

Consumer Search, Incomplete Exchange Rate Pass-Through and Optimal Interest Rate Policy\*

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Abstract: This paper studies utility-maximizing monetary policy in a two-country economy with consumer search frictions. Search frictions provide a micro-foundation for incomplete exchange rate pass-through and international deviations from the law of one price. I show that optimal interest rate policy targets deviations from the law of one price and acts to mitigate the effect of search frictions. In a quantitative setting, with internationally correlated technology and preference shocks, optimal policy generates positive cross-country correlation of nominal interest rates.

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## 1. INTRODUCTION

Exchange rate pass-through to import prices is a key factor in the design of monetary policy in open economies. Research concerned with the policy implications of incomplete exchange rate pass-through has focused primarily on frictions associated with infrequent price adjustment.<sup>1</sup> This paper studies utility-maximizing monetary policy in an open economy, where prices are flexible, but exchange rate pass-through is incomplete due to consumer search frictions.<sup>2</sup> Search frictions provide a micro-foundation for incomplete exchange rate pass-through and international deviations from the law of one price. The main result of the paper is that monetary policy should target deviations from the law of one price and mitigate the effect of search frictions.

To understand the role of consumer search frictions for monetary policy, consider a standard, two-country (home and foreign), two-good economy, with country-specific real shocks to technology or preferences, and a cash-in-advance restriction on household transactions.<sup>3</sup> Suppose the home country receives a positive shock that causes its terms of trade - the relative price of home's output - to deteriorate. As home consumption and labor supply rise, the optimal policy response is to raise the nominal interest rate. This policy lowers (raises) labor supply in the home (foreign) country, whilst allowing both countries to benefit from an increase in consumption. In this example, interest rate policy is driven by international risk sharing and the efficient use of resources (specifically, labor) across countries.

When there are consumer search frictions, movements in the real wage affect the opportunity

cost of search, and this leads to an endogenous price-markup. Because the opportunity cost of search may differ across countries, so can markups. Consumer search frictions therefore result in international deviations from the law of one price. Deviations from the law of one price mean that country-specific real shocks generate smaller movements in the terms of trade than when product markets are frictionless. There is also a reduced incentive to share risk internationally because consumption implicitly accounts for local-market (non-traded) search activity.

I start by providing analytical solutions for optimal interest rate policy when international deviations from the law of one price and the price-markup for the domestic good are the only relevant policy targets. I show that, for a given markup, the home interest rate should fall when the export price of the home good rises relative to the domestic price; that is, the optimal interest rate depends negatively on the deviation from the law of one price. Interest rates do not account directly for search activities over imported goods. Thus, whilst monetary policy acts to stabilize deviations from the law of one price by raising the opportunity cost of search in the domestic market, the policy maker is forced to trade-off one inefficiency - the deviation from the law of one price - for another - the domestic price-markup.

I also find that the optimal response of the interest rate is stronger - i.e., monetary policy is more aggressive - when exchange rate pass-through is low. This is reflected in the finding that, for a given policy in each country, the lower is the degree of exchange rate pass-

through, the greater is the movement in the deviation from the law of one price, and the greater (smaller) is the change in relative home consumption (output). Optimal policy acts to bring movements in the terms of trade closer to that which would occur with full pass-through. However, due to the trade-off generated by deviations from the law of one price and the domestic price-markup, optimal policy does not replicate the outcome with frictionless product markets.

I then calibrate the model and study the response of nominal interest rates to internationally correlated technology and preference shocks. In doing so, I compare the interest rate response under optimal policy with a Taylor-type interest rate rule.<sup>4</sup> When there are technology and preference shocks, optimal policy generates positive cross-country correlation of nominal interest rates, and a negative correlation between output and the terms of trade. The cross-correlation of nominal interest rates is less than the cross-correlation of output, whereas the opposite holds when monetary policy is specified as a Taylor rule. When technology shocks are the only source of aggregate uncertainty, optimal policy produces a higher cross-correlation of interest rates, but there is a positive correlation between output and the terms of trade.

I investigate these results by performing a sensitivity analysis. I find that in economies with lower exchange rate pass-through, the cross-country correlation of nominal interest rates is considerably higher, even when there are technology and preference shocks. This result is consistent with the analytical section of the paper which implies monetary policy is more

aggressive when exchange rate pass-through is low. Moreover, in the benchmark calibration, the Armington elasticity (the elasticity of substitution between home and foreign goods) is set above unity. The cross-correlation of nominal interest rates rises once this elasticity is lowered. Thus, it is quite possible to generate higher cross-country correlation of nominal interest rates than output under optimal policy, even when there is a negative correlation between output and the terms of trade.

The empirical relevance of consumer search frictions for international deviations from the law of one price can be understood by considering the potential sources of price dispersion within countries. Kaplan and Menzio (2015) use the Kilts-Nielsen Consumer Panel data set and find that the variation in price dispersion across different types of goods is consistent with the view that search frictions are an important component of overall price dispersion.<sup>5</sup> Time use studies, such as Aguiar and Hurst (2005), find that consumers with a lower opportunity cost of time spend relatively more time shopping per-purchase, with shopping time negatively related to the purchase price of a good.<sup>6</sup>

In an international context, search frictions imply firms choose different markups for the same good in different markets, and thus price-to-market.<sup>7</sup> In corroboration of this search-based hypothesis, Alessandria and Kaboski (2011) study pricing-to-market using unit values for the universe of US exports. They find that wages have substantially more explanatory power for pricing-to-market than income per-capita, and that pricing-to-market appears strongest for those goods for which search frictions are likely to be important. In the model developed

below, an increase in the wage raises the opportunity cost of search. Firms account for the cross-country wage differential when choosing prices in their domestic and export markets. This generates deviations from the law of one price.

