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# A macroeconomic model of international price discrimination

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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, making the price elasticity of demand country-specific and a function of the exchange rate. Profit-maximizing monopolistic firms drive a wedge between prices across countries, optimally dampening the response of import and consumer prices to exchange-rate movements. We derive general equilibrium expressions for the pass-through into import and consumer prices, tracing the differential impact of real and monetary shocks on marginal cost and markup fluctuations through the exchange rate.


*Keywords:* Exchange-rate pass-through; Deviations from the law of one price; International transmission; Distribution services; New open-macro macroeconomics

*JEL classification:* F3; F4

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## 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 goods–market arbitrage is quick and effective in eliminating international price discrepancies for most types of tradable goods and services.[1] In particular, 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, not only in the short run.[2] On the one hand, incomplete exchange rate pass-through is due to destination-specific markup adjustment by firms—which is possible because of market segmentation and may reflect 'pricing-to-market' (henceforth PTM) by firms.[3] With PTM, high exchange rate volatility implies that buyers across national markets face systematic differences in the prices of identical goods—when expressed in the same currency.[4] On the other hand, differences in consumer prices are also due to local currency price stability resulting from the presence of local components in marginal costs, particularly distribution services, which are known to be a significant portion of the retail price of tradables.

This paper introduces endogenous PTM and incomplete pass-through into a general equilibrium open-economy model. To facilitate comparison with the literature, we build on the analytical framework of Corsetti and Pesenti (2001a,b) and Obstfeld and Rogoff (1996, 2000). In our model, upstream firms with monopoly power sell tradables to competitive retailers situated in different locations. Because of local-input-intensive distribution services, the elasticity of demand differs across markets for the same good. This way of modelling vertical interaction among firms located in different markets yields several novel results, helping to qualitatively reconcile theoretical predictions with key stylized facts of the international economy.

First, deviations from the law of one price at both wholesale and retail level in our model derive *endogenously* from optimal pricing by monopolistic firms. 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

[1] See Rogoff (1996) for an excellent survey on the evidence of 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)).

[2] According 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 after 1 year; for other industrialized countries this fraction appears to be somewhat higher, but lower than 1 (e.g., see Campa and Goldberg (2004)).

[3] Krugman (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%. Similar findings are in Knetter (1989, 1993) and Gagnon and Knetter (1995), for Germany and the US.

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

is incomplete—its degree depending on the type of shocks hitting the economy. 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. However, as firms optimally insulate local prices from exchange rate movements, the exchange rate may have a lesser impact on the relative prices of domestic and foreign goods, in relation to what is implied by the received view. This is consistent with the reasoning in Krugman (1989), that in the presence of deviations from the law of one price and incomplete pass-through, large swings in the exchange rate may be required to bring about quantity adjustment. Indeed, in our model large movements in the nominal and real exchange rates translate into small changes in consumption, employment and price levels in equilibrium. Furthermore, nominal and real exchange rates, positively correlated, are generally more volatile than fundamentals.

A specific contribution of this paper is to marry the insights from the literature on PTM in international trade with open economy macroeconomic models. We derive general equilibrium expressions for the exchange rate pass-through into import and consumer prices, tracing the differential impact of real and monetary shocks on marginal cost and markup fluctuations through their impact on the exchange rate. Our analysis therefore addresses a crucial limitation of partial equilibrium studies of exchange rate pass-through into prices, namely, the fact that nominal and real exchange rate movements are treated as exogenous to firms' marginal cost and revenue.

There are several qualified empirical studies that present estimates of exchange rate pass-through coefficients, attempting to control for costs and markups. A recent example is the study by Campa and Goldberg (2004), according to which the average exchange rate pass-through into import prices across OECD countries is of the order of 80% over a 1-year horizon. While our analysis can rationalize these findings, spelling out conditions under which the maintained assumptions underlying the empirical model are valid in general equilibrium, it also shows that an assessment of movements in the import prices or CPI associated to exchange rate fluctuations is by no means trivial. Shocks may move import and consumer prices differently, even in opposite directions, with respect to the exchange rate. This should suggest caution in attributing structural interpretations to low pass-through estimates, say, as an indicator of 'exchange rate disconnect' of prices, or in using the coefficients from pass-through regressions to predict the inflationary consequences of particular episodes of exchange rate variability.

Our model is in the tradition of the international macroeconomics literature pointing to distribution services as a key reason for the failure of Purchasing Power Parity (henceforth PPP).[5] Dornbusch (1989), for 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, advertising and local transportation, the average

[5] Recent 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 surveyed in Anderson and van Wincoop (2004) on barriers to trade.

distribution margin is as high as 55% (see Anderson and van Wincoop (2004) and Burstein et al. (2003a,b)).

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, without however deriving any implication for import prices.[6] Relative to this literature, we take a step further by modelling market segmentation resulting from vertical interactions between monopolistic producers and retailers, to analyze the implications of distributive trade on the degree of exchange rate pass-through into import prices. We are motivated by the strong evidence of the importance of distribution services and price discrimination in accounting for local currency price stability—such as the one presented by Goldberg and Verboven (2001). Based on comprehensive and detailed data of automobile retail prices in five European countries, these authors show that a 1% change in the nominal exchange rate induces a 0.46% adjustment in the export prices in exporter currency, equivalent to a 0.54 pass-through. They attribute a pass-through between 0.37 and 0.39% to local cost (i.e., nominal wages) in the destination country, while markup adjustment accounts for the rest.

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.[7] They buy tradable goods and distribute them to consumers using nontraded goods as the only input in production.

[6] Burstein et al. (2003a,b) assume that distribution requires local inputs, focusing on the case of perfect competition in the goods market.

[7] Due 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, all goods prices are flexible. Nonetheless, we allow for nominal rigidities by assuming that workers and firms agree on the nominal wage rate one period in advance.[8] In what follows, we describe our setup 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.

### 2.1. 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 is, respectively:

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

where $\phi$ 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 $\phi$, 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 Burstein et al. (2003a,b), we thus assume that bringing one unit of traded goods to consumers requires $\eta$ units of a basket of differentiated nontraded goods

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

We note here that the Dixit–Stiglitz index (with identical elasticities) above also applies to the consumption of differentiated nontraded goods, specified in the next subsection. In equilibrium, then, the basket of 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.[9]

[8] Christiano et al. (2001) and Smets and Wouters (2003) 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 as in the above contributions.

[9] For 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 nontraded good market, as these can be accounted for by varying the level of productivity in the nontradable sector.

### 2.2. Preferences

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

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

where $\beta<1$ is the discount factor 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:

$$C_{\mathrm{H},t}(j) \equiv \left[\int_0^1 C_t(h,j)^{\frac{\theta-1}{\theta}} dh\right]^{\frac{\theta}{\theta-1}}, \quad C_{\mathrm{F},t}(j) \equiv \left[\int_0^1 C_t(f,j)^{\frac{\theta-1}{\theta}} df\right]^{\frac{\theta}{\theta-1}},$$

$$C_{\mathrm{N},t}(j) \equiv \left[\int_0^1 C_t(n,j)^{\frac{\theta-1}{\theta}} dn\right]^{\frac{\theta}{\theta-1}}.$$

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

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

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

As in Corsetti and Pesenti (2001a), the parameters describing consumption preferences are the same in the Home and Foreign country.

