}}{W_t Z_{N,t}^*} \right)^2}, \\ & \frac{\partial \left[\frac{\mathcal{E}_t + \frac{\eta}{\theta - 1} \frac{W_t Z_{F,t}}{W_t^* Z_{N,t}}}{\mathcal{E}_t + \frac{\eta \theta}{\theta - 1} \frac{W_t Z_{F,t}}{W_t^* Z_{N,t}}} \right]}{\partial \mathcal{E}_t} \\ &= \mu_t \frac{\eta \frac{W_t Z_{F,t}}{W_t^* Z_{N,t}}}{\left(\mathcal{E}_t + \frac{\eta \theta}{\theta - 1} \frac{W_t Z_{F,t}}{W_t^* Z_{N,t}} \right)^2}. \end{aligned}$$

For $\frac{\mu_t^*}{\mu_t} = 1$ and $\frac{Z_{F,t}}{Z_{N,t}} = \frac{Z_{H,t}}{Z_{N,t}^*} = \frac{Z_{T,t}}{Z_{N,t}}$ a sufficient condition for the existence of multiple equilibria is that

$$\begin{aligned} \eta \frac{Z_{T,t}}{Z_{N,t}} &\geq 1 + 2 \frac{\eta}{\theta - 1} \frac{Z_{T,t}}{Z_{N,t}} + \theta \left(\frac{\eta}{\theta - 1} \frac{Z_{T,t}}{Z_{N,t}} \right)^2 \\ 0 &\geq 1 + \eta \left(\frac{2}{\theta - 1} - 1 \right) \frac{Z_{T,t}}{Z_{N,t}} + \theta \left(\frac{\eta}{\theta - 1} \frac{Z_{T,t}}{Z_{N,t}} \right)^2 \iff \\ (\theta - 1) \frac{(\theta - 3) - \sqrt{\theta^2 - 10\theta + 9}}{2\theta} \frac{Z_{N,t}}{Z_{T,t}} &\leq \eta \leq (\theta - 1) \frac{(\theta - 3) + \sqrt{\theta^2 - 10\theta + 9}}{2\theta} \frac{Z_{N,t}}{Z_{T,t}}. \end{aligned}$$

By way of example, consider the case in which $\theta = 10$ and the productivity level is identical in the two sectors. In this case, the above condition is satisfied by $\frac{9}{5} \leq \eta \leq \frac{9}{2}$.

A.3 Solving the model

The problem of the Home representative consumer The Home agent j chooses a consumption plan, a portfolio plan and a wage rate, such as to maximize utility (3) subject to the budget constraint (7) and total labor demand (68).

The first order conditions of the Home consumer's problem with respect to $C_{H,t}(j)$, $C_{F,t}(j)$, $C_{N,t}(j)$, $B_{H,t+1}(j)$, $B_{F,t+1}$ and $M_t(j)$ are, respectively:

$$\frac{\gamma}{C_{H,t}(j)} = 2\lambda_t(j) P_{H,t} \quad (48)$$

$$\frac{\gamma}{C_{F,t}(j)} = 2\lambda_t(j) P_{F,t} \quad (49)$$

$$\frac{1-\gamma}{C_{N,t}(j)} = \lambda_t(j) P_{N,t} \quad (50)$$

$$\lambda_t(j) = \beta E_t \lambda_{t+1}(j) (1 + i_{t+1}) \quad (51)$$

$$\mathcal{E}_t \lambda_t(j) = \beta E_t \mathcal{E}_{t+1} \lambda_{t+1}(j) (1 + i_{t+1}^*) \quad (52)$$

$$\lambda_t(j) = \beta E_t \lambda_{t+1}(j) + \chi_t \left(\frac{M_t(j)}{P_t} \right)^{-\varepsilon} P_t \quad (53)$$

From these conditions, it is easy to see that, at the optimum, the individual demand for Home, Foreign and non-traded consumption goods is a constant share of total consumption expenditure:

$$P_t C_t(j) = \frac{2}{\gamma} P_{H,t} C_{H,t}(j) = \frac{2}{\gamma} P_{F,t} C_{F,t}(j) = \frac{1}{1-\gamma} P_{N,t} C_{N,t}(j). \quad (54)$$