The results presented in this paper emphasize the positive cross-country correlation of nominal interest rates and output reported in Kollmann (2001) and Henriksen, Kydland, and Sustek (2013). Kollmann explains the cross-country correlation of interest rates and output using a New Keynesian model, where monetary policy is specified as an exogenous process for the money supply. Henriksen, Kydland, and Sustek use a flexible-price model with a Taylor-type interest rate feedback rule. There are important differences between these papers and mine. I consider interest rate movements to be the outcome of an optimal policy decision taken by each country. As exchange rate pass-through falls, the cross-country correlation of interest rates rises.<sup>8</sup> Second, the model of incomplete pass-through I adopt implies that the terms of trade have a data-consistent correlation with output.

The contribution of this paper can also be understood by placing it relative to a literature focusing on real rigidities, such as costly distribution (Corsetti and Dedola 2005) and deep habits (Ravn, Schmitt-Grohe, and Uribe 2007), as a source of incomplete exchange rate pass-through.<sup>9</sup> These real rigidities have been successfully combined with the assumption of nominal rigidity - in Corsetti, Dedola, and Leduc (2008) and Jacob and Uuskula (2016) - to rationalize deviations from the law of one price with only a small amount of price-stickiness. This paper focuses on search frictions as a source of incomplete pass-through,

without nominal rigidity. When pass-through is incomplete, interest rate policy targets deviations from the law of one price.<sup>10</sup>

There are other papers which focus on the role of search frictions in the product market for open economy models of the business cycle. This paper follows Alessandria's (2009) general equilibrium version of Burdett and Judd's (1983) model of consumer search. Drozd and Nosal (2012b) develop a model with marketing frictions in a search and matching environment. They account for the discrepancy between the low short-run and high long-run estimates of the price elasticity of trade flows (the elasticity puzzle). Bai and Rios-Rull (2015) use a model of directed search and analyze how demand shocks can generate low cross-country correlation of consumption relative to that of output (the quantity anomaly).

The remainder of the paper is organized as follows. I develop a two-country open economy monetary model with consumer search frictions in section 2. Analytical results for optimal interest rate policy are discussed in section 3. I provide a quantitative analysis of the model in section 4. Section 5 concludes.

## 2. MODEL ECONOMY

This section outlines the model economy. There are two identical countries - home and foreign - each populated by a continuum of households with mass normalized to one. Countries are specialized in the production of a single homogeneous good. In each country, households supply labor to firms and consume a basket of domestic and imported goods. Households actively search to purchase goods and there is a cash-in-advance restriction on household

transactions. Each government controls the money supply through lump-sum transfers. Finally, there are shocks to technology and preferences in each country.

In what follows, I focus the exposition of the model on the home country, with the understanding that analogous expressions hold for the foreign country. Consumption, output, and the nominal price of the home/foreign output are denoted with  $h/f$ -subscripts. Asterisks denote foreign country variables.

### 2.1. Households

Households have the following intertemporal utility function,

$$\sum_{t=0}^{\infty} \beta^t \left[ u(c_t) - \theta_t \left( \frac{l_t^{1+v}}{1+v} + \eta s_t \right) \right] \quad (1)$$

where  $c_t$  is total consumption - defined over the home ( $c_{h,t}$ ) and foreign ( $c_{f,t}$ ) good - and  $l_t$  and  $s_t$  are the mass of workers and shoppers, respectively.<sup>11</sup> Utility from total consumption is increasing and strictly concave. The total mass of shoppers,  $s_t = s_{h,t} + s_{f,t}$ , is such that  $s_{h,t}$  ( $s_{f,t}$ ) shoppers search for the home (foreign) good. The parameter  $\beta \in (0, 1)$  is the discount factor,  $v$  is the inverse Frisch elasticity of labor supply with respect to wages, and  $\eta \geq 0$  captures the exogenous dis-utility of search relative to work. Finally, I follow Alessandria (2009) and introduce a preference parameter, denoted  $\theta_t$ , that affects the marginal dis-utility of labor.<sup>12</sup>

Households enter period  $t$  with nominal wealth  $\mathcal{W}_t$ . They receive a lump-sum transfer  $T_t$ , choose money holdings  $M_t$ , domestic bond holdings  $B_t$ , and purchase  $A_{t+1}$  units of home-



currency, internationally-traded, state-contingent securities.<sup>1</sup> In the asset market, at the beginning of period  $t$ , households face the following constraint,

$$M_t + B_t + E_t Q_{t,t+1} A_{t+1} - T_t \leq W_t \quad (2)$$

where  $Q_{t,t+1}$  is the beginning of period  $t$  price of securities normalized by the probability of the occurrence of the state. After leaving the asset market, households enter the goods and labor markets.