### 2.3. 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:

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

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

$$P_{\mathrm{T},t} = P_{\mathrm{H},t}^{1/2} P_{\mathrm{F},t}^{1/2}, \quad P^*_{\mathrm{T},t} = \left(P^*_{\mathrm{H},t}\right)^{1/2}\left(P^*_{\mathrm{F},t}\right)^{1/2}$$

$$P_t = P_{\mathrm{T},t}^{\gamma} P_{\mathrm{N},t}^{1-\gamma}, \quad P^*_t = \left(P^*_{\mathrm{T},t}\right)^{\gamma}\left(P^*_{\mathrm{N},t}\right)^{1-\gamma}.$$

## 2.4. Household budget constraints and asset markets

Home agents hold Home currency $M$, two international bonds, $B_{\mathrm{H}}$ and $B_{\mathrm{F}}$, 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:[10]

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

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 $t$ 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 $B_{\mathrm{H},t} = -B^*_{\mathrm{H},t}$ and $B_{\mathrm{F},t} = -B^*_{\mathrm{F},t}$.

## 2.5. 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

[10] The 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 $B_{\mathrm{H},t}(j)$ and $B_{\mathrm{F},t}(j)$ denote agent $j$'s bonds accumulated during period $t-1$ and carried over into period $t$.

$\mu_t \equiv P_t C_t$. Using this variable, we can write the optimality conditions of the representative households as follows

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

$$M_t = \chi_t \frac{1 + i_{t+1}}{i_{t+1}} \mu_t. \tag{10}$$

These expressions imply that a given time path of $\mu_t$ can always be achieved with a corresponding sequence of the Home money stock. Namely, a temporary Home monetary easing at time $t$, associated with a higher $\mu_t$, corresponds to a higher $M_t$ and a lower interest rate $i_{t+1}$.

## 3. An optimizing model of pricing-to-market

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 local nontraded goods implies that the elasticity of demand for the $h$ ($f$) brand at wholesale level is 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.

### 3.1. Firms' optimization and optimal price discrimination

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

$$C(n) + \eta(n) = [p_t(n)]^{-\theta} P_{\mathrm{N},t}^{\theta}\left[C_{N,t} + \eta\left(\int_0^1 C_t(h)dh + \int_0^1 C_t(f)df\right)\right]. \tag{11}$$

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

$$p_t(n) = P_{\mathrm{N},t} = \frac{\theta}{\theta - 1}\frac{W_t}{Z_{\mathrm{N},t}}. \tag{12}$$

Note that nominal wage rigidities do not translate into price rigidities: the price of the nontraded 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

$$p_t(h) = \bar{p}_t(h) + \eta P_{\mathrm{N},t}. \tag{13}$$

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:

$$\text{Max}_{\bar{p}(h),\bar{p}^*(h)}\left[\bar{p}_t(h)C_t(h)+\mathcal{E}_t\bar{p}_t^*(h)C_t^*(h)\right]-\frac{W_t}{Z_{\text{H},t}}\left[C_t(h)+C_t^*(h)\right] \tag{14}$$

where

$$C_t(h)=\left(\frac{\bar{p}_t(h)+\eta P_{\text{N},t}}{P_{\text{H},t}}\right)^{-\theta}C_{\text{H},t},\quad C_t^*(h)=\left(\frac{\bar{p}_t^*(h)+\eta P_{\text{N},t}^*}{P_{\text{H},t}^*}\right)^{-\theta}C_{\text{H},t}^*. \tag{15}$$

Making use of Eq. (12), the optimal wholesale prices $\bar{p}(h)$ and $\bar{p}^*(h)$ are:

$$\bar{p}_t(h)=\frac{\theta}{\theta-1}\left(1+\frac{\eta}{\theta-1}\frac{Z_{\text{H},t}}{Z_{\text{N},t}}\right)\frac{W_t}{Z_{\text{H},t}}, \tag{16}$$

$$\mathcal{E}_t\bar{p}_t^*(h)=\frac{\theta}{\theta-1}\left(1+\frac{\eta}{\theta-1}\frac{\mathcal{E}_tW_t^*}{W_t}\frac{Z_{\text{H},t}}{Z_{\text{N},t}^*}\right)\frac{W_t}{Z_{\text{H},t}}. \tag{17}$$

Unlike the case of nontraded goods (12), 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 $mk_{\text{H},t}$ and $mk_{\text{H}*,t}$ denote the state contingent component of markups:

$$mk_{\text{H},t}=1+\frac{\eta}{\theta-1}\frac{Z_{\text{H},t}}{Z_{\text{N},t}}, \tag{18}$$

$$mk_{\text{H}^*,t}=1+\frac{\eta}{\theta-1}\frac{\mathcal{E}_tW_t^*}{W_t}\frac{Z_{\text{H},t}}{Z_{\text{N},t}^*}. \tag{19}$$

Since in general $mk_{\text{H},t}$ will not equal to $mk_{\text{H}*,t}$, the optimal wholesale price of tradable goods will not obey the law of one price $\left(\bar{p}_t(h)\neq\mathcal{E}_t\bar{p}_t^*(h)\right)$. 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:

$$\xi_{C_t(h),\bar{p}_t(h)}\equiv-\frac{\partial C_t(h)}{\partial\bar{p}_t(h)}\frac{\bar{p}_t(h)}{C_t(h)}=\theta\frac{\bar{p}_t(h)}{\bar{p}_t(h)+\eta P_{\text{N},t}}=\theta\frac{1+\frac{\eta}{\theta-1}\frac{Z_{\text{H},t}}{Z_{\text{N},t}}}{1+\eta\frac{\theta}{\theta-1}\frac{Z_{\text{H},t}}{Z_{\text{N},t}}}. \tag{20}$$

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:

$$\xi_{C_t^*(h),\bar{p}_t^*(h)}\equiv-\frac{\partial C_t^*(h)}{\partial\bar{p}_t^*(h)}\frac{\bar{p}_t^*(h)}{C_t^*(h)}=\theta\frac{\bar{p}_t^*(h)}{\bar{p}_t^*(h)+\eta P_{\text{N},t}^*}=\theta\frac{1+\frac{\eta}{\theta-1}\frac{\mathcal{E}_tW_t^*}{W_t}\frac{Z_{\text{H},t}}{Z_{\text{N},t}^*}}{1+\eta\frac{\theta}{\theta-1}\frac{\mathcal{E}_tW_t^*}{W_t}\frac{Z_{\text{H},t}}{Z_{\text{N},t}^*}}. \tag{21}$$

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.

The expression (21) emphasizes two important properties of our model, characterizing the price elasticity of export demand. First, $\xi_{C_t^*(h),\bar{p}_t^*(h)}$ 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, it is increasing in the wholesale price—as shown by the PTM literature (e.g., see Marston, 1990), this is a sufficient condition for incomplete exchange rate pass-through (we will discuss this topic in detail below).

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

$$\xi_{C_t(h),\bar{p}_t(h)} = \theta\left(1 - \frac{\eta P_{\mathrm{N},t}}{p_t(h)}\right) = \theta(1 - \delta_t(h)),$$

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

The demand elasticities to the wholesale prices are monotonic functions of the distribution margins: distributive trade lowers price elasticities below the constant preference parameter $\theta$.

## 3.2. On the role of arbitrage across national markets

As in most open macro models with monopolistic competition, we also assume that firms have the power to segment markets across national borders—ruling out arbitrage across wholesale markets.[11] Yet, there is no reason to exclude the possibility that domestic retailers buy goods from foreign retailers, rather than from monopolistic producers in the wholesale market. In the previous section we derived the optimal prices (16) and (17) disregarding this possibility. Here we study the extent to which arbitrage between the retail and the wholesale market may prevent optimal price discrimination between domestic and foreign dealers.