Using these expressions, it is easy to verify that

$$P_t C_t(j) = P_{H,t} C_{H,t}(j) + P_{F,t} C_{F,t}(j) + P_{N,t} C_{N,t}(j). \quad (55)$$

The intertemporal allocation of consumption is determined according to the Euler equation:

$$\frac{1}{C_t(j)} = \beta (1 + i_{t+1}) E_t \left(\frac{P_t}{P_{t+1}} \frac{1}{C_{t+1}(j)} \right) \quad (56)$$

Finally, condition (53) can be written as the money demand function:

$$\left(\frac{M_t(j)}{P_t} \right)^\varepsilon = \chi_t \frac{1 + i_{t+1}}{i_{t+1}} C_t(j) \quad (57)$$

Define the variable $Q_{t,t+1}(j)$ as:

$$Q_{t,t+1}(j) \equiv \beta \frac{P_t C_t(j)}{P_{t+1} C_{t+1}(j)} \quad (58)$$

which is agent j ' stochastic discount rate. Comparing (58) with (51) and (52), we obtain:

$$E_t Q_{t,t+1}(j) = \frac{1}{1 + i_{t+1}}, \quad E_t \left[Q_{t,t+1}(j) \frac{\mathcal{E}_{t+1}}{\mathcal{E}_t} \right] = \frac{1}{1 + i_{t+1}^*} \quad (59)$$

It follows that the risk-adjusted uncovered interest parity linking domestic and foreign nominal interest rates is:

$$\frac{1 + i_{t+1}}{1 + i_{t+1}^*} = E_t \left(\frac{\mathcal{E}_{t+1}}{P_{t+1} C_{t+1}(j)} \right) \left[E_t \left(\frac{\mathcal{E}_t}{P_{t+1} C_{t+1}(j)} \right) \right]^{-1} \quad (60)$$

Note that, in the absence of uncertainty the previous condition collapses to the familiar expression $1 + i_{t+1} = (1 + i_{t+1}^*) \mathcal{E}_{t+1}/\mathcal{E}_t$.

Using (59) we can write:

$$M_t(j) + B_{H,t+1}(j) = \frac{i_{t+1} M_t(j)}{1 + i_{t+1}} + E_t \{ Q_{t,t+1}(j) [M_t(j) + (1 + i_{t+1}) B_{H,t+1}(j)] \} \quad (61)$$

and:

$$\mathcal{E}_t B_{F,t+1}(j) = E_t \{ Q_{t,t+1}(j) (1 + i_{t+1}^*) \mathcal{E}_{t+1} B_{F,t+1}(j) \} \quad (62)$$

It follows that the flow budget constraint (7) is:

$$\frac{i_{t+1} M_t(j)}{1 + i_{t+1}} + E_t \{ Q_{t,t+1}(j) A_{t+1}(j) \} \leq A_t(j) + R_t(j) - T_t(j) - P_t C_t(j) \quad (63)$$

where A_{t+1} is wealth (net assets) at the beginning of period $t + 1$, defined as:

$$A_{t+1}(j) \equiv M_t(j) + (1 + i_{t+1}) B_{H,t+1}(j) + (1 + i_{t+1}^*) \mathcal{E}_{t+1} B_{F,t+1}(j). \quad (64)$$

Optimization implies that households exhaust their intertemporal budget constraint: the flow budget constraint hold as equality and the transversality condition below is satisfied:

$$\lim_{N \rightarrow \infty} E_t [Q_{t,N}(j)A_N(j)] = 0 \quad (65)$$

where $Q_{t,N} \equiv \prod_{s=t+1}^N Q_{s-1,s}$. If an interior solution exists (as is the case given our parameterization), the resource constraint holds as equality as well. Similar results characterize the optimization problem of Foreign agent j^* .