In the goods market, household members search across different firms and purchase goods using a reservation-price strategy. A fraction  $z$  of shoppers receive a single price quote. The remaining  $1 - z$  shoppers receive two price quotes.<sup>13</sup> Firms do not know whether a household has received a second price quote, are indifferent between setting prices within an equilibrium range, and price according to a mixed strategy within this range. The cumulative distribution of the lowest price quote received by a household is,

$$J(p_{i,t}) = zF(p_{i,t}) + (1 - z) \{1 - [1 - F(p_{i,t})]^2\} \quad \text{for } i = \{h, f\} \quad (3)$$

where  $p_{i,t}$  is the price quote of good  $i$  and  $F(p_{i,t})$  is the distribution function. A good is purchased at the expected price  $P_{i,t}$ , with probability  $J(p_{i,t})$ , only when  $p_{i,t} \leq \tilde{p}_{i,t}$ , where  $\tilde{p}_{i,t}$  is the reservation price.

In period  $t$ , the shopper expects to purchase  $\sum_i P_{i,t} J(\tilde{p}_{i,t}) = \sum_i \int_0^{\tilde{p}_{i,t}} p_{i,t} dJ(p_{i,t})$  units of con-

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<sup>1</sup>Each security pays one unit of money at the beginning of period  $t + 1$  in a particular state.

sumption, subject to the following cash-in-advance restriction,

$$\sum_i P_{i,t} c_{i,t} \leq M_t \quad (4)$$

where  $c_{i,t} = s_{i,t} \times J(\tilde{p}_{i,t})$ . Households also receive nominal labor income,  $W_t l_t$ , and dividends from firms,  $\Phi_t$ . Nominal wealth at the beginning of period  $t + 1$  is,

$$W_{t+1} = M_t + R_t B_t + A_{t+1} - \sum_i P_{i,t} c_{i,t} + W_t l_t + \Phi_t \quad (5)$$

where  $R_t \geq 1$  is the gross nominal interest rate at date  $t$ .

Households maximize lifetime utility, equation (1), subject to the constraints specified in equations (2)-(5), choosing  $\{A_{t+1}, B_t, M_t\}_{t=0}^{\infty}$  and  $\{\tilde{p}_{i,t}, s_{i,t}, l_t\}_{t=0}^{\infty}$ . The first-order conditions imply,

$$Q_{t-1,t} = \frac{\beta u_{c_h}(t) / u_{c_h}(t-1)}{\tilde{p}_{h,t} / \tilde{p}_{h,t-1}} \quad \text{and} \quad E_t [Q_{t,t+1}] = 1/R_t \quad ; \quad Q_{t,t} \equiv 1 \quad (6)$$

and,

$$u_{c_h}(t) / u_{c_f}(t) = \tilde{p}_{h,t} / \tilde{p}_{f,t} \quad \text{and} \quad W_t / \tilde{p}_{h,t} = \theta_t R_t l_t^v / u_{c_h}(t) \quad (7)$$

and,

$$\eta \theta_t / u_{c_i}(t) = (1 - P_{i,t} / \tilde{p}_{i,t}) J(\tilde{p}_{i,t}) \quad (8)$$

where  $u_{c_i}(t)$  is the period  $t$  marginal utility with respect to the consumption of good  $i$ .

The first equation in (6) determines the price at time  $t$  of one unit of money at time  $t + 1$ , for each state of nature, normalized by the conditional probability of the occurrence of the

state. The second equation reflects the optimal choice of domestic bonds.<sup>14</sup> Equations (7) are intratemporal conditions that define the allocation of consumption between the home and foreign good (demand functions) and set the intratemporal marginal rate of substitution between consumption and leisure equal to the real wage, adjusted for the cost of holding money (labor-leisure condition).

Equation (8) determines the household's optimal search effort. Search is costly because it reduces the time that can be allocated to work or leisure. Each household faces a trade-off between allocating more time to search activities, with the expectation of paying  $P_{i,t}$  per-unit of consumption, versus receiving a lower price quote,  $p_{i,t}$ . This trade-off can be seen directly once equation (8) is re-written using the labor-leisure condition. In this case,  $\eta W_t / R_t l_t^\nu = J(\tilde{p}_{i,t})(\tilde{p}_{i,t} - P_{i,t})$ , where the left-hand side of this expression captures the opportunity cost of search. One implication of the cash-in-advance restriction on household transactions is that the cost of holding money affects search activity. If, for example, the interest rate rises, agents substitute out of consumption and into leisure, as in Cooley and Hansen (1989). With search frictions, however, the cost of holding money influences the markup charged by firms because the nominal interest rate affects the opportunity cost of search.

## 2.2. Firms

In each country, there are many firms producing a country-specific good. The mass of firms is normalized to one. Each firm has production function  $y_t = a_t l_t^{1-\alpha}$ , where  $a_t$  is a technology

parameter, and  $\alpha < 1$ . The profit for a firm serving the domestic and export market is,

$$\pi_t = p_{h,t}d_{h,t} - W_t l_{h,t} + e_t p_{h,t}^* d_{h,t} - W_t l_{h,t}^* \quad (9)$$

where  $d_{h,t} = z + 2(1-z)[1 - F(p_{h,t})]$  is the demand curve per-household for the domestic good, with an analogous condition for  $d_{h,t}^*$ , and  $e_t p_{h,t}^*$  is the home-currency export price.<sup>15</sup>

The firm maximizes profit per-shopper - choosing  $p_{h,t}$  and  $p_{h,t}^*$  - with reservation prices and input costs given, such that,  $d_{h,t} = c_{h,t}$  and  $d_{h,t}^* = c_{h,t}^*$ . The following proposition characterizes the optimal price chosen by firms in each market.