Consider the consumer price of the good $h$ in both markets, which can be calculated adding the distribution costs ($\eta P_{\mathrm{N}}$ and $\eta^* P_{\mathrm{N}}^*$) to the optimal producer prices derived above:

$$p_t(h) = \frac{\theta}{\theta - 1}\left(1 + \frac{\eta}{\theta - 1}\frac{Z_{\mathrm{H},t}}{Z_{\mathrm{N},t}}\right)\frac{W_t}{Z_{\mathrm{H},t}} + \eta\frac{\theta}{\theta - 1}\frac{W_t}{Z_{\mathrm{N},t}}, \tag{22}$$

$$\mathcal{E}_t p_t^*(h) = \frac{\theta}{\theta - 1}\left(1 + \frac{\eta}{\theta - 1}\frac{\mathcal{E}_t W_t^*}{W_t}\frac{Z_{\mathrm{H},t}}{Z_{\mathrm{N},t}^*}\right)\frac{W_t}{Z_{\mathrm{H},t}} + \eta\frac{\theta}{\theta - 1}\frac{\mathcal{E}_t W_t^*}{Z_{\mathrm{N},t}^*}. \tag{23}$$

[11] 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 sets 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:

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

$$p_t(h) = \bar{p}_t(h) + \eta P_{\mathrm{N},t} \geq \mathcal{E}_t \bar{p}_t^*(h).$$

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

$$\frac{1}{\theta} \leq \frac{\mathcal{E}_t W_t^*}{W_t} \frac{Z_{\mathrm{N},t}}{Z_{\mathrm{N},t}^*} \leq \theta. \tag{24}$$

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 foreign wholesale price and the domestic price equal to each other: $\mathcal{E}_t \bar{p}_t^*(h) = p_t(h)$. 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 $\bar{p}_t(h) = \mathcal{E}_t p_t^*(h)$.[12]

Without presenting a formal derivation of optimal prices subject to the no-arbitrage condition (24) (discussed in detail by Corsetti and Dedola (2002)), 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 (16) and (17), Home firms will now raise $\bar{p}_t(h)$ above (16) while lowering $\bar{p}_t^*(h)$ below (17). 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.[13]

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 Eq. (13) would be multiplied by the constant $\theta/(\theta-1)$. Thus, double marginalization would influence the level of consumer prices (both Eqs. (22) and (23) would be multiplied by $\theta/(\theta-1)$, but not their wholesale counterpart (16) and (17). For this reason, the equilibrium response of prices to nominal

[12] Conditions (24) are symmetric: a relatively higher $\mathcal{E}_t$ constraining Foreign wholesale prices by the Home firms, simultaneously requires Foreign firms to set $\bar{p}_t^*(f) = p_t(f)/\mathcal{E}_t$.

[13] It is easy to verify that, holding Eq. (14), 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.

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. Equilibrium exchange rate determination

Distribution services play a key role in differentiating our results relative to other models in the literature. We have already shown above that distribution services can generate deviations from the law of one price and make price elasticities non-linear functions of the exchange rate. In what follows we focus on the link between distributive trade and the price elasticity of goods demand. We show that this link makes our framework qualitatively consistent with other stylized facts of the international economy supported by a large body of empirical evidence, but difficult to incorporate in standard models (e.g., Obstfeld and Rogoff (1996, 2000), Corsetti and Pesenti (2001a), and Devereux and Engel (2003)). Namely, once we endogenize exchange rate determination, our model predicts that in general equilibrium the exchange rate tends to move more than the underlying economic fundamentals; second, nominal and real exchange rates are positively correlated; third, nominal depreciations tend to worsen the terms of trade.

### *4.1. Characterizing the model solution*

From now on, we focus on symmetric equilibria within a country (though not necessarily symmetric across countries). Thus, we will write prices with country-specific, rather than firm-specific indexes, e.g., $\bar{P}_{F,t}$ rather than $\bar{p}_t(f)$, dropping the indices $j$ and $j^*$ and interpreting all variables in per-capita (or aggregate) terms. The world equilibrium is characterized as follows. Given the stochastic processes driving monetary stances ($\mu_t$ and $\mu_t^*$) and the shocks to productivity and preferences (all the $Z$'s, $\chi_t$, $\chi_t^*$, $\kappa_t$ and $\kappa_t^*$), 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 ($\ell_t^*$, $C_{H,t}$, $C_{F,t}$, $C_{N,t}$, $M_{t+1}$, $B_{H,t+1}$, $B_{F,t+1}$, $\bar{P}_{H,t}$, $\bar{P}_{H,t}^*$, $P_{N,t}$ and $W_t$) and their Foreign counterparts ($\ell_t^*$, $C_{H,t}^*$, $C_{F,t}^*$, $C_{N,t}^*$, $M_{t+1}^*$, $B_{H,t+1}^*$, $B_{F,t+1}^*$, $\bar{P}_{F,t}^*$, $\bar{P}_{F,t}$, $P_{N,t}^*$ 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 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.,

$$\bar{A}_{t+1} \equiv (1 + i_{t+1}) B_{H,t+1} + \left(1 + i_{t+1}^*\right) \mathcal{E}_{t+1} B_{F,t+1}; \tag{25}$$

$\bar{A}^*$ is similarly defined. Expression (36) states the risk-adjusted uncovered interest parity conditions, where we have used the fact that in equilibrium $\mu_t = P_t C_t$ and $\mu_t^* = P_t^* C_t^*$. Eq. (37) is the bond market-clearing equation, while Eq. (38) is the current account. These three equations simultaneously determine the nominal exchange rate and external

Table 1
Equilibrium characterization

$$\mathcal{E}_t = \frac{\mu_t}{\mu_t^*}\,\frac{E_t\left(\frac{1}{\mu_{t+1}}\right)}{E_t\left(\frac{1}{\mathcal{E}_{t+1}\mu_{t+1}^*}\right)} = \frac{\mu_t}{\mu_t^*} \times \frac{E_t\left(\frac{\mathcal{E}_{t+1}}{\mu_{t+1}}\right)}{E_t\left(\frac{1}{\mu_{t+1}^*}\right)} \tag{36}$$

$$\bar{A}_t = -\mathcal{E}_t \bar{A}_t^* \tag{37}$$

$$E_t\left\{\frac{\beta\mu_t}{\mu_{t+1}}\bar{A}_{t+1}\right\} = \bar{A}_t - \frac{\gamma}{2}\left[\mu_t\,\frac{1+\frac{\eta}{\theta-1}\frac{W_t}{\mathcal{E}_tW_t^*}\frac{Z_{\mathrm{F},t}}{Z_{\mathrm{N},t}}}{1+\frac{\eta\theta}{\theta-1}\frac{W_t}{\mathcal{E}_tW_t^*}\frac{Z_{\mathrm{F},t}}{Z_{\mathrm{N},t}}} - \mathcal{E}_t\mu_t^*\,\frac{1+\frac{\eta}{\theta-1}\frac{\mathcal{E}_tW_t^*}{W_t}\frac{Z_{\mathrm{H},t}}{Z^*_{\mathrm{N},t}}}{1+\frac{\eta\theta}{\theta-1}\frac{\mathcal{E}_tW_t^*}{W_t}\frac{Z_{\mathrm{H},t}}{Z^*_{\mathrm{N},t}}}\right] \tag{38}$$

