

# Monetary Policy and the Adjustment to Country-Specific Shocks

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The question of the optimal degree of exchange rate variability among countries has been long standing in international economics. Friedman (1953) argued in favor of flexible exchange rates: when nominal goods prices are sticky, the adjustment of the nominal exchange rate allows for the necessary relative price adjustment to a country-specific shock. Recent articles by Devereux and Engel (2003) and Corsetti and Pesenti (2001), however, show that the optimal degree of exchange rate variability between two countries subject to country-specific real shocks depends critically on the nature of price stickiness, in particular, whether prices are sticky in the currency of the producer or in the currency of the buyer.

When prices are preset in the currency of the buyer, unanticipated movements in the nominal exchange rate do not affect the price of imported goods on impact. That is, as suggested by the empirical evidence, the pass-through of exchange rate changes to consumer prices in the short run is low.<sup>1</sup> The findings in Devereux and Engel (2003) and Corsetti and Pesenti (2001) show that when prices are preset in the currency of the buyer (and, therefore, as suggested by the data, do not respond to movements in the exchange rate), optimal monetary policy implies that the nominal exchange rate does not respond to country-specific shocks.<sup>2</sup> This finding is in sharp contrast with Friedman's

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<sup>1</sup> Recent empirical studies have documented a low pass-through of changes in the exchange rate to consumer prices: in the short run, consumer prices respond little to changes in the nominal exchange rate. See, for example, Engel (1993, 1999) and Engel and Rogers (1996), among others.

<sup>2</sup> If, instead, prices are sticky in the currency of the producer, then consumer prices of imported goods change proportionally with unanticipated changes in the nominal exchange rate (com-

(1953) argument in favor of nominal exchange rate flexibility in the presence of nominal price rigidities and country-specific shocks.

In this article I study optimal monetary policy in a two-country model that features nontraded goods and in which producers in each country set prices one period in advance in the currency of the buyer. The article shows that the presence of nontraded goods has important implications for the optimal degree of nominal exchange rate variability in response to country-specific shocks.

When all goods are traded, I find that, as in Devereux and Engel (2003) and Corsetti and Pesenti (2001), both monetary authorities respond in the same manner to country-specific shocks. In the absence of nontraded goods, home and foreign agents consume the same basket of traded goods, and the nominal exchange rate does not move in response to country-specific shocks when countries follow their optimal monetary rules. As a consequence, a fixed exchange rate regime can be supported by optimal monetary policies. An important feature of the model when all goods are traded is that it implies that there are no relative price differentials across countries under a fixed exchange rate regime. There exists, however, evidence of such price differentials across countries that participate in a currency union (and, therefore, have a constant nominal exchange rate). Duarte (2003), for example, documents inflation differentials among member countries of the European Monetary Union as big as 4 percentage points.

When a set of consumption goods is nontraded and the consumption basket is distinct across countries, I show that the model is consistent with the observed relative price differentials across countries under a fixed exchange rate regime. I find, however, that in this situation a fixed exchange rate regime is not supported by optimal monetary policies since the monetary authorities choose to respond differently to country-specific shocks. That is, a flexible exchange rate regime is supported by optimal monetary policies when the model is consistent with two observations—that of relative price differentials across countries under a fixed exchange rate regime, as well as the observation of low pass-through of exchange rate changes to consumer prices.

The presence of nontraded goods has been shown to have important implications in open-economy models in dimensions other than the optimal degree of exchange rate variability. Stockman and Tesar (1995) show that nontraded goods play an important role in accounting for the properties of the international business cycle of industrialized countries. More recently, Corsetti and Dedola (2002) and Burstein, Neves, and Rebelo (2003) show that nontraded goods, used in the distribution sector, play an important role in explaining ob-

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plete exchange rate pass-through). In this case, Devereux and Engel (2003) and Corsetti and Pesenti (2001) find that a flexible exchange rate regime can be supported by optimal monetary policies.

served deviations from the law of one price and low pass-through of exchange rate changes to consumer prices.

In Section 1, I present a two-country model in which agents consume traded and nontraded goods and in which prices are sticky. In the following section, I study the implications of the presence of nontraded goods for relative price differentials across countries under a fixed exchange rate regime and for the optimal response of a monetary authority seeking to maximize the expected utility of the representative agent in the country.

## 1. THE MODEL

In this section I develop a general equilibrium model of a world economy with two countries, denominated home and foreign, which builds upon the work of Obstfeld and Rogoff (1995). Both countries are populated by a continuum of monopolistic producers, indexed by  $i \in [0, 1]$  in the home country and  $i^* \in [0, 1]$  in the foreign country. Each agent produces two goods, a differentiated traded good and a differentiated nontraded good.<sup>3</sup> Agents consume all varieties of home and foreign-traded goods and all varieties of the local-nontraded good. In each country there is a monetary authority that prints local currency and distributes it to the individual agents through lump sum transfers.

I now describe the home economy. The foreign economy is analogous to the home economy. Foreign variables are denoted with an asterisk.

### Preferences

All agents have identical preferences defined over a consumption index, real money balances, and work effort. To keep the algebra to a minimum, the lifetime expected utility of a typical home agent  $j$  is defined as

$$U_0(j) = E_0 \sum_{t=0}^{\infty} \beta^t \left( \ln c_t(j) + \chi \ln \frac{M_t(j)}{P_t} - l_t(j) \right). \quad (1)$$

The real consumption index  $c_t(j)$  is defined as

$$c_t(j) = \frac{c_{T,t}(j)^\gamma c_{N,t}(j)^{1-\gamma}}{\gamma^\gamma (1-\gamma)^{1-\gamma}}, \quad (2)$$

where  $c_{T,t}(j)$  denotes the agent's consumption index of traded goods and  $c_{N,t}(j)$  denotes the agent's consumption index of nontraded goods. The consumption index of traded goods is defined as

$$c_{T,t}(j) = \frac{c_{H,t}(j)^\eta c_{F,t}(j)^{1-\eta}}{\eta^\eta (1-\eta)^{1-\eta}}, \quad (3)$$