PROPOSITION 1. *The domestic and export market reservation prices for the home good are given by the following expressions,*

$$\tilde{p}_{h,t} = [1 + \mu_{h,t}/z] x_t \quad \text{and} \quad e_t \tilde{p}_{h,t}^* = [1 + (\mu_{h,t}^*/z^*) (e_t x_t^*/x_t)] x_t \quad (10)$$

where,

$$\mu_{h,t} \equiv [z\eta/(1-z)] W_t/R_t l_t^v x_t \quad \text{and} \quad x_t \equiv W_t l_t^\alpha / (1-\alpha) a_t \quad (11)$$

*The terms in square brackets in equations (10) are gross destination-specific markups and  $x_t$  is the marginal cost of production ( $\mu_{h,t}^*$  and  $x_t^*$  are defined similarly over foreign variables).*

PROOF. See Appendix. ■

The two pricing equations in Proposition 1 show that the markup is increasing in the exogenous relative dis-utility of search,  $\eta \geq 0$ . As  $\eta$  rises, search is relatively less attractive, and so the markup rises. The markup is also increasing in the probability that the household

will receive a single price quote,  $0 < z < 1$ . As  $z$  rises, fewer households receive a second price quote, and the goods market is less competitive. Due to the interaction between households and firms, the price-markup is endogenous, and due to the cash-in-advance constraint, the markup depends on the nominal interest rate. As in standard cash-in-advance models, a higher interest rate will reduce the return to work effort, since wage income is received only after a one period lag. With consumer search, a rise in the interest rate lowers the opportunity cost of search, forcing firms to reduce their markup.<sup>16</sup>

The second implication of Proposition 1 is the possibility of international deviations from the law of one price. Without consumer search frictions, flexible prices imply that the law of one price holds, and  $\tilde{p}_{h,t} = e_t \tilde{p}_{h,t}^*$ .<sup>17</sup> As Alessandria (2009) shows, when the opportunity cost of search differs across countries, this no longer need be the case. For example, suppose the exogenous component of search costs are equal across countries. Then, if  $W_t/l_t^v R_t < (e_t W_t^*)/l_t^{*v} R_t^*$ , the home good is relatively more expensive in the foreign country; i.e.,  $\tilde{p}_{h,t} < e_t \tilde{p}_{h,t}^*$ , and the home currency is undervalued (Engel 2011). This inequality reflects differences in the cost-adjusted terms-of-labor. Short-run adjustments in the terms-of-labor and the relative opportunity cost of search depend on the structure of the international asset market, which I discuss below.

Consumer search frictions also generate within-country price dispersion. Throughout the analysis, I use the coefficient of variation in posted prices as the measure of price dispersion. An analytical expression is provided in the following proposition.

PROPOSITION 2. *Price dispersion - as measured by the coefficient of variation in posted prices - is increasing in the destination-specific markup. Price dispersion in the domestic market is determined by the following expression,*

$$cv_t = \frac{\phi}{\Sigma + z/(1-z)\mu_{h,t}} \quad (12)$$

where  $\phi \equiv \{[z/(1-z)^2(2-z)] - \Sigma^2\}^{1/2}$  and  $\Sigma \equiv (1/2)[z/(1-z)^2] \ln(2/z-1)$  are positive coefficients.

PROOF. See Appendix. ■

Within-country price dispersion is comprised of the markup and the probability that the household will receive a single price quote. The dispersion of posted prices is falling in  $z$ , for a given markup, whereas price dispersion and the price-markup have a positive relationship.<sup>18</sup>

### 2.3. Foreign Economy and Equilibrium

The foreign resource (output and shopping) constraints are,

$$a_t^* (l_t^*)^{1-\alpha} = c_{f,t}^* + c_{h,t}^* \quad \text{and} \quad s_t^* = s_{f,t}^* + s_{h,t}^* \quad (13)$$

where  $s_{f,t}^* = c_{f,t}^*$  and  $s_{h,t}^* = c_{h,t}^*$ .

Foreign households and firms solve an analogous set of problems to those of home private agents. Foreign households have access to domestic (i.e., foreign-currency) bonds that are not traded internationally and home-currency state-contingent assets. This implies the following international risk-sharing condition holds,

$$u_{c_f^*}(t) / u_{c_h}(t) = e_t \tilde{p}_{f,t}^* / \tilde{p}_{h,t} \quad (14)$$

The left-hand side of equation (14) is the ratio of marginal utilities with respect to the consumption of domestic output in the home and foreign country, and the right-hand side is the relative price of foreign output to home output, expressed in terms of the home currency.<sup>19</sup>

The home government budget constraint in period  $t$  is given by,

$$T_t = M_t - M_{t-1} \tag{15}$$

An analogous condition holds for the foreign government.