$$\ell_t = \frac{\theta-1}{\theta}\,\frac{\mu_t}{W_t}\left[1+\frac{\frac{\gamma}{2}\mathcal{E}_t\mu_t^*/\mu_t}{1+\frac{\eta\theta}{\theta-1}\frac{\mathcal{E}_tW_t^*}{W_t}\frac{Z_{\mathrm{H},t}}{Z^*_{\mathrm{N},t}}} + \frac{\frac{\gamma}{2}\eta}{\frac{\eta\theta}{\theta-1}+\frac{\mathcal{E}_tW_t^*}{W_t}\frac{Z_{\mathrm{N},t}}{Z_{\mathrm{F},t}}} - \frac{\gamma}{2}\,\frac{1+\eta\frac{\theta+1}{\theta-1}\frac{Z_{\mathrm{H},t}}{Z_{\mathrm{N},t}}}{1+\frac{\eta\theta}{\theta-1}\frac{Z_{\mathrm{H},t}}{Z_{\mathrm{N},t}}}\right] \tag{39}$$

$$\ell_t^* = \frac{\theta-1}{\theta}\,\frac{\mu_t^*}{W_t^*}\left[1+\frac{\frac{\gamma}{2}\mu_t/\mathcal{E}_t\mu_t^*}{1+\frac{\eta\theta}{\theta-1}\frac{W_t}{\mathcal{E}_tW_t^*}\frac{Z_{\mathrm{F},t}}{Z_{\mathrm{N},t}}} + \frac{\frac{\gamma}{2}\eta}{\frac{\eta\theta}{\theta-1}+\frac{W_t}{\mathcal{E}_tW_t^*}\frac{Z^*_{\mathrm{N},t}}{Z_{\mathrm{H},t}}} - \frac{\gamma}{2}\,\frac{1+\eta\frac{\theta+1}{\theta-1}\frac{Z_{\mathrm{F},t}}{Z^*_{\mathrm{N},t}}}{1+\frac{\eta\theta}{\theta-1}\frac{Z_{\mathrm{F},t}}{Z^*_{\mathrm{N},t}}}\right] \tag{40}$$

$$C_t = \frac{\theta-1}{\theta}\,\frac{\mu_t}{W_t}\left(Z_{\mathrm{N},t}\right)\left(\frac{Z_{\mathrm{N},t}}{Z_{\mathrm{H},t}}+\frac{\eta\theta}{\theta-1}\right)^{-\frac{\gamma}{2}}\left(\frac{Z_{\mathrm{N},t}}{Z_{\mathrm{F},t}}\,\frac{\mathcal{E}_tW_t^*}{W_t}+\frac{\eta\theta}{\theta-1}\right)^{-\frac{\gamma}{2}} \tag{41}$$

$$C_t^* = \frac{\theta-1}{\theta}\,\frac{\mu_t^*}{W_t^*}\left(Z^*_{\mathrm{N},t}\right)\left(\frac{Z^*_{\mathrm{N},t}}{Z_{\mathrm{F},t}}+\frac{\eta\theta}{\theta-1}\right)^{-\frac{\gamma}{2}}\left(\frac{Z^*_{\mathrm{N},t}}{Z_{\mathrm{H},t}}\,\frac{W_t}{\mathcal{E}_tW_t^*}+\frac{\eta\theta}{\theta-1}\right)^{-\frac{\gamma}{2}} \tag{42}$$

$$W_t = \frac{\phi}{\phi-1}\,\frac{E_{t-1}\kappa_t\ell_t}{E_{t-1}\left(\frac{\ell_t}{\mu_t}\right)} \tag{43}$$

borrowing. Employment and consumption in both countries (corresponding to the expressions (39), (40), (41) and (42)) can then be derived as a function of exogenous shocks, wages and the nominal exchange rate. In each country, the nominal wage rate (43) (or Eq. (44)) is preset given the joint distribution of employment, $\kappa_t$ (or $\kappa_t^*$) and domestic monetary shocks.

In our model the real exchange rate can be broken down as follows:

$$\begin{aligned}\frac{\mathcal{E}_tP_t^*}{P_t} &= \left(\frac{\mathcal{E}_tP^*_{\mathrm{T},t}}{P_{\mathrm{T},t}}\right)\left(\frac{P^*_{\mathrm{N},t}}{P^*_{\mathrm{T},t}}\,\frac{P_{\mathrm{T},t}}{P_{\mathrm{N},t}}\right)^{1-\gamma} \\ &= \left[\left(\frac{\mathcal{E}_tP^*_{\mathrm{H},t}}{P_{\mathrm{H},t}}\right)\left(\frac{\mathcal{E}_tP^*_{\mathrm{F},t}}{P_{\mathrm{F},t}}\right)\right]^{\frac{1}{2}}\left(\frac{P^*_{\mathrm{N},t}}{P^*_{\mathrm{T},t}}\,\frac{P_{\mathrm{T},t}}{P_{\mathrm{N},t}}\right)^{1-\gamma}.\end{aligned} \tag{26}$$

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.[14] This is in sharp contrast to 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. 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).

As shown by Corsetti and Dedola (2002), our economy can have multiple non-stochastic steady states, for (perhaps too) large values of the distribution margin. Specifically, the steady state can be characterized by either one or three equilibrium allocations. In this paper we abstract from steady-state multiplicity by restricting the parameters' values to the region where the equilibrium is unique—leaving a detailed analysis of this issue to future research. Nevertheless, it is worth mentioning the result that with multiplicity of equilibria, identical fundamentals may correspond to vastly different equilibrium values for the exchange rate and the terms of trade—yet because of distributive trade and its implications for price elasticities, differences in the price level, consumption and employment would be much smaller.[15]

### 4.2. Exchange rates and international prices

If we let agents trade a full set of contingent nominal bonds, i.e., claims to one unit of currency in each state of nature, it can be easily shown that in our specification the exchange rate would be determined exclusively by monetary factors:

$$\mathcal{E}_t = \frac{\mu_t}{\mu_t^*}. \tag{27}$$

Notably, this is also the characterization of the equilibrium exchange rate in our model with incomplete asset markets, in the limiting case when $\eta \to 0$ and the initial net foreign asset position is zero. In this limiting case, our specification becomes similar to Corsetti and Pesenti (2001a) and Obstfeld and Rogoff (2000). In other words, if either asset markets are complete, or there are no distribution costs (and no initial foreign wealth), 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 $\mu_t/\mu_t^*$, and not directly.

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

[15] In Corsetti and Dedola (2002) we analyze a numerical example in which, relative to the perfectly symmetric steady state, there is a second steady state in which the Home nominal and real exchange rates are 41 and 36% stronger, respectively, while the Home terms of trade are 28% higher (see the working paper version for the assumed parameter values). Yet, because of distributive trade, aggregate consumption and employment are relatively unaffected—both are less than 1% higher relative to their values in the symmetric equilibrium. Despite the extremely large differences in the exchange rate and relative wages, the Home price level is only 3% lower.

Second, the volatility of the nominal exchange rate would coincide with that of monetary factors—so that the model could not generate any excess volatility.