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<sup>3</sup> See Obstfeld and Rogoff (1996, 661) for a discussion of the environment where individuals, instead of firms, are the locus of monopoly power.

where  $c_{H,t}(j)$  and  $c_{F,t}(j)$  denote agent  $j$ 's consumption index of home and foreign-traded goods, respectively.<sup>4</sup> Finally, the consumption indexes of home-traded goods,  $c_{H,t}(j)$ , foreign-traded goods,  $c_{F,t}(j)$ , and local-nontraded goods,  $c_{N,t}(j)$ , are each defined over consumption of all the varieties of each good, as

$$c_{H,t}(j) = \left[ \int_0^1 c_t(h, j)^{\frac{\theta-1}{\theta}} dh \right]^{\frac{\theta}{\theta-1}}, \quad (4)$$

$$c_{F,t}(j) = \left[ \int_0^1 c_t(f, j)^{\frac{\theta-1}{\theta}} df \right]^{\frac{\theta}{\theta-1}}, \quad (5)$$

and

$$c_{N,t}(j) = \left[ \int_0^1 c_t(n, j)^{\frac{\theta-1}{\theta}} dn \right]^{\frac{\theta}{\theta-1}}. \quad (6)$$

In equation (4),  $c_t(h, j)$  denotes agent  $j$ 's consumption of home-traded variety  $h$ ,  $h \in [0, 1]$ , at date  $t$ . The terms  $c_t(f, j)$  and  $c_t(n, j)$  in equations (5) and (6) have analogous interpretations.

Note that in equations (2) and (3) it is assumed that the elasticity of substitution between the composite goods of home and foreign-traded varieties ( $c_H(j)$  and  $c_F(j)$ ) and the elasticity of substitution between the composite goods of traded and nontraded varieties ( $c_T(j)$  and  $c_N(j)$ ) are equal to one. In expressions (4) through (6), however, the elasticity of substitution between distinct varieties of a given good (nontraded or traded) is given by  $\theta$ , which is assumed to be greater than one.<sup>5</sup>

Let's denote by  $P_{H,t}(h)$  and  $P_{F,t}(f)$  the home-currency prices of varieties  $h$  and  $f$  of the home and foreign-traded goods at date  $t$ , respectively. And let  $P_{N,t}(n)$  denote the home-currency price of variety  $n$  of the local-nontraded good. The utility-based home price index,  $P_t$ , is then given by<sup>6</sup>

$$P_t = P_{T,t}^\gamma P_{N,t}^{1-\gamma}, \quad (7)$$

where the price of one unit of the composite good of all traded varieties,  $P_{T,t}$ , and the price of one unit of the composite good of nontraded varieties,  $P_{N,t}$ ,

<sup>4</sup> I follow Corsetti and Pesenti (2001) and Devereux and Engel (2003) in assuming that foreign agent  $j^*$ 's consumption index of traded goods is defined as  $c_{T,t}^*(j^*) = \frac{c_{H,t}^*(j^*)^\eta c_{F,t}^*(j^*)^{1-\eta}}{\eta^\eta (1-\eta)^{1-\eta}}$ . That is, home and foreign agents consume the same basket of home- and foreign-traded goods. This specification, for example, does not generate home bias.

<sup>5</sup> This assumption is required to ensure that an interior equilibrium with a positive level of output exists.

<sup>6</sup> The price index  $P_t$  is defined as the minimum expenditure required to buy one unit of the composite good  $c_t$ , given the prices of all individual varieties. The other price indexes have analogous interpretations. See the appendix for the derivation of the price indexes and the demand functions (11) through (13) presented below.

are given by

$$P_{T,t} = P_{H,t}^\eta P_{F,t}^{1-\eta}, \quad (8)$$

and

$$P_{N,t} = \left[ \int_0^1 P_{N,t}(n)^{1-\theta} dn \right]^{\frac{1}{1-\theta}}. \quad (9)$$

The prices of one unit of the composite goods of home and foreign-traded varieties, in turn, are given by

$$P_{H,t} = \left[ \int_0^1 P_{H,t}(h)^{1-\theta} dh \right]^{\frac{1}{1-\theta}}; \quad P_{F,t} = \left[ \int_0^1 P_{F,t}(f)^{1-\theta} df \right]^{\frac{1}{1-\theta}}. \quad (10)$$

For the above specification of consumption indexes, agent  $j$ 's demands for variety  $h$  and  $f$  of home and foreign-traded goods are given by

$$c_t(h, j) = \eta \gamma \left( \frac{P_{H,t}(h)}{P_{H,t}} \right)^{-\theta} \frac{P_t}{P_{H,t}} c_t(j), \quad (11)$$

and

$$c_t(f, j) = (1 - \eta) \gamma \left( \frac{P_{F,t}(f)}{P_{F,t}} \right)^{-\theta} \frac{P_t}{P_{F,t}} c_t(j). \quad (12)$$

The agent's demand for variety  $n$  of the nontraded good is given by

$$c_t(n, j) = (1 - \gamma) \left( \frac{P_{N,t}(n)}{P_{N,t}} \right)^{-\theta} \frac{P_t}{P_{N,t}} c_t(j). \quad (13)$$

### Production Technologies

The home agent  $j$  operates two technologies, one to produce a variety  $h$  of the home-traded good and the other to produce a variety  $n$  of the nontraded good. Both technologies are linear in labor. The corresponding resource constraints, which equate the quantities demanded and supplied of each variety, are

$$z_t l_{T,t}(j) \geq \int_0^1 c_t(h, i) di + \int_0^1 c_t^*(h, i^*) di^*, \quad (14)$$

and

$$z_t l_{N,t}(j) \geq \int_0^1 c_t(n, i) di, \quad (15)$$

where  $z_t$  denotes a country-specific productivity shock to both nontraded and traded technologies.<sup>7</sup> The term  $\int_0^1 c_t(h, i) di$  represents aggregate demand

<sup>7</sup>This article concerns the adjustment to country-specific shocks, and, therefore, I abstract from sector-specific shocks.

in the home country for home variety  $h$ . The other integrals have analogous interpretations. The terms  $l_{T,t}(j)$  and  $l_{N,t}(j)$  denote the fraction of time that agent  $j$  allocates to production of the traded and nontraded varieties, respectively. The agent's total work effort,  $l_t(j)$ , is given by  $l_{T,t}(j) + l_{N,t}(j)$ .