#### *2.4. Model Summary and International Relative Prices*

Table 1 summarizes the conditions for the world economy in terms of reservation prices for goods, wages, and allocations, for given interest rate policy in each country.

===== TABLE 1 =====

I now introduce definitions for international relative prices. The terms of trade are the ratio of the import price to the export price. The home country terms of trade are given by  $\rho_t \equiv \tilde{p}_{f,t}/e_t\tilde{p}_{h,t}^*$ . Without search, and when the law of one price holds, the terms of trade are also the intratemporal price of the home good relative to the foreign good, defined as  $\gamma_t \equiv \tilde{p}_{f,t}/\tilde{p}_{h,t}$ . With search frictions, it is necessary to define a law of one price (LOP) gap. When the LOP gap is defined as  $\psi_{i,t} \equiv e_t\tilde{p}_{i,t}^*/\tilde{p}_{i,t}$ , the terms of trade are the ratio of the intratemporal price and the LOP gap. Thus, for the home economy,  $\rho_t \equiv \gamma_t/\psi_{h,t}$ , where the

foreign good LOP gap is such that  $\psi_{f,t} = (\gamma_t^*/\gamma_t) \psi_{h,t}$ . The foreign country terms of trade are  $\rho_t^* = 1/\rho_t$ .

With markets for securities specified I can write LOP gaps as functions of the price-markup.

PROPOSITION 3. *When the exogenous components of search costs are equal across countries, the home and foreign good LOP gaps are,*

$$\psi_{h,t} = \frac{z + \mu_{h,t}(\theta_t^*/\theta_t)}{z + \mu_{h,t}} \quad \text{and} \quad \psi_{f,t} = \frac{z + \mu_{f,t}^*}{z + \mu_{f,t}^*(\theta_t/\theta_t^*)} \quad (16)$$

*Fluctuations in LOP gaps are independent of endogenous variables when marginal costs are independent of the scale of production ( $\alpha = 0$ ) and the dis-utility of labor is linear ( $v = 0$ ).*

PROOF. Take the ratio of the optimal firm pricing conditions presented in Table 1. Use the labor-leisure conditions to eliminate local currency output prices from the international risk-sharing condition. Expressing the relative wage as a function of exogenous shocks generates the equations in (16). ■

There are two important implications from Proposition 3. First, whilst we know that  $\psi_{h,t} \leq 1$  depends on the relative opportunity cost of search (i.e.,  $W_t/R_t l_t^v \leq (e_t W_t^*)/R_t^* l_t^{*v}$ ), once international risk-sharing is introduced, this inequality can be expressed as  $\theta_t \geq \theta_t^*$ . However, this simple relationship between the LOP gap and the preference parameters is subject to caveats. Proposition 3 assumes that exogenous search costs are equal across countries, and this matters for long-run deviations from the law of one price.<sup>20</sup> Moreover, short-run LOP gaps are not generally independent of endogenous variables since markups vary with employment when  $0 < \alpha < 1$  or  $v > 0$ .



A second point arising from Proposition 3 relates to currency misalignments. Engel (2011) defines a currency misalignment as the average deviation of consumer prices in the foreign country from consumer prices in the home country.<sup>21</sup> For given markups, LOP gaps are positively correlated, and the inequality  $\theta_t \geq \theta_t^*$  is equivalent to  $\psi_{h,t} \leq 1$ . In this case, the inequality  $\theta_t \geq \theta_t^*$  also applies to currency misalignments. A low realization of the home preference parameter ( $\theta_t$ ) generates a positive home good LOP gap (i.e.,  $\psi_{h,t} > 1$ ) and a positive currency misalignment. A high realization of the home technology parameter ( $a_t$ ) leads to a larger LOP gap, for any  $\eta \neq \eta^*$ , such that if search is relatively costly in the home country, the long-run deviation from the law of one price is such that  $p_{h,t} > e_t p_{h,t}^*$ .

In both examples just considered (a low realization of  $\theta_t$ , or a high realization of  $a_t$ ), the result is higher home output. One important implication of consumer search frictions is that the terms of trade will only have a negative correlation with output, as they do in the data, if the LOP gap moves sufficiently against the intratemporal relative price. For example, we can write the home intratemporal relative price as  $\gamma_t = [z(e_t x_t^*/x_t) + \mu_{h,t}] / (z + \mu_{h,t})$ , where  $e_t x_t^*/x_t = [(\theta_t^*/a_t^*) / (\theta_t/a_t)] (R_t^*/R_t)$  are the cost-adjusted terms-of-labor. Moreover, recall that the home terms of trade can be written as  $\rho_t = \gamma_t / \psi_{h,t}$ . A low (high) realization of the home preference (technology) parameter translates into a higher value of  $\gamma_t$ , but the response of the terms of trade depends on  $\psi_{h,t}$ . Without search, output and the terms of trade have a positive correlation because deviations from the law of one price are ruled out.

### 3. ANALYTICAL RESULTS FOR OPTIMAL INTEREST RATE POLICY

In this section, I study utility-maximizing monetary policy. I first specify functional forms for consumption and derive an explicit expression for the optimal home interest rate as a function of international relative prices. I then consider a simplified setting in which I show how search frictions affect the optimal response of interest rates and macroeconomic quantities to changes in technology and preferences.