Our framework with distributive trade and incomplete asset markets allows for a richer set of factors driving the exchange rate, and therefore yields a richer set of results. To see this, consider a world economy under the assumption of financial autarky—i.e., with no international trade in financial assets. Under this assumption, the exchange rate is implicitly determined by the balanced trade condition ($\mathcal{E}_t \bar{P}^*_{\mathrm{H},t} C^*_{\mathrm{H},t} = \bar{P}_{\mathrm{F},t} C_{\mathrm{F},t}$) as a non-linear function of relative monetary policy stance $\mu/\mu^*$ and relative productivity:

$$\mathcal{E}_t \mu_t^* \frac{1 + \dfrac{\eta}{\theta - 1} \dfrac{\mathcal{E}_t W_t^*}{W_t} \dfrac{Z_{\mathrm{H},t}}{Z^*_{\mathrm{N},t}}}{1 + \dfrac{\eta\theta}{\theta - 1} \dfrac{\mathcal{E}_t W_t^*}{W_t} \dfrac{Z_{\mathrm{H},t}}{Z^*_{\mathrm{N},t}}} = \mu_t \frac{\mathcal{E}_t + \dfrac{\eta}{\theta - 1} \dfrac{W_t}{W_t^*} \dfrac{Z_{\mathrm{F},t}}{Z_{\mathrm{N},t}}}{\mathcal{E}_t + \dfrac{\eta\theta}{\theta - 1} \dfrac{W_t}{W_t^*} \dfrac{Z_{\mathrm{F},t}}{Z_{\mathrm{N},t}}}. \tag{28}$$

The exchange rate therefore depends not only on the relative monetary stance $\mu_t/\mu_t^*$, but also on the ratio of import wholesale and consumer prices at Home and abroad.

As regards the volatility of international prices, note that the Home demand for imports can be written as:

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

hence the elasticity of the import demand with respect to the wholesale price $\bar{P}_{\mathrm{F},t}$ is decreasing in the distribution margin in the Home market for the Foreign good, $\delta_{\mathrm{F},t}$ ($\equiv \eta(P_{\mathrm{N},t}/P_{\mathrm{F},t})$):

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

By the definition of $\delta_{\mathrm{F},t}$, this expression is decreasing in $\eta$, and equal to 1 for $\eta=0$. Distribution services reduce the effective price elasticity of aggregate import demand—below what is implied by the assumption of Cobb–Douglas preferences. But by lowering the price elasticity of imports, distributive trade induces larger price movements for any given quantity change. It is worth stressing that the above result suggests that in general price elasticities do not depend exclusively on consumers' preferences—a point that proved useful in designing calibrated numerical models of the international economy (as in Corsetti et al. (2003)).

The link between distributive trade and price elasticities is a novel result relative to previous important contributions analyzing retail services (e.g., Burstein et al. (2003a,b)). These contributions have focused on competitive small open-economy models, namely abstracting from the feedback from distribution to trade elasticities and therefore to international prices and nominal exchange rates. But a feedback from (contingent) trade elasticities to the exchange rate has important implications for the general-equilibrium predictions of the model regarding volatility and comovement of international prices. Below we analyze these implications in greater detail by linearizing the model under financial autarky around a symmetric steady state with $Z_{\mathrm{H}}=Z_{\mathrm{F}}$, $Z^*_{\mathrm{N}}=Z_{\mathrm{N}}$ and equal wage levels $(\phi/\phi-1)\kappa\mu$ across countries. In the next section we will build numerical examples showing that our results derived under financial autarky hold more generally when we introduce an international market for default-free bonds.

#### 4.2.1. Exchange rate volatility

A first important feature of our model is that the nominal exchange rate is more volatile than the underlying fundamental shocks. Consider first the response of the nominal exchange rate to monetary policy shocks in the form of unexpected changes in the ratio of $\mu_t$ to $\mu_t^*$. For given nominal wages the log-linearized expression for the exchange rate is:

$$\hat{\mathcal{E}}_t = \frac{mk_{\mathrm{H}}}{mk_{\mathrm{H}} - 2\delta}\left(\hat{\mu}_t - \hat{\mu}_t^*\right), \tag{29}$$

where $mk_{\mathrm{H}}$ and $\delta$ denote the symmetric steady state values of Eq. (18) and of the distribution margin, respectively, and a hat '^' denotes percentage deviations from steady state values. Since $mk_{\mathrm{H}}=mk_{\mathrm{F}}>1$, for an average distribution margin $\delta$ that (realistically) is not much larger than 0.5, the coefficient multiplying the relative monetary shock in the above equation is positive and larger than one. Hence, on impact a Home monetary expansion leads to more than a proportional currency depreciation.[16]

The exchange rate response to real productivity shocks is:

$$\hat{\mathcal{E}}_t = \frac{\delta}{mk_{\mathrm{H}} - 2\delta}\left[\hat{Z}_{\mathrm{N},t} + \hat{Z}_{\mathrm{H},t} - \hat{Z}^*_{\mathrm{N},t} - \hat{Z}\mathrm{F},t\right]. \tag{30}$$

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. The size of exchange rate movements in response to productivity shocks depends on the relative magnitude of $\eta$ and $\theta$: it is more than proportional for standard parameters' values—such that $3\delta>mk_{\mathrm{H}}>2\delta$.

#### 4.2.2. Nominal and real exchange rates

Nominal and real exchange rates are positively correlated in equilibrium. Consider first the comovement of these two variables conditional on nominal shocks only:

$$\left(\widehat{\frac{\mathcal{E}_t P_t^*}{P_t}}\right) = \left[1 - \frac{1-\delta}{mk_{\mathrm{H}}}\gamma\right]\hat{\mathcal{E}}_t, \tag{31}$$

where $\hat{\mathcal{E}}_t$ is given by Eq. (29). 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. But since the coefficient of $\hat{\mathcal{E}}_t$ in the above expression is less than one, the real exchange rate will move by less.

[16] When $mk_{\mathrm{H}}-2\delta>0$, the conditions for the existence of multiple steady states derived by Corsetti and Dedola (2002) do not hold. If the distribution margin is large enough for the economy to 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.

Eq. (31) also characterizes the response of the real exchange rate to shocks to tradables, whereas $\hat{\mathcal{E}}_t$ is given by Eq. (30) in place of Eq. (29).[17] As regards shocks to nontraded productivity, instead, we have:

$$\left(\widehat{\frac{\mathcal{E}_t P_t^*}{P_t}}\right) = \left[1 - \frac{1-\delta}{mk_{\mathrm{H}}}\gamma\right]\left(\hat{\mathcal{E}}_t + \left(\hat{Z}_{\mathrm{N},t} - \hat{Z}^*_{\mathrm{N},t}\right)\right) = \left[1 - \frac{1-\delta}{mk_{\mathrm{H}}}\gamma\right]\left[\frac{mk_{\mathrm{H}} - \delta}{\delta}\right]\hat{\mathcal{E}}_t,$$

where again we use Eq. (30). We have seen above that, regardless of the sector in which they occur, domestic productivity increases 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, as arguably $mk_{\mathrm{H}}-2\delta>0$, the second term in brackets is larger than 1 and the real depreciation will be attenuated in the case of shocks to $Z_{\mathrm{H},t}$ relative to the case of shocks to $Z_{\mathrm{N},t}$.

*4.2.3. Exchange rate and terms of trade*

Nominal depreciations tend to be associated with a worsening of the terms of trade. Linearizing the latter around a symmetric steady state, we obtain

$$\widehat{\frac{\bar{P}_{\mathrm{F},t}}{\mathcal{E}\bar{P}^*_{\mathrm{H},t}}} = \frac{(1-(mk_{\mathrm{H}}-1))\hat{\mathcal{E}}_t + \left(\hat{Z}_{\mathrm{H},t} - \hat{Z}^*_{\mathrm{F},t}\right) - (mk_{\mathrm{H}}-1)\left(\hat{Z}_{\mathrm{N},t} - \hat{Z}^*_{\mathrm{N},t}\right)}{mk_{\mathrm{H}}}. \qquad (32)$$

where $\hat{\mathcal{E}}_t$ is given by either Eq. (29) or (30), depending on the nature of the shock. The coefficient of $\hat{\mathcal{E}}_t$ in the above expression is positive for $(mk_{\mathrm{H}}-1)<1$—a condition that is satisfied for the empirically relevant case of average markups not exceeding 100% (recall that the gross wholesale markup is $\theta/(\theta-1)mk_{\mathrm{H}}$). 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 in the Home nontradable sector. Conditional on these shocks, the above equation simplifies to:

$$\widehat{\frac{\bar{P}_{\mathrm{F},t}}{\mathcal{E}\bar{P}^*_{\mathrm{H},t}}} = \frac{\delta - (mk_{\mathrm{H}}-1)}{\delta}\hat{\mathcal{E}}_t.$$

While unambiguously depreciating the Home currency, shocks to nontradables also have a positive effect on the terms of trade. This is because, by reducing the cost of distributive

[17] This result appears to run against the Balassa–Samuelson hypothesis that shocks to tradables should appreciate the real exchange rate via an increase in the relative price of nontradables. Our result can be reconciled with the Balassa–Samuelson theory by noting that the textbook version of this theory typically assumes away any terms-of-trade effect, positing that tradables are perfect substitutes across countries.