### Budget Constraint

Agent  $j$  holds local currency,  $M_t(j)$ , and trades state-contingent nominal bonds (denominated in the home currency) with foreign agents. We denote the price at date  $t$  when the state of the world is  $s_t$  of a bond paying one unit of currency at date  $t + 1$  if the state of the world is  $s_{t+1}$  by  $Q_{s_{t+1}|s_t}$ , and we denote the number of these bonds purchased by the home agent at date  $t$  by  $B_{s_{t+1}}(j)$ . Bond revenues received at date  $t$  when the state of the world is  $s_t$  are denoted by  $B_{s_t}(j)$ .

The agent's budget constraint, expressed in home-currency units, is

$$\begin{aligned} P_t c_t(j) + \sum_{s_{t+1}} Q_{s_{t+1}|s_t} B_{s_{t+1}}(j) + M_t(j) \\ \leq R_t(j) + B_{s_t}(j) + M_{t-1}(j) + T_t(j), \end{aligned} \quad (16)$$

where  $P_t c_t(j)$  is nominal expenditure in consumption,  $R_t(j)$  denotes sales revenues, and  $T_t(j)$  denotes lump sum transfers received from the monetary authority.

Revenues from selling the traded variety  $h$  and the nontraded variety  $n$ ,  $R_t(j)$ , are given by

$$\begin{aligned} R_t(j) = & P_{H,t}(h) \int_0^1 c_t(h, i) di + e_t P_{H,t}^*(h) \int_0^1 c_t^*(h, i^*) di^* \\ & + P_{N,t}(n) \int_0^1 c_t(n, i) di. \end{aligned}$$

In this expression,  $P_{H,t}^*(h)$  denotes the foreign currency price of home-traded variety  $h$ , and  $P_{H,t}^*(h) \int_0^1 c_t^*(h, i^*) di^*$  denotes agent  $j$ 's sales revenue in the foreign country (expressed in foreign currency units). The nominal exchange rate in period  $t$ , denoted by  $e_t$ , converts foreign currency sales revenue into home-currency units.

### The Agent's Problem

Agent  $j$  maximizes his expected lifetime utility (equation (1)) subject to the resource constraints for the home-traded variety  $h$  and nontraded variety  $n$  he produces (equations (14) and (15)) and his budget constraint (equation (16)), by choosing sequences of consumption, bond holdings, money holdings, and prices for the varieties  $h$  and  $n$ , taking other prices as given.

I assume that agents choose the nominal price of their traded and non-traded varieties one period in advance.<sup>8</sup> Moreover, I assume that producers can segment home and foreign markets and set prices for the traded variety in the currency of the buyer. Then, home producer  $j$  producing home-traded variety  $h$  and nontraded variety  $n$  chooses prices  $P_{H,t}(h)$ ,  $P_{H,t}^*(h)$ , and  $P_{N,t}(n)$  (where  $P_{H,t}^*(h)$  is denominated in foreign currency units) at time  $t - 1$ , taking other prices as given. The agent's problem is solved in Appendix A.

In a symmetric equilibrium, the first-order condition for consumption implies

$$\lambda_t = \frac{1}{P_t c_t}, \quad (17)$$

where  $\lambda_t$ , the Lagrange multiplier of the budget constraint, is the marginal utility of the (representative) agent's marginal wealth. The first-order condition for real money balances implies the money demand function

$$\frac{M_t}{P_t} = \chi c_t \frac{1 + i_{t+1}}{i_{t+1}}, \quad (18)$$

where  $1 + i_{t+1}$  is the gross return in period  $t + 1$  of a riskless bond and is given by

$$\frac{1}{1 + i_{t+1}} = \beta E_t \left[ \frac{P_t c_t}{P_{t+1} c_{t+1}} \right]. \quad (19)$$

Finally, from the first-order conditions for state-contingent bond holdings for home and foreign agents, we obtain the risk sharing condition<sup>9</sup>

$$P_t c_t = e_t P_t^* c_t^*. \quad (20)$$

For the momentary utility specification in equation (1), complete risk sharing implies that nominal expenditure in consumption (when expressed in the same currency) is equalized across countries. Note that consumption of the composite good differs across the two countries only to the extent that its price (when expressed in the same currency) differs across countries, that is, when there are deviations from purchasing power parity (or  $P_t \neq e_t P_t^*$ ).

In a symmetric equilibrium, the optimal pricing equations are

$$P_{H,t}(h) = P_{H,t} = \frac{\theta}{\theta - 1} E_{t-1} \left[ \frac{P_t c_t}{z_t} \right], \quad (21)$$

$$P_{H,t}^*(h) = P_{H,t}^* = \frac{\theta}{\theta - 1} E_{t-1} \left[ \frac{P_t c_t}{e_t z_t} \right], \quad (22)$$

<sup>8</sup> As in Corsetti and Pesenti (2001) and Devereux and Engel (2003), I abstract from a richer price adjustment setting in order to simplify the analytical solution of the model.

<sup>9</sup> Several recent articles have assumed complete nominal asset markets. See, for example, Chari, Kehoe, and McGrattan (2003) or Devereux and Engel (2003) for a discussion.

and

$$P_{N,t}(n) = P_{N,t} = P_{H,t}(h). \quad (23)$$

Since prices are set in advance in the currency of the buyer, it follows that, in the event of an unanticipated shock, consumer prices remain unchanged for one period. On impact, therefore, there is no pass-through of nominal exchange rate movements to consumer prices, and unanticipated changes in the nominal exchange rate cause ex-post deviations from the law of one price (that is,  $P_{H,t}(h) \neq e_t P_{H,t}^*(h)$ ).