### 3.1. Functional Forms

I specify the following functional forms for utility from consumption.

$$u(c_t) = \frac{c_t^{1-\sigma} - 1}{1-\sigma} \quad \text{and} \quad c_t = \left( c_{h,t}^{(\omega-1)/\omega} + \phi^{1/\omega} c_{f,t}^{(\omega-1)/\omega} \right)^{\omega/(\omega-1)} \quad (17)$$

where  $1/\sigma > 0$  is the intertemporal elasticity of substitution in consumption,  $\omega > 0$  is the Armington elasticity (the elasticity of substitution between the home and foreign good), and  $\phi > 0$  indexes openness to trade. The main implication of the specification of utility in equation (17) is that, when  $\sigma\omega > 1$ , the home and foreign good are substitutes in utility - the marginal utility of one good is decreasing with consumption of the other good, or,  $\text{sign}\left(\frac{\partial}{\partial c_{f,t}} u_{c_i}(t)\right) = \text{sign}(1 - \sigma\omega)$ .<sup>22</sup>

### 3.2. Optimal Interest Rate Policy

The home country (Ramsey) optimal policy problem is to maximize lifetime utility subject to the equilibrium conditions of the world economy, as presented in Table 1, with the foreign country interest rate,  $R_t^*$ , taken as given.<sup>23</sup> I simplify the policy problem such that the policy maker chooses relative prices  $\{\gamma_t^*, (e_t W_t^*/W_t)\}$  and allocations  $\{l_t, c_{h,t}, c_{f,t}, c_{h,t}^*, c_{f,t}^*\}$

with constraints on home resources, home and foreign demand functions for goods, foreign labor supply, and intratemporal relative prices. I characterize optimal interest rate policy in the following proposition.

PROPOSITION 4. *When  $\alpha = v = 0$ , the optimal home country interest rate is,*

$$R_t = 1 + \kappa\chi_t + \phi^* (1/\psi_{h,t})^{\omega+1} (c_t/c_t^*)^\kappa (1 + \kappa\chi_t^*) - \eta\delta_t \quad (18)$$

where,

$$\chi_t \equiv \phi / (\phi + \gamma_t^{\omega-1}) \quad \text{and} \quad \chi_t^* \equiv 1 / [1 + \phi^* (\gamma_t^*)^{\omega-1}] \quad (19)$$

are functions of intratemporal relative prices,  $\gamma_t = p_{f,t}/p_{h,t}$  and  $\gamma_t^* = p_{f,t}^*/p_{h,t}^*$ , and,

$$\delta_t \equiv \{[z/(1-z)] - \kappa[\chi_t - (1-\chi_t)\phi/\gamma_t^\omega]\} a_t \quad \text{and} \quad \kappa \equiv \sigma\omega - 1 \quad (20)$$

where  $\psi_{h,t} \equiv e_t \tilde{p}_{h,t}^*/\tilde{p}_{h,t}$  is the home good LOP gap and  $\rho_t = \gamma_t/\psi_{h,t}$  are the terms of trade.

PROOF. See Appendix. ■

Proposition 4 highlights the way in which deviations from the law of one price and the price-markup affect optimal interest rate policy. Optimal policy depends on movements in international relative prices through three related terms. Home and foreign intratemporal relative prices,  $\gamma_t$  and  $\gamma_t^*$ ; relative consumption,  $c_t/c_t^*$ , which, due to risk sharing, is a function of the consumption-based real exchange rate; the home good LOP gap,  $\psi_{h,t}$ . The endogenous price-markup is captured by the term  $\delta_t > 0$  and this is also influenced by intratemporal relative price.<sup>24</sup>

It is instructive to consider what happens when search frictions are absent and exchange rate pass-through is complete. Suppose firms produce country-specific differentiated goods and households have constant elasticity of substitution utility across goods. The elasticity of substitution determines the (fixed) gross price-markup, which I denote as  $\bar{\mu} > 1$ . Specifying product markets in this way implies optimal home interest rate policy is,  $R_t = (1/\bar{\mu}) [1 + \kappa\chi_t + \phi^* (1 + \kappa\chi_t^*) (c_t/c_t^*)^\kappa]$ , where  $\gamma_t^* = \gamma_t = \rho_t$ . We now immediately see that there is an additional role for the Armington elasticity when search frictions are present. The Armington elasticity affects optimal interest rate policy directly, through the LOP gap, and indirectly, via the markup term, which depends on the relative price,  $\gamma_t = \rho_t \times \psi_{h,t}$ .

### 3.3. Interest Rates and International Co-movement in a Special Case

In this section, I generate closed-form solutions for the model under optimal policy. I impose log preferences over total consumption, Cobb-Douglas preferences over home and imported goods, and an equal weight on home and imported goods in total consumption - that is,  $u(c_t) = \ln(0.5 \times \sqrt{c_{h,t}c_{f,t}})$ , and similarly for  $c_t^*$ .<sup>25</sup>

Proposition 4 implies the following expressions hold for home and foreign interest rates,

$$R_t = (1/\psi_{h,t})^2 + \{1 - \eta [z/(1-z)] a_t\} \quad \text{and} \quad R_t^* = (\psi_{f,t})^2 + \{1 - \eta [z/(1-z)] a_t^*\} \quad (21)$$