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. Pass-through and exchange rate fluctuations

Overwhelming empirical evidence on pass-through shows that goods prices typically vary far less than one-to-one with exchange rates. In this section, we use our model to derive general equilibrium expressions for the exchange rate pass-through into import and consumer prices. 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. Most important, we are able to address a crucial limitation of partial equilibrium studies of the exchange rate pass-through, namely, the fact that exchange rate movements are treated as exogenous to firms' marginal costs and revenues.

### *5.1. Exchange rate pass-through*

#### *5.1.1. Import prices*

Following the approach in the PTM literature (e.g., Marston (1990) and Goldberg and Knetter (1997)), we derive an expression for the elasticity of the Home imports prices $\bar{P}_{F,t}$ with respect to the exchange rate—denoted by $\xi_{\bar{P}_{F,t},\mathcal{E}_t}$. To simplify notation, we adopt the convention that the inverse of the exchange rate elasticities with respect to productivity shocks–e.g., $\xi^{-1}_{\mathcal{E}_t,Z_{F,t}}$–are equal to zero when the corresponding shock does not materialize. Below we focus our discussion on the case of Home currency depreciation.

We derive $\xi_{\bar{P}_{F,t},\mathcal{E}_t}$ by taking the total differential of the Home import prices $\bar{P}_{F,t}$—which is the analog of Eq. (17) set by Foreign exporters. As in the PTM literature we decompose $\xi_{\bar{P}_{F,t},\mathcal{E}_t}$ into a 'marginal-cost elasticity' $\xi_{mc_{F,t},\mathcal{E}_t}$ and a 'markup elasticity' $\xi_{mk_{F,t},\mathcal{E}_t}$:

$$\begin{aligned}\xi_{\bar{P}_{F,t},\mathcal{E}_t} &\equiv \frac{\partial \bar{P}_{F,t}}{\partial \mathcal{E}_t}\frac{\mathcal{E}_t}{\bar{P}_{F,t}} = \xi_{mc_{F,t},\mathcal{E}_t} + \xi_{mk_{F,t},\mathcal{E}_t} \\ &= \left[1 + \xi_{W_t^*,\mathcal{E}_t} - \xi^{-1}_{\mathcal{E}_t,Z_{F,t}}\right] \\ &\quad + \left[\left(mk^{-1}_{F,t} - 1\right)\left(1 + \xi_{W_t^*,\mathcal{E}_t} - \xi^{-1}_{\mathcal{E}_t Z_{F,t}} - \xi_{W_t,\mathcal{E}_t} + \xi^{-1}_{\mathcal{E}_t,Z_{N,t}}\right)\right] \end{aligned} \tag{33}$$

where $mc_{F,t}$ denotes marginal costs of Foreign producers in the importer's currency, i.e., $\frac{\mathcal{E}_t W_t^*}{Z_{F,t}}$, and–in analogy to Eq. (19)–$mk_{F,t} \equiv 1 + \frac{\eta}{\theta - 1}\frac{W_t}{\mathcal{E}_t W_t^*}\frac{Z_{F,t}}{Z_{N,t}}$.

Focus first on the marginal-cost elasticity, $\xi_{mc_{F,t},\mathcal{E}_t} = 1 + \xi_{W_t^*,\mathcal{E}_t} - \xi^{-1}_{\mathcal{E}_t,Z_{F,t}}$. Given nominal wages and productivity, a Home currency depreciation raises the Home-currency value of Foreign marginal costs one-to-one. But in general equilibrium the currency depreciation may depend on shocks that also affect factor prices and productivity–as captured by $\xi_{W_t^*,\mathcal{E}_t}$ and $\xi^{-1}_{\mathcal{E}_t,Z_{F,t}}$–therefore changing marginal costs in Foreign currency. For instance, according to our general equilibrium analysis in the previous section, we know that $\xi_{W_t,\mathcal{E}_t} = 0$ and $\xi^{-1}_{\mathcal{E}_t,Z_{F,t}} < 0$.

To appreciate the importance of this point, consider our economy in the limiting case with $\eta \to 0$, when our specification is the same as Obstfeld and Rogoff (2000). In this case, the exchange rate does not respond at all to productivity shocks. Hence $-\xi^{-1}_{\mathcal{E}_t,Z_{\mathrm{F},t}} \to \infty$ and the marginal cost elasticity is infinite. In other words, import prices move one-to-one with the foreign marginal cost $W^*/Z_{\mathrm{F}}$, while the exchange rate is unaffected. In the more general case with $\eta>0$, however, a fall in Foreign tradable productivity depreciates the Home currency: hence $\xi_{mc_{\mathrm{F},t},\mathcal{E}_t}$ will fall with $\xi^{-1}_{\mathcal{E}_t,Z_{\mathrm{F},t}}$. Note that a larger $\eta$ lowers the marginal-cost elasticity to the exchange rate.

In general our results in the previous section imply that the marginal cost elasticity will be equal to 1 conditional on all shocks but $Z_{\mathrm{F}}$—namely, shocks to $\mu$, $\mu^*$, $Z_{\mathrm{H}}$, $Z_{\mathrm{N}}$, $Z^*_{\mathrm{N}}$. Interestingly, for these shocks exchange rate movements can be considered exogenous to Foreign marginal costs. Exogeneity of exchange rates to marginal costs is the (often implicit) maintained assumption in partial equilibrium studies of pass-through. Our general equilibrium model shows that this assumption will be correct only conditional on the absence of shocks to foreign productivity.[18]

Turning to the 'markup elasticity' component of Eq. (33), $\xi_{mk_{\mathrm{F},t},\mathcal{E}_t}$ is a function of the same elasticities included in the marginal cost component, but also depends on the level of Foreign markups, $\xi_{W_t,\mathcal{E}_t}$ and $\xi^{-1}_{\mathcal{E}_t,Z_{\mathrm{N},t}}$. As shown in Section 3.1, this is due to the fact that the demand price elasticity of Foreign producers is decreasing in the distribution margin—in turn a function of Foreign marginal cost and local nontradable marginal costs. Moreover, our general equilibrium analysis in Section 4 shows that $\xi^{-1}_{\mathcal{E}_t,Z_{\mathrm{N},t}}>0$.