If, instead, agents choose prices after observing the current realization of productivity shocks, then the price rules above hold in each state of the world and not just in expectation. Note that with flexible prices,  $P_{H,t}(h) = e_t P_{H,t}^*(h)$  holds every period (i.e., the law of one price holds). That is, even though firms can segment home and foreign markets, they optimally choose to charge the same price (when denominated in the same currency) in both markets when prices are flexible.

### Monetary Authority

The monetary authority prints money and rebates the seigniorage revenue to agents through lump sum transfers. Its budget constraint is

$$\int_0^1 (M_t(j) - M_{t-1}(j)) dj = \int_0^1 T_t(j) dj.$$

I assume that the monetary authority controls the nominal interest rate and supplies the amount of nominal money balances demanded. I follow Corsetti and Pesenti (2001) in characterizing monetary policy in each country by the reciprocal of the marginal utility of the representative agent's nominal wealth,  $\mu \equiv \frac{1}{\lambda}$ . In equilibrium, the marginal utility of wealth is given by equation (17), and the nominal interest rate (equation (19)) can be expressed as

$$\frac{1}{1 + i_{t+1}} = \beta E_t \left[ \frac{\mu_t}{\mu_{t+1}} \right].$$

Given a time path for  $\mu$ , there is a corresponding sequence of home nominal interest rates. Note that, for an unchanged  $E_t \left[ \frac{1}{\mu_{t+1}} \right]$ , an expansionary monetary policy shock (higher  $\mu_t$  and higher nominal expenditure  $P_t c_t$  in equilibrium) is associated with a lower nominal interest rate  $i_{t+1}$  and, therefore (from equation (18)), with higher money balances demanded.

### The Solution of the Model

The solution of the model can be easily obtained in closed form by expressing all endogenous variables as functions of real shocks ( $z_t$  and  $z_t^*$ ) and monetary stances ( $\mu_t$  and  $\mu_t^*$ ). The solution of the model is derived in Appendix B.



From equation (20), it follows that the nominal exchange rate is given by

$$e_t = \frac{\mu_t}{\mu_t^*}. \quad (24)$$

Total consumption in the home country is given by

$$c_t = \frac{\mu_t}{P_t}, \quad (25)$$

where the price index  $P_t$  is given by

$$P_t = \frac{\theta}{\theta - 1} E_{t-1} \left( \frac{\mu_t}{z_t} \right)^{\eta\gamma + (1-\gamma)} E_{t-1} \left( \frac{\mu_t}{z_t^*} \right)^{(1-\eta)\gamma}. \quad (26)$$

Total labor effort in the home country is given by

$$l_t = \frac{1}{z_t \frac{\theta}{\theta-1}} \left[ \frac{(\gamma\eta + (1-\gamma)) \mu_t}{E_{t-1} \left( \frac{\mu_t}{z_t} \right)} + \frac{\gamma\eta \mu_t^*}{E_{t-1} \left( \frac{\mu_t^*}{z_t} \right)} \right]. \quad (27)$$

Note that consumption in the home country is independent of (contemporaneous) changes in the nominal exchange rate when prices are preset in the buyer's currency. Therefore, consumption in the home country is not affected by foreign monetary policy,  $\mu_t^*$ . Note also that, for given  $\mu_t$  and  $\mu_t^*$ , real shocks do not have a contemporaneous impact on consumption (and, therefore, output), only affecting labor effort in the country where the shock occurs. In response to a positive productivity shock in the home country, home agents produce the same quantity of traded and nontraded goods with less hours of work.

It is also useful to characterize total consumption and labor allocations when prices are flexible. In this case, total consumption and total labor effort in the home country (denoted with the superscript  $fl$ ) are given by

$$c_t^{fl} = \frac{z_t^{\gamma\eta + (1-\gamma)} z_t^{*(1-\eta)\gamma}}{\frac{\theta}{1-\theta}} \quad (28)$$

and

$$l^{fl} = \frac{2\gamma\eta + (1-\gamma)}{\frac{\theta}{1-\theta}}. \quad (29)$$

With flexible prices, total consumption depends only on real shocks and is independent of monetary policy. In response to a positive productivity shock in the home country, total consumption increases more in the home country than in the foreign country. Since this shock affects total consumption differently in the two countries, it is associated with an equilibrium real interest rate differential across the two countries. Note also that, since foreign-traded goods become relatively more expensive than home goods (traded and nontraded), agents substitute consumption toward goods produced in the home country

and away from goods produced in the foreign country.<sup>10</sup> Labor effort in each sector remains unchanged.

## 2. MONETARY POLICY

In this section, I start by studying the implications of nontraded goods for the nature of relative price differentials across countries under a fixed exchange rate regime. I then turn to the implications of the presence of nontraded goods for the optimal response of monetary policy to country-specific shocks.

### Relative Price Differentials

Under a fixed nominal exchange rate regime, it follows from equation (24) that home and foreign monetary stances,  $\mu$  and  $\mu^*$ , are proportional. That is,  $\mu_t = \bar{e}\mu_t^*$ , where  $\bar{e}$  is the fixed level of the nominal exchange rate.<sup>11</sup> The price level in the home country,  $P_t$ , is given by equation (26) while the price level in the foreign country (expressed in foreign currency units),  $P_t^*$ , is given by

$$P_t^* = \frac{1}{\bar{e}} \frac{\theta}{\theta - 1} E_{t-1} \left[ \frac{\mu_t}{z_t} \right]^{\eta\gamma} E_{t-1} \left[ \frac{\mu_t}{z_t^*} \right]^{(1-\eta)\gamma+1-\gamma}.$$

The relative price across countries is then given by

$$\frac{\bar{e}P_t^*}{P_t} = \left( \frac{E_{t-1} \left[ \frac{\mu_t}{z_t^*} \right]}{E_{t-1} \left[ \frac{\mu_t}{z_t} \right]} \right)^{1-\gamma}.$$

Note that when  $\gamma \rightarrow 1$  (that is, when agents do not consume local-nontraded goods and consume the same basket of traded goods), the relative price across countries is constant. This feature results from the fact that home and foreign agents consume the exact same basket of goods, and the nominal exchange rate is constant. Therefore, without nontraded goods, the model cannot account for the observed relative price differentials across countries when the nominal exchange rate is fixed.<sup>12</sup>

In the presence of nontraded goods ( $\gamma < 1$ ), home and foreign agents consume distinct baskets of goods, and country-specific shocks lead to relative price differentials across countries (one period after the shock) under a fixed

<sup>10</sup> In the home country, for example, it follows from the pricing rules and demand functions presented above that the relative price of home-traded goods in terms of foreign-traded goods is  $\frac{P_{H,t}}{P_{F,t}} = \frac{z_t^*}{z_t}$ , and the ratio of home to foreign-traded goods consumed is  $\frac{c_{H,t}}{c_{F,t}} = \frac{\eta}{1-\eta} \frac{z_t}{z_t^*}$ .