In equations (21), the open economy element of optimal policy is captured by the LOP gap, since the term in braces in each expression is identical to the desired interest rate in the closed economy. These conditions make the following point clear: for a given level of technology, the optimal interest rate depends negatively on the domestic good LOP gap, whilst the

foreign (home) good LOP gap is irrelevant for the home (foreign) interest rate because, by restricting preferences, policy is unconcerned with search activities over imported goods.<sup>26</sup>

Equations (21) also show that, in general, the policy maker is forced to trade-off one inefficiency - the domestic markup - for another - the deviation from the law of one price. In fact, it is possible to express the interest rate as a function of the price-markup and the LOP gap. For example, home interest rate policy can be written as,  $R_t = (1 + \psi_{h,t}^{-2}) / (1 + \mu_{h,t})$ , where  $\mu_{h,t}$  is defined in Proposition 1, and the home good LOP gap,  $\psi_{h,t}$ , is defined in Proposition 3. Since the markup can be expressed as a function of the LOP gap, equations (21) determine the relationship between the LOP gap and the price-markup. For example, optimal policy in the home country implies,  $\eta [z / (1 - z)] (1 + 1/\mu_{h,t}) a_t = 1 + (1/\mu_{h,t})^2$ .

To better understand why exchange rate pass-through plays an important role for the design of monetary policy, I determine how the terms of trade respond to changes in technology and preferences, for given monetary policy in each country. I write the home terms of trade as  $\widehat{\rho}_t = \widehat{\gamma}_t - \widehat{\psi}_t$ , where a circumflex denotes the log deviation of a variable from its steady-state value, and  $\widehat{\psi}_t \equiv \widehat{\psi}_{h,t} = \widehat{\psi}_{f,t} = [\mu / (z + \mu)] (\widehat{\theta}_t^* - \widehat{\theta}_t)$  is the currency misalignment.<sup>27</sup> I then express the terms of trade as a function of the home and foreign interest rate and the home technology and preference parameters.

$$\widehat{\rho}_t = [z / (z + \mu)] \left[ \widehat{a}_t - \left( \widehat{R}_t - \widehat{R}_t^* \right) \right] + [(\mu - z) / (z + \mu)] \widehat{\theta}_t \quad (22)$$

where  $\mu \equiv \mu_h = \mu_f^*$ . Using equation (22) we can consider two cases. First, suppose that there are no search frictions and the law of one price holds. We can think of  $\mu \rightarrow 0$  as

a limiting case, such that  $\widehat{\rho}_t = \widehat{\gamma}_t = \widehat{a}_t - \widehat{\theta}_t$ , with or without optimal interest rate policy. Then, imposing  $\widehat{R}_t = \widehat{R}_t^* = 0$  on equation (22), it is clear that search frictions dampen the impact of changes in technology and preference parameters on the terms of trade.<sup>28</sup>

Optimal interest rate policy with search frictions can be written as,

$$\widehat{R}_t - \widehat{R}_t^* = -\mu \{ \widehat{a}_t - 2[(1 + \mu) / (z + \mu)] \} \widehat{\theta}_t \quad (23)$$

Using equation (23) to eliminate interest rates from equation (22) leads to the following conclusions. For changes in technology, when interest rates react optimally, policy acts to raise fluctuations in the terms of trade. However, the terms of trade always fluctuate by less than when product markets are frictionless. For changes in the preference parameter, whilst there is no strict ranking, optimal policy also acts to raise fluctuations in the terms of trade. Thus, optimal policy always mitigates the effect of search frictions. Since the role of search frictions in the above expressions is linked to the markup, there is a natural relationship between optimal policy and the coefficient of exchange rate pass-through, which is  $\partial \ln P_{f,t} / \partial \ln e_t = 1 / \{1 + \mu_{h,t} [x_t / (e_t x_t^*)]\}$ . The higher the price-markup, the lower is exchange rate pass-through, and the more aggressive is monetary policy. Overall, however, because there is a trade-off between the markup distortion and the LOP gap, optimal policy never replicates the outcome with frictionless product markets.

Finally, I characterize the response of macroeconomic quantities to changes in technology and preferences. In particular, I consider relative home consumption and output,

$$\widehat{c}_t - \widehat{c}_t^* = -[\mu / (z + \mu)] \widehat{\theta}_t \quad \text{and} \quad \widehat{y}_t - \widehat{y}_t^* = -[z / (z + \mu)] \left[ (\widehat{R}_t - \widehat{R}_t^*) + (\widehat{\theta}_t - \widehat{a}_t) \right] \quad (24)$$

Relative home consumption only depends on the preference parameter. As exchange rate pass-through falls, the sensitivity of relative consumption to changes in the preference parameter rises. For output, the opposite is true, and optimal policy increases the movement in relative output. The most obvious comparison for equations (24) is with the sticky-price model of Betts and Devereux (2000). They argue that, the lower is the degree of pass-through, the lower is the co-movement in consumption across countries, but the higher is the co-movement in output. Despite the mechanism being very different - flexible prices with consumer search - a similar point arises in my analysis. Moreover, in this setting, optimal policy attempts to weaken the movement in relative output, which is a reflection of policy attempting to reduce the impact of search frictions on movements in the terms of trade.