The level of foreign markups is an important determinant of ERPT. This is most clear when we put the two components $\xi_{mc_{\mathrm{F},t},\mathcal{E}_t}$ and $\xi_{mk_{\mathrm{F},t},\mathcal{E}_t}$ together, and assume that the only shocks hitting the economy are $\mu$, $\mu^*$, $Z_{\mathrm{H}}$ and $Z^*_{\mathrm{N}}$. Conditional on these shocks $\xi^{-1}_{\mathcal{E}_t,Z_{\mathrm{F},t}} = \xi^{-1}_{\mathcal{E}_t,Z_{\mathrm{N},t}} = 0$, and ERPT is equal to $mk^{-1}_{\mathrm{F},t}$, thus decreasing in the equilibrium markup charged by Foreign firms in the Home market. Thus, our model predicts that ERPT falls with firms' monopoly power (a lower $\theta$) and the size of the distribution margin (a larger $\eta$). This prediction is in accordance with the finding by Campa and Goldberg (2004), who attribute the recent decline in ERPT observed in OECD countries to a change in the composition of trade, toward a larger share of differentiated manufactured goods—arguably produced by firms with market power.

The term $mk^{-1}_{\mathrm{F},t}$ is a correct description of ERPT when the exchange rate is exogenous to marginal costs and demand price elasticities. As shown in Section 4, according to our model this will always be the case when asset markets are complete, whereas the perfect risk-sharing condition (27) holds and the nominal exchange rate is affected exclusively by monetary factors. With incomplete markets, instead, the term $mk^{-1}_{\mathrm{F},t}$ could be viewed as a measure of the direct effect of exchange rate changes on import prices abstracting from the general equilibrium effects of shocks on costs and markups that contribute to determine $\xi_{\bar{P}_{\mathrm{F},t},\mathcal{E}_t}$. As such, it can be related to regression estimates of ERPT coefficients which appropriately control for costs and markups. For instance, Campa and Goldberg (2004) estimate ERPT into import prices across OECD countries at around 80% over a 1-year horizon. According to this study, other things equal

[18] Partial equilibrium studies typically proxy marginal costs with the wage rate, and consider this as given. We thank Charles Engel for pointing out this difference between partial and general-equilibrium studies.

a 1% exchange rate depreciation would result in a 0.8% increase in import prices. A simple back-of-the-envelope calculation using our model suggests that this estimate would be consistent with an average (net) state-contingent markup equal to 25% (i.e., $mk_{F,t}$=1.25).

Nevertheless, the *actual* response of import prices to exchange rate fluctuations will be different from $mk_{F,t}^{-1}$ because of general equilibrium effects relating the exchange rate to marginal costs and markups. When asset markets are incomplete shocks to $Z_F$ and $Z_N$ imply that $\xi_{\bar{P}_{F,t},\mathcal{E}_t}$ is equal to $mk_{F,t}^{-1}(1-\xi_{\mathcal{E}_t,Z_{F,t}}^{-1})$ and $1-(1-mk_{F,t}^{-1})(1+\xi_{\mathcal{E}_t,Z_{N,t}}^{-1})$, respectively. With an increase in $Z_N$, the actual ERPT may even be negative, as the one-to-one increase in the Home currency value of Foreign marginal costs due to depreciation is more than offset by the fall in the markup charged by foreign exporters because of an increasing demand price elasticity.

Finally, it is worth stressing that pass-through can be incomplete independent of nominal rigidities. Our model predicts that, even if all prices and wages were fully flexible, firms may still choose to discriminate prices optimally in response to productivity differentials across countries and sectors, as well as wage differentials arising from country-specific shocks to labor supply, because of their effect on demand price elasticities.

### 5.1.2. Consumer prices

The presence of distribution costs further reduces the exchange rate pass-through into prices at consumer level, bringing about a high degree of local currency price stability. Consider the exchange rate elasticity of the Foreign good retail prices in the Home market:

$$\xi_{P_{F,t},\mathcal{E}_t} = (1-\delta_{F,t})\xi_{\bar{P}_{F,t},\mathcal{E}_t} + \delta_{F,t}\xi_{P_{N,t},\mathcal{E}_t} = (1-\delta_{F,t})\xi_{mk_{F,t},\mathcal{E}_t} + \left[(1-\delta_{F,t})\xi_{mc_{F,t},\mathcal{E}_t} + \delta_{F,t}\left(\xi_{W_t,\mathcal{E}_t} - \xi_{\mathcal{E}_t,Z_{N,t}}^{-1}\right)\right] \tag{34}$$

In analogy to Eq. (33), ERPT into the retail price of imports can be decomposed into a ‘markup elasticity’ and a ‘marginal-cost’ elasticity. The latter now includes the Home currency costs incurred by domestic firms distributing the imported goods to consumers, which correspond to the last term in brackets in Eq. (34). As stressed by the PTM literature (e.g., Goldberg and Knetter, 1997; Goldberg and Verboven, 2001), this decomposition is a challenge to empirical studies, given that only prices and exchange rates are observed. The crucial question is the extent to which the stability of the local currency retail price of imports results from markup adjustment as opposed to local components in marginal costs.

In general, ignoring local components in marginal costs leads to overestimating the role of markup fluctuations. As is apparent in Eq. (34), for any given ERPT into import prices $\xi_{\bar{P}_{F,t},\mathcal{E}_t}$, a larger distribution margin $\delta_{F,t}$ translates into a smaller elasticity of retail prices $\xi_{P_{F,t},\mathcal{E}_t}$. In the presence of distributive trade, $\xi_{P_{F,t},\mathcal{E}_t}$ is less than one even if the exchange rate pass-through into import prices is complete and there is no markup adjustment (so that $\xi_{mk_{F,t},\mathcal{E}_t}=0$ and $\xi_{\bar{P}_{F,t},\mathcal{E}_t}=\xi_{mc_{F,t},\mathcal{E}_t}=1$).

However, the observed high degree of local currency stability of retail prices does not arise exclusively from local components in marginal costs. This is clearly suggested not only by the evidence on incomplete ERPT import prices, but also by studies that directly estimate structural equations similar to Eq. (34). Among these studies, the important contribution by Goldberg and Verboven (2001) looks at the determinants of the dispersion of car retail prices in Europe. According to their estimates, the average ERPT into retail prices of cars is 54% over a 1-year horizon: a 37–39% pass-through can be attributed to local marginal cost of distribution, the rest to markup adjustment—suggesting that both components are quite relevant in explaining local currency price stability.

Notably, these authors point out that their results are consistent with available estimates of local costs in the value of a car-up to 35% (mainly explained by a market structure characterized by the presence of many small dealers). If, using our model, we set the distribution margin $\delta_{\mathrm{F},t}$ equal to 35% and the retail price elasticity $\xi_{P_{\mathrm{F},t},\mathcal{E}_t}$ equal to 54%, we obtain that the exchange rate elasticity of import prices is approximately equal to 80%–i.e., $\xi_{\bar{P}_{\mathrm{F},t},\mathcal{E}_t} \simeq 0.8$–entirely arising from markup adjustment that is indicative of price discrimination. Our back of the envelope calculation is again consistent with a realistic number for ERPT into import prices, strikingly similar to the estimates in Campa and Goldberg (2004).

It is important to stress that the response of retail prices of Foreign goods to exchange rate fluctuations can be quite different from that of import prices. For instance, shocks to Home nontradables for which $\xi_{\mathcal{E}_t,Z_{\mathrm{N},t}}>0$ strongly reduce the exchange rate elasticity of retail prices because of falling prices in the distribution sector operating in the Home market.