<sup>11</sup> Note that a fixed exchange rate regime can be interpreted as a monetary policy prescription where home and foreign monetary policy stances are proportional. Later in this section, I will show under which conditions such a prescription is optimal.

<sup>12</sup> See, for example, Duarte (2003) for empirical evidence on relative price differentials across countries in the European Union.

exchange rate regime. With nontraded goods, the model is consistent with observed relative price across countries when the exchange rate is fixed.

### Country-Specific Shocks

I now turn to the implications of the presence of nontraded goods for the optimal response of monetary policy to country-specific shocks. I follow Corsetti and Pesenti (2001) and Devereux and Engel (2003) and assume that the monetary authority in each country commits to preannounced state-contingent monetary stances,  $\{\mu(s_\tau), \mu^*(s_\tau)\}_{\tau=t}^\infty$ , chosen to maximize the (non-monetary) expected utility of the country's representative agent and taking the monetary policy rule of the other country as given.<sup>13</sup> That is, the monetary authority in the home country solves

$$\max_{\{\mu(s_{t+\tau})\}_{\tau=0}^\infty} E_{t-1} \left[ \sum_{\tau=t}^{\infty} \beta^{\tau-t} (\ln c(s_\tau) - l(s_\tau)) \right], \quad (30)$$

taking  $\{\mu^*(s_{t+\tau}), z(s_{t+\tau}), z^*(s_{t+\tau})\}_{\tau=0}^\infty$  as given. It is shown in the Appendix C that the optimal monetary stances of the home and foreign monetary authorities are given by

$$\mu_t = \left[ \frac{\eta\gamma + (1-\gamma)}{z_t E_{t-1} \left( \frac{\mu_t}{z_t} \right)} + \frac{(1-\eta)\gamma}{z_t^* E_{t-1} \left( \frac{\mu_t^*}{z_t^*} \right)} \right]^{-1}, \quad (31)$$

and

$$\mu_t^* = \left[ \frac{\eta\gamma}{z_t E_{t-1} \left( \frac{\mu_t^*}{z_t} \right)} + \frac{(1-\eta)\gamma + (1-\gamma)}{z_t^* E_{t-1} \left( \frac{\mu_t^*}{z_t^*} \right)} \right]^{-1}. \quad (32)$$

Note first that, in the absence of nontraded goods (that is,  $\gamma \rightarrow 1$ ), the two monetary authorities choose to respond equally to country-specific shocks. Therefore, when home and foreign agents consume exactly the same basket of goods, the nominal exchange rate does not respond to country-specific productivity shocks: a fixed nominal exchange rate regime is consistent with the optimal monetary policy rules. This result replicates the findings in Devereux and Engel (2003) and Corsetti and Pesenti (2001). Note, however, that as we have seen, in this case the model misses on an important aspect of the empirical evidence by not implying relative price differentials across countries.

When agents consume local-nontraded goods (that is,  $\gamma < 1$ ), consumption baskets differ across countries, and the rules above imply that the home

<sup>13</sup> As it is standard in the literature, I assume that governments ignore the utility from real balances and consider optimal policies when  $\chi \rightarrow 0$ .

and foreign monetary authorities choose to respond differently to country-specific productivity shocks. Therefore, the nominal exchange rate responds to country-specific productivity shocks (equation (24)) and a fixed nominal exchange rate regime is not consistent with the optimal monetary rules. Furthermore, consistent with the evidence, if the two countries adopt a fixed exchange rate regime, the model implies relative price differentials across countries.

In response to a positive productivity shock in the home country (and starting from a symmetric equilibrium), rules (31) and (32) require a larger expansionary monetary policy (higher  $\mu$ ) in the home country than in the foreign country when  $\gamma < 1$ . These responses are associated with a depreciation of the nominal exchange rate (equation (24)). As in the case with flexible prices, total consumption increases more in the home country than in the foreign country in response to a positive real shock in the home country. The terms of trade, however, are not affected by this shock (as they would be if prices were flexible) since prices are preset in the buyer's currency. That is, there is no consumption substitution toward goods produced in the home country: consumption of all goods in a given country increases in the same proportion.

In a fixed exchange rate regime, identical responses by both home and foreign monetary authorities cannot generate the distinct consumption paths across countries associated with a country-specific shock. This result follows from the fact that countries share a common nominal interest rate and prices are preset. Therefore, the optimal responses by the monetary authorities, which generate the distinct response of consumption across countries, require independent monetary policies and, hence, an adjustable nominal exchange rate. This result is consistent with Friedman's (1953) case in favor of nominal exchange rate flexibility in the presence of nominal price rigidities and country-specific shocks.

### 3. CONCLUSION

In this article I develop a two-country general equilibrium model with traded and nontraded goods where goods prices are set one period in advance in the currency of the buyer. The monetary authority in each country follows a state-contingent monetary policy rule that maximizes the expected utility of the representative agent.

I show that the presence of nontraded goods has important implications for the nature of price differentials across countries under a fixed exchange rate regime and for the optimal degree of nominal exchange rate variability in response to country-specific shocks. When there are nontraded goods, agents in different countries consume different baskets of goods and the optimal monetary policy implies that the nominal exchange rate varies in response

to country-specific shocks. In contrast, when all goods are traded, agents in different countries consume the same basket of goods, and the optimal monetary policy implies that the nominal exchange rate is constant in response to country-specific shocks.