Wage setting Consider now the problem of choosing an optimal nominal wage rate one period in advance. Let $W(j)$ denote the nominal wage of worker j , and define the Home country wage index W as

$$W_t = \left[\int_0^1 W_t(j)^{1-\phi} dj \right]^{\frac{1}{1-\phi}} \quad (66)$$

The (constant-elasticity) demand for labor input j by the firm n can be expressed as follows

$$L_t(n, j) = \left[\frac{W_t(j)}{W_t} \right]^{-\phi} \frac{Y_t(n)}{Z_{N,t}} \quad (67)$$

Using the fact that ϕ is the same across sectors, the total demand for the labor input supplied by j to all domestic firms is

$$L_t(i, j) = \left[\frac{W_t(j)}{W_t} \right]^{-\phi} \left[\int_{h=0}^1 \frac{Y_t(h)}{Z_{H,t}} dh + \int_{n=0}^1 \frac{Y_t(n)}{Z_{N,t}} dn \right] \quad (68)$$

Workers are assumed to be monopolistic suppliers of a particular type of labor; thus, they take into account the above demand schedule when fixing the nominal wage rate. We posit that the number of workers is large enough so that they ignore the impact of their own pricing decision on the aggregate wage index. As in Obstfeld and Rogoff [2000a], the first order condition for this problem is the expression

$$W_t(j) = \frac{\phi}{\phi - 1} \frac{E_{t-1}(\kappa_t \ell_t(j))}{E_{t-1}\left(\frac{\ell_t(j)}{P_t C_t(j)}\right)} \quad (69)$$

With a competitive labor market, the nominal wage rate equates the disutility of labor to the marginal utility of consumption of an additional unit of nominal revenue. Because of workers'

monopoly power, the wage rate is set with a markup $\phi/(\phi - 1)$ over the expected utility cost of labor effort, expressed in units of domestic currency. Having set the wage rate optimally, workers stand ready to provide any amount of labor to firms at the going rate, as long as the real wage is above the marginal disutility of labor. We restrict the size of shocks in such a way that this will always be the case.

The current account We focus on an equilibrium in which domestic agents are symmetric within a country (although there could be asymmetries across countries). Aggregating the individual budget constraints and using the government budget constraint we obtain an expression for the Home current account:

$$E_t \left\{ Q_{t,t+1} \bar{A}_{t+1} \right\} = \bar{A}_t + R_t - P_t C_t \quad (70)$$

where \bar{A} is defined as wealth net of money balances, or

$$\bar{A}_{t+1} \equiv A_{t+1} - M_t. \quad (71)$$

Now, R_t is defined as:

$$\begin{aligned} R_t &\equiv (\bar{P}_{H,t} + \eta P_{N,t}) C_{H,t} + P_{N,t} C_{N,t} + \mathcal{E}_t \bar{P}_{H,t}^* C_{H,t}^* + \eta P_{N,t} C_{F,t} \\ &= P_t C_t - P_{F,t} C_{F,t} + \mathcal{E}_t P_{H,t}^* C_{H,t}^* + \eta P_{N,t} \frac{P_{F,t}}{P_{F,t}} C_{F,t} - \eta \mathcal{E}_t P_{N,t}^* \frac{P_{H,t}^*}{P_{H,t}^*} C_{H,t}^* \\ &= P_t C_t - \frac{\gamma}{2} P_t C_t + \frac{\gamma}{2} \mathcal{E}_t P_t^* C_t^* + \eta \frac{\gamma}{2} \frac{P_{N,t}}{P_{F,t}} P_t C_t - \eta \frac{\gamma}{2} \frac{P_{N,t}^*}{P_{H,t}^*} \mathcal{E}_t P_t^* C_t^* \\ &= P_t C_t \left(1 - \frac{\gamma}{2} + \frac{\gamma}{2} \eta \frac{P_{N,t}}{P_{F,t}} \right) + \frac{\gamma}{2} \mathcal{E}_t P_t^* C_t^* \left(1 - \eta \frac{P_{N,t}^*}{P_{H,t}^*} \right) \end{aligned}$$

Thus the Home current account becomes

$$E_t \left\{ Q_{t,t+1} \bar{A}_{t+1} \right\} = \bar{A}_t - \frac{\gamma}{2} \mu_t \left(1 - \eta \frac{P_{N,t}}{P_{F,t}} \right) + \frac{\gamma}{2} \mathcal{E}_t \mu_t^* \left(1 - \eta \frac{P_{N,t}^*}{P_{H,t}^*} \right)$$

Clearly, in equilibrium $\bar{A}_t = -\mathcal{E}_t \bar{A}_t^*$, for all t .