Turning to the overall consumer price index, its elasticity to the exchange rate is:

$$\begin{aligned}\xi_{P_t,\mathcal{E}_t} &= \frac{\gamma}{2}\left(\xi_{P_{\mathrm{F},t},\mathcal{E}_t} + \xi_{P_{\mathrm{H},t},\mathcal{E}_t}\right) + \gamma\xi P_{\mathrm{N},t,\mathcal{E}_t} \\ &= \frac{\gamma}{2}\left[mk_{\mathrm{F},t}^{-1}(1-\delta_{\mathrm{F},t})\left(1-\xi_{\mathcal{E}_t,Z_{\mathrm{F},t}}^{-1}\right) - mk_{\mathrm{H},t}^{-1}(1-\delta_{\mathrm{H},t})\xi_{\mathcal{E}_t,Z_{\mathrm{H},t}}^{-1}\right] + \\ &\quad - \left\{1-\frac{\gamma}{2}\left[(1-\delta_{\mathrm{H},t})mk_{\mathrm{H},t}^{-1} + (1-\delta_{\mathrm{F},t})mk_{\mathrm{F},t}^{-1}\right]\right\}\xi_{\mathcal{E}_t,Z_{\mathrm{N},t}}^{-1}. \end{aligned} \tag{35}$$

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

The consumer price index behavior will of course vary with the nature of the shocks bringing about a Home currency depreciation: the CPI will be more 'insulated' from the exchange rate conditional on shocks to (domestic and foreign) tradables, rather than conditional on nominal shocks and shocks to $Z_{\mathrm{N},t}^{*}$. Interestingly, in response to positive disturbances to $Z_{\mathrm{N},t}$, the CPI may fall or rise, depending on the size of markups and distribution margins across sectors.[19]

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

[19] All these effects are considered by Burstein et al. (2003a,b) in a price-accounting framework that draws on both Burstein et al. (2003a) and the present paper.

### 5.2. Some numerical results

To complete the analysis of the linkage between exchange rates and prices in our model, we carry out a numerical exercise under the assumption that agents can trade international nominal bonds.[20] Specifically, we compute the impact effects on prices, exchange rates, pass-through and exchange rate elasticities, of nominal and real shocks, defined as a 1% deviation from their initial steady state values, allowing for both permanent and temporary disturbances (i.e., lasting only one period).[21]

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 $Z_T/Z_N=2$. The values of $\eta$ and $\theta$ are set to 0.8 and 8, such that the distribution margin is around 55%–a number that is in line with available estimates for the US and other OECD countries (see Anderson and Van Wincoop, 2004), and the inverse of the steady state value of the state-contingent markup in Eq. (18) is about 80%–thus, in line with the estimates of ERPT in Campa and Goldberg (2004). In turn, this implies plausible industry markups, approximately varying between 15% in the nontradable sector and 40% in the tradable sector. Tradables and nontradables are given the same weight in consumption, i.e., $\gamma=0.5$.[22] The results of our exercise are shown in Table 2.

The equilibrium response to shocks in the economies with trade in bonds is broadly in line with our analysis in Section 4. Consider first the response of exchange rates to monetary innovations. With incomplete markets and distribution costs, nominal and real exchange rates are more volatile than the underlying shock. As shown in the table, a 1% temporary increase in $\mu$–equivalent to a 1 percentage point drop in the short-term nominal interest rate–depreciates $\mathcal{E}$ by 1.5% in the bond economy.[23] Second, consistent with Eq. (30), 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. For instance, a 1% permanent productivity shock in the tradable sector depreciates $\mathcal{E}$ by 5.9%. Third, nominal and real exchange rates are positively correlated in response to all shocks: as shown in the table,

[20] Corsetti et al. (2003, 2004) carry out extensive quantitative analysis of the model, using more general specifications of preferences and technology, allowing for nominal price rigidities and providing extensive robustness analysis regarding parameter values, asset market structure and the size of the distribution sector. Notably, the results from fully fledged numerical analysis tend to confirm the main highlights from the simpler numerical exercise performed in this section.

[21] When 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), ch. 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.

[22] Using the conditions derived by Corsetti and Dedola (2002), it can be verified that these parameter values ensure a unique steady state.

[23] Under financial autarky, instead, the exchange rate would depreciate by about 12%, as can be seen by making use of Eq. (29). 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. However, higher net exports in equilibrium require larger movements in the terms of trade and in nominal and real exchange rates.

Table 2
Impact responses of selected variables to nominal and real shocks[a] (percentage deviations from steady-state values and elasticities)

| | Monetary shock | Shock to tradables | | Shock to nontradables | | Economy-wide shock | |
|---|---|---|---|---|---|---|---|
| | | 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* $\xi$ | | | | | | | |
| 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 $\xi_{P_t,\mathcal{E}_t}$ | 0.12 | −0.32 | 0.08 | −3.34 | −0.03 | −1.87 | 0.02 |

[a] See the main text for an explanation of the experiments.

these rates always move in the same direction in equilibrium. Finally, with the exception of temporary productivity shocks 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 shown in the bottom half of Table 2, recall that the parameterization of the state-contingent markup implies that $mk^{-1} \simeq 0.8$, and thus a roughly 80% pass-through into import prices conditional on the exchange rate being exogenous to markups and marginal costs. A first result highlighted in the table is that pass-through is at most as high as 82%, corresponding to shocks to tradables; it is lower for any of the other shocks.[24]

Reflecting a low degree of pass-through, our model predicts that, overall, domestic prices move much less than international prices. Following a 1% nominal depreciation, ERPT onto the retail price of imports is at most one half of ERPT on import prices, while CPI inflation never exceeds 0.12%. 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 (2004) 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% but retail inflation in imports and overall CPI is only 4.1 and 0.3%, respectively.

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

[24] Remarkably, this result would also obtain under a systematic monetary policy that replicates the flexible price allocation (see Corsetti and Dedola (2002)).

relative to the exchange rate. For instance, nominal shocks and shocks to $Z_{\mathrm{H}}$ whether or not permanent, all imply essentially the same exchange rate pass-through into import prices, at both producer level (around 80%) and consumer level (around 40%). Yet pass-through on CPI ranges between 12% and −32%! These numerical results question strong interpretations of empirical estimates of average pass-through: as shown by our model, a subdued response of 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 link between ERPT into import prices and the exchange rate response to economy-wide productivity shocks (to $Z_{\mathrm{H}}$ and $Z_{\mathrm{N}}$ 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 pass-through should be increasing in the size of exchange rate changes.[25]

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 long-run asymmetries in fundamentals across countries. For instance, suppose that the productivity level in the tradable sector is 25% 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% 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%, much larger than the productivity differential.

## 6. Conclusions

Many recent contributions stress the importance of placing international price differentials centerstage in open-economy macroeconomic 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.

[25] 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 adjustment costs for changing nominal prices. 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 in equilibrium only reflects optimal price discrimination.

As a consequence, the law of one price fails to hold at both producer and consumer levels, independently of nominal rigidities. Furthermore, 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. Last, a currency depreciation generally worsens the terms of trade: despite low pass-through the international transmission of monetary shocks can have expenditure-switching effects.

Key to our approach is that distributive trade requires local inputs, introducing 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 types of good is set equal to one, and there is no difference between nontraded goods and distribution services.[26] We have also 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). Most crucially, the evidence suggests that the degree of pass-through is not constant over different time horizons. This evidence calls for building models where optimal markup adjustment interacts with price rigidities, generating dynamics in the degree of local currency price stability.[27]

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[26] Another 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.

[27] There is a large general-equilibrium literature studying the macroeconomic implications of local currency price stability in the model with nominal rigidities. Early contributions assume that foreign exporters quote their prices in local currency—see Engel (2002) for a survey of the literature, and Corsetti and Pesenti (2001b) for a generalization of this approach. Recent work by Bacchetta and Van Wincoop (2002), Corsetti and Pesenti (2002) and Devereux et al. (2004) analyzes the problem of producers who can choose whether to preset prices in domestic currency only or in both domestic and foreign currencies.

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