The results in this article indicate the importance of observed price differentials across countries in the evaluation of alternative exchange rate regimes. The results indicate that the existence of nontraded goods imposes a welfare cost to countries in a currency area that face country-specific shocks.

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## APPENDIX A: THE AGENT'S PROBLEM

### Intratemporal problem

Given the consumption index (4), the utility-based price index  $P_H$  is the price of  $c_H$  that solves

$$\min_{c(h,j)} \int_0^1 c(h,j) P_H(h) dh$$

s.t.

$$c_H(j) = \left[ \int_0^1 c(h,j)^{\frac{\theta-1}{\theta}} dh \right]^{\frac{\theta}{\theta-1}} = 1.$$

The equation for  $P_H$  in (10) in the text is the solution to this problem. The other price indexes are obtained from analogous problems.

To solve for the demand for individual variety  $h$ , consider the problem of allocating a given level of nominal expenditure  $X_H$  among varieties of home-traded good:

$$\max_{c(h,j)} \left[ \int_0^1 c(h,j)^{\frac{\theta-1}{\theta}} dh \right]^{\frac{\theta}{\theta-1}}$$

s.t.

$$\int_0^1 c(h,j) P_H(h) dh = X_H.$$

From the first-order conditions for any pair of varieties  $h$  and  $h'$  we have

$$\begin{aligned}
\frac{c(h, j)}{c(h', j)} &= \left( \frac{P_H(h)}{P_H(h')} \right)^{-\theta} \Leftrightarrow \\
c(h, j)^{\frac{\theta-1}{\theta}} P_H(h')^{1-\theta} &= c(h', j)^{\frac{\theta-1}{\theta}} P_H(h)^{1-\theta} \Rightarrow \\
\left( \int_0^1 c(h, j)^{\frac{\theta-1}{\theta}} P_H(h')^{1-\theta} dh' \right)^{\frac{\theta}{\theta-1}} &= \\
\left( \int_0^1 c(h', j)^{\frac{\theta-1}{\theta}} P_H(h)^{1-\theta} dh' \right)^{\frac{\theta}{\theta-1}} &\Leftrightarrow \\
c(h, j) \underbrace{\left( \int_0^1 P_H(h')^{1-\theta} dh' \right)^{\frac{\theta}{\theta-1}}}_{P_H^{-\theta}} &= \\
P_H(h)^{-\theta} \underbrace{\left( \int_0^1 c(h', j)^{\frac{\theta-1}{\theta}} dh' \right)^{\frac{\theta}{\theta-1}}}_{c_H(j)} &\Leftrightarrow \\
c(h, j) &= \left( \frac{P_H(h)}{P_H} \right)^{-\theta} c_H(j). \quad (33)
\end{aligned}$$

Note that by rearranging equation (33) we obtain  $\int_0^1 c(h, j) P_H(h) dh = P_H c_H(j)$ .

Following analogous derivations, we obtain

$$c_H(j) = \eta \frac{P_T}{P_H} c_T(j)$$

and

$$c_T(j) = \gamma \frac{P}{P_T} c(j).$$

Combining these two expressions with equation (33) yields equation (11) in the text. Equations (12) and (13) are obtained in a similar way.

### Intertemporal problem

The problem of home agent  $j$ , who produces traded variety  $h$  and nontraded variety  $n$ , is

$$\max E_0 \sum_{t=0}^{\infty} \beta^t \left( \ln c_t(j) + \chi \ln \frac{M_t(j)}{P_t} - l_t(j) \right),$$

subject to the budget constraint

$$P_t c_t(j) + \sum_{s_{t+1}} Q_{s_{t+1}|s_t} B_{s_{t+1}}(j) + M_t(j) \leq R_t(j) + B_{s_t}(j) + M_{t-1}(j) + T_t(j),$$

where revenues,  $R_t(j)$ , and labor effort,  $l_t(j)$ , are given by

$$R_t(j) = P_{H,t}(h) \int_0^1 c_t(h, i) di + e_t P_{H,t}^*(h) \int_0^1 c_t^*(h, i^*) di^* + P_{N,t}(n) \int_0^1 c_t(n, i) di,$$

and

$$l_t(j) = l_{T,t}(j) + l_{N,t}(j) = \frac{1}{z_t} \left( \int_0^1 c_t(h, i) di + \int_0^1 c_t^*(h, i^*) di^* + \int_0^1 c_t(n, i) di \right).$$

The first-order conditions with respect to  $c_t(j)$ ,  $M_t(j)$ , and  $B_{s_{t+1}}(j)$  are, respectively,

$$\frac{1}{c_t(j)} = \lambda_t(j) P_t, \quad (34)$$

$$\frac{\chi}{M_t(j)} = \lambda_t(j) - \beta E_t[\lambda_{t+1}(j)], \quad (35)$$

and

$$\lambda_{s_t}(j) Q_{s_{t+1}|s_t} = \beta \pi(s_{t+1}|s_t) \lambda_{s_{t+1}}(j), \quad (36)$$

where  $\pi(s_{t+1}|s_t)$  is the conditional probability of event  $s_{t+1}$ , given  $s_t$ .

Recall that pricing decisions are made before the realization of period  $t$  shocks. Therefore, the first-order conditions with respect to  $P_{H,t}(h)$ ,  $P_{H,t}^*(h)$ , and  $P_{N,t}(n)$  are, respectively,

$$E_{t-1} \left[ \underbrace{-(-\theta) \frac{\int_0^1 c_t(h, i) di}{z_t P_{H,t}(h)}}_{\frac{\partial l_t(j)}{\partial P_{H,t}(h)}} + \lambda_t(j) \underbrace{(1 - \theta) \int_0^1 c_t(h, i) di}_{\frac{\partial R_t(j)}{\partial P_{H,t}(h)}} \right] = 0, \quad (37)$$

$$E_{t-1} \left[ -\theta \frac{\int_0^1 c_t^*(h, i) di}{z_t P_{H,t}^*(h)} + \lambda_t(j) (1 - \theta) \int_0^1 c_t^*(h, i) di \right] = 0, \quad (38)$$

and

$$E_{t-1} \left[ -\theta \frac{\int_0^1 c_t(n, i) di}{z_t P_{N,t}(n)} + \lambda_t(j) (1 - \theta) \int_0^1 c_t(n, i) di \right] = 0. \quad (39)$$