#### 4. QUANTITATIVE ANALYSIS

In this section, I provide a quantitative analysis of the model. I relax the assumptions imposed in section 3 and study the impact of internationally correlated technology and preference shocks under different monetary policy regimes. I also conduct a sensitivity analysis and relate the results of this paper to those in which nominal rigidities generate incomplete exchange rate pass-through.

##### *4.1. Parameterization and Calibration*

Each period is a quarter. I set  $\beta = 0.99$ , which implies the annualized real interest rate is 4.1 percent. The CRRA parameter ( $\sigma$ ) is set at 2, which is a standard value in the business cycle literature, the Frisch elasticity of labor supply ( $1/\nu$ ) is set at 0.5, following Christoffel,

Coenen, and Warne (2008), and the Armington elasticity ( $\omega$ ) is set at 1.2, consistent with the values suggested by Ruhl (2008). I assume the home country is the EU and the foreign country is the US. Annual post-1984 average CPI inflation rates in the EU (home) and US (foreign,  $\star$ ) are 3.2 percent and 2.8 percent, respectively, which implies quarterly net inflation rates of 0.0079 and 0.0069.<sup>29</sup>

I calibrate the remaining parameters of the model to steady-state targets (EU and US). Table 2 presents the parameters used in the analysis and their respective targets.

===== TABLE 2 =====

For employment and labor-income share I use OECD data for the Euro Area and US economy.<sup>30</sup> The price-markups (of 35 and 23 percent) and imports-to-output shares (of 18 and 13 percent) are taken from Bayoumi, Laxton, and Pesenti (2004).<sup>31</sup>

The final two targets in Table 2 are less standard. Propositions 1 and 2 imply that once a markup has been chosen, the parameter  $z$  determines the coefficient of variation of prices as,  $cv = \phi / [\Sigma + z / (1 - z) \mu]$ , where  $\mu > 0$  the net markup. To calibrate US (foreign) price dispersion, I use the study of Kaplan and Menzio (2015). They use data from the Kilts-Nielsen Consumer Panel data set for the period 2004-2009. Using the definition of a good as the set of products that share the same features, the same size, and the same brand (“Generic Brand Aggregation”) the average standard deviation of normalized prices is 21 percent (page 9, Table 2, column 2). To calibrate EU (home) price dispersion, I use the



study of Reiff and Rumler (2014). They present disaggregated price data, also collected by Nielsen, for 47 products between 2008-2011. The average coefficient of variation across all products and brands is 34.6 percent (page 10, Table 1, column “CV across”).

The final target is the ratio of shopping time-to-market labor (search time). This is determined by the parameter  $a$  and is defined as  $(s_f + s_h) / l$ . To calibrate US search time, I use the American Time Use Survey. Over the period 2003-2016, the widest range available, between 0.72 and 0.81 hours were used purchasing goods and services per day, whilst between 3.46 and 3.81 hours were allocated to working and work-related activities. Average search time over the period was 21.2 percent. I use two sources for EU search time. First, I use the Harmonized European Time Use Survey. Based on data for France, Germany, Spain and Italy, for males and females, the average search time (ratio of shopping and services-to-main and second job) is 18.2 percent.<sup>32</sup> I also use the Irish National Time Use Survey (McGinnity *et al.* 2005). For males and females across weekdays and weekends the average search time (shopping-to-employment) is reported as 17 percent (page 8, Table 2.2).

#### 4.2. Optimal Interest Rate Policy

In this section, I consider the optimal policy response to a one-time shock to technology and preferences. Technology and preferences are assumed to follow an autoregressive process,

$$\lambda_{t+1} = A_0 + A\lambda_t + \varepsilon_{t+1} \quad ; \quad \varepsilon_{t+1} \sim N(0, V) \quad (25)$$

where  $\lambda_t = [\ln(a_t), \ln(\theta_t), \ln(a_t^*), \ln(\theta_t^*)]^T$  and  $\varepsilon = [\varepsilon^a, \varepsilon^\theta, \varepsilon^{a^*}, \varepsilon^{\theta^*}]^T$  is the vector of shocks.

The parameter values assigned to  $A_0 = [a, \theta, a^*, \theta^*]^T$  are discussed above, and the values as-

signed to the matrix of autoregressive terms,  $A$ , and the covariance terms,  $V$ , are taken from Alessandria (2009), and reported in the Appendix. The main features of this parameterization are that technology and preferences are highly persistent, and the path of technology (preferences) is independent (depends negatively) of the path of preferences (technology). Innovations to technology and preferences have positive spillovers internationally and negative spillovers domestically.

Figure 1 presents the impulse responses of selected variables to a one-time positive (negative) shock to EU technology (preferences) of 1 percent.

===== FIGURE 1 =====

The first row of Figure 1 presents impulse responses to the technology shock. Because technology is correlated internationally, a 1 percent increase in EU technology leads to a maximum increase in US technology of 0.2 percent, after two and a half years. With higher current and expected future technology, consumption and output increase. The LOP gaps rise with the shock for two reasons. The path of preferences depends negatively on the path of technology, and with cross-country heterogeneity, shocks to technology, by virtue of affecting the price-markup, influence the path of the LOP gap. The terms of trade initially rise in response to the shock because the LOP gap displays a hump-shaped path of adjustment. Finally, the EU interest rate