All agents within one country solve identical problems and therefore make identical choices (even though they produce differentiated varieties of the traded and nontraded goods). In a symmetric equilibrium in which all individual variables are identical, it follows that aggregate quantities are equal to per capita quantities (since the measure of agents is one in both countries) and that the price indexes  $P_{H,t}$ ,  $P_{H,t}^*$ , and  $P_{N,t}$  equal the price of its varieties ( $P_{H,t}(h)$ ,  $P_{H,t}^*(h)$ , and  $P_{N,t}(n)$ , respectively). That is, per capita consumption of variety  $h$  in the home country is  $c_t(h, i)$ ,  $\forall i$ , which is equal to aggregate consumption of this variety:  $c_{H,t} \equiv \int_0^1 c_t(h, i) di = c_t(h, i)$ . Per capita total consumption is  $c_t(i)$ , which is equal to aggregate total consumption:  $c_t \equiv \int_0^1 c_t(i) di = c_t(i)$ . In what follows, I focus on the symmetric equilibrium and therefore drop the index for the agent.

Combining equations (36) and (34) implies that

$$Q_{s_{t+1}|s_t} = \beta \pi(s_{t+1}|s_t) \frac{P_{s_t} c_{s_t}}{P_{s_{t+1}} c_{s_{t+1}}}. \quad (40)$$

Let's denote the gross return in period  $t + 1$  of a riskless bond as  $1 + i_{t+1}$ . Note that the gross return  $1 + i_{t+1}$  is equal to the reciprocal of the price in period  $t$  of a bond paying one unit of home currency in period  $t + 1$  with certainty,  $Q_{t+1}$ . Since asset markets are complete, it follows that  $Q_{t+1} = E_t[Q_{s_{t+1}|s_t}]$ . And from (40), it follows that

$$\frac{1}{1 + i_{t+1}} = Q_{t+1} = \beta E_t \left[ \frac{P_t c_t}{P_{t+1} c_{t+1}} \right]. \quad (41)$$

The first-order condition for money, equation (35), can be written as

$$\chi \frac{P_t c_t}{M_t} = 1 - \beta E_t \left[ \frac{P_t c_t}{P_{t+1} c_{t+1}} \right],$$

in a symmetric environment. Combining this expression with equation (41) yields the money demand equation (18) in the text.

I now turn to the pricing equations (37) through (39). Note from equation (11) that, in a symmetric equilibrium, expenditure in the composite good of home-traded varieties is a constant share (given by  $\eta\gamma$ ) of total expenditure, that is,  $P_{H,t} c_{H,t} = \eta\gamma P_t c_t$ . Equation (37) can be simplified by making use of equation (34) and this relationship between total expenditure and expenditure in the composite good of home-traded varieties. Taking into account that  $P_{H,t}(h)$  is known as of  $t - 1$ , equation (37) can be rewritten as

$$\frac{\theta}{P_{H,t}(h)^2} E_{t-1} \left[ \frac{\eta\gamma P_t c_t}{z_t} \right] = \frac{(\theta - 1)}{P_{H,t}(h)} \eta\gamma,$$

from where equation (21) in the text directly follows. Equations (22) and (23) can be obtained in a similar fashion.



The foreign agent solves a similar problem to the one of the home agent. Note, however, that since bonds are denominated in home currency, the budget constraint of foreign agent  $j^*$  (expressed in foreign currency units) is

$$\begin{aligned} & P_t^* c_t^*(j^*) + \sum_{s_{t+1}} \frac{Q_{s_{t+1}|s_t}}{e_t} B_{s_{t+1}}^*(j^*) + M_t^*(j^*) \\ & \leq R_t^*(j^*) + \frac{B_{s_t}^*(j^*)}{e_t} + M_{t-1}^*(j^*) + T_t^*(j^*). \end{aligned}$$

The first-order condition with respect to bond holdings is (in a symmetric equilibrium)

$$Q_{s_{t+1}|s_t} = \beta \pi(s_{t+1}|s_t) \frac{e_{s_t} P_{s_t}^* c_{s_t}^*}{e_{s_{t+1}} P_{s_{t+1}}^* c_{s_{t+1}}^*}.$$

Combining this equation with equation (40) implies that  $\frac{P_{s_{t+1}} c_{s_{t+1}}}{e_{s_{t+1}} P_{s_{t+1}}^* c_{s_{t+1}}^*} = \frac{P_{s_t} c_{s_t}}{e_{s_t} P_{s_t}^* c_{s_t}^*}$ . By iterating this equation backwards we obtain  $\frac{P_{s_t} c_{s_t}}{e_{s_t} P_{s_t}^* c_{s_t}^*} = \frac{P_0 c_0}{e_0 P_0^* c_0^*}$ . Assuming an equal wealth distribution across countries at date 0 implies  $\frac{P_0 c_0}{e_0 P_0^* c_0^*} = 1$ , which gives equation (24) in the text.

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## APPENDIX B: SOLUTION OF THE MODEL

To write real aggregate consumption as a function of real shocks ( $z_t$  and  $z_t^*$ ) and monetary stances ( $\mu_t$  and  $\mu_t^*$ ), note that, in equilibrium,  $P_t c_t = \mu_t$ . Using equations (7) and (8), and the pricing equations (21) through (23), we can write the price level  $P_t$  as

$$P_t = \underbrace{\left( \left( \frac{\theta}{\theta-1} E_{t-1} \left( \frac{\mu_t}{z_t} \right) \right)^\eta \left( \frac{\theta}{\theta-1} E_{t-1} \left( \frac{\mu_t}{z_t^*} \right) \right)^{1-\eta} \right)^\gamma}_{P_{t,t}}$$

$$\underbrace{\left( \frac{\theta}{\theta-1} E_{t-1} \left( \frac{\mu_t}{z_t} \right) \right)^{1-\gamma}}_{P_{N,t}} = \frac{\theta}{\theta-1} \left( E_{t-1} \left( \frac{\mu_t}{z_t} \right) \right)^{\eta\gamma+(1-\gamma)}$$

$$\left( E_{t-1} \left( \frac{\mu_t}{z_t} \right) \right)^{(1-\eta)\gamma}.$$

Total consumption is then given by

$$\begin{aligned} c_t &= \frac{\mu_t}{P_t} \\ &= \frac{\mu_t}{\frac{\theta}{\theta-1} \left( E_{t-1} \left( \frac{\mu_t}{z_t} \right) \right)^{\eta\gamma+(1-\gamma)} \left( E_{t-1} \left( \frac{\mu_t}{z_t^*} \right) \right)^{(1-\eta)\gamma}}. \end{aligned}$$

The expression for foreign aggregate consumption can be obtained in a similar way.

From the market clearing conditions for home-traded goods and nontraded goods, it follows that labor effort in the home-traded and nontraded sectors can be written as, respectively,

$$\begin{aligned} l_{T,t} &= \frac{c_{H,t} + c_{H,t}^*}{z_t}, \\ &= \frac{1}{z_t} \frac{\gamma\eta}{\theta-1} \left( \frac{\mu_t}{E_{t-1} \left( \frac{\mu_t}{z_t} \right)} + \frac{\mu_t^*}{E_{t-1} \left( \frac{\mu_t^*}{z_t} \right)} \right), \end{aligned}$$

and

$$\begin{aligned} l_{N,t} &= \frac{c_{N,t}}{z_t}, \\ &= \frac{1}{z_t} \frac{1-\gamma}{\theta-1} \frac{\mu_t}{E_{t-1} \left( \frac{\mu_t}{z_t} \right)}, \end{aligned}$$

where the second equalities follow from substituting for the demand functions. Total labor effort is simply given by  $l_t = l_{T,t} + l_{N,t}$ .

If, instead of setting prices before the realization of uncertainty, producers set prices after observing the current realization of productivity and monetary stance shocks (flexible prices) then, as noted in the text, the pricing equations (21) through (23) hold in every state of the world and not only in expectation. That is, with flexible prices, the prices of nontraded goods and home-traded goods at home and abroad are given by

$$P_{N,t} = P_{H,t} = \frac{\theta}{\theta-1} \frac{\mu_t}{z_t},$$

and

$$P_{H,t}^* = \frac{P_{H,t}}{e_t}.$$

The above expressions for aggregate consumption and total labor effort in the home country simplify to equations (28) and (29) in the text.

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**APPENDIX C: OPTIMAL POLICIES**

The monetary authority in each country commits to state-contingent monetary stances  $\mu (s_t)$  and  $\mu^* (s_t)$ , chosen to maximize the (non-monetary) expected utility of the country's representative agent, taking the monetary policy rule of the other country as given. The problem of the home monetary authority is

$$\max_{\{\mu(s_{t+\tau})\}_{\tau=0}^{\infty}} E_{t-1} \left[ \sum_{\tau=t}^{\infty} \beta^{\tau-t} (\ln c (s_{\tau}) - l (s_{\tau})) \right], \quad (42)$$

taking  $\{\mu^* (s_{t+\tau}), z (s_{t+\tau}), z^* (s_{t+\tau})\}_{\tau=0}^{\infty}$  as given.

Let's focus on the choice of  $\mu (s_t)$  and rewrite (42) as

$$\max_{\{\mu(s_{t+\tau})\}_{\tau=0}^{\infty}} \sum_{s_t} \pi (s_t | s_{t-1}) [\ln c (s_t) - l (s_t)] + E_{t-1} \left[ \sum_{\tau=t+1}^{\infty} \beta^{\tau-t} (\ln c (s_{\tau}) - l (s_{\tau})) \right].$$

First, note that  $E_{t-1} [l (s_t)] = l^l (s_t)$ . Second, note that, by using equation (25), we have

$$\begin{aligned} \ln c_{s_t} &= \ln \mu_{s_t} - (\gamma \eta + 1 - \gamma) \ln \left( \sum_{s_t} \pi (s_t | s_{t-1}) \frac{\mu (s_t)}{z (s_t)} \right) \\ &\quad - \gamma (1 - \eta) \ln \left( \sum_{s_t} \pi (s_t | s_{t-1}) \frac{\mu (s_t)}{z^* (s_t)} \right) + a, \end{aligned}$$

where  $a$  is a constant.

The first-order condition of the monetary authority's problem with respect to  $\mu (\tilde{s}_t)$  is

$$\begin{aligned} &\frac{\pi (\tilde{s}_t | s_{t-1})}{\mu (\tilde{s}_t)} - \sum_{s_t} \pi (s_t | s_{t-1}) \\ &\left[ \frac{(\gamma \eta + 1 - \gamma) \frac{\pi (\tilde{s}_t | s_{t-1})}{z (\tilde{s}_t)}}{\sum_{s_t} \pi (s_t | s_{t-1}) \frac{\mu (s_t)}{z (s_t)}} + \frac{\gamma (1 - \eta) \frac{\pi (\tilde{s}_t | s_{t-1})}{z^* (\tilde{s}_t)}}{\sum_{s_t} \pi (s_t | s_{t-1}) \frac{\mu (s_t)}{z^* (s_t)}} \right] = 0. \end{aligned}$$

Since the term in square brackets is independent of  $s_t$  and  $\sum_{s_t} \pi (s_t | s_{t-1}) = 1$ , we can rewrite the above first-order condition as

$$\frac{1}{\mu (\tilde{s}_t)} = \frac{\gamma \eta + 1 - \gamma}{z (\tilde{s}_t) \sum_{s_t} \pi (s_t | s_{t-1}) \frac{\mu (s_t)}{z (s_t)}} + \frac{\gamma (1 - \eta)}{z^* (\tilde{s}_t) \sum_{s_t} \pi (s_t | s_{t-1}) \frac{\mu (s_t)}{z^* (s_t)}},$$

which yields equation (31) in the text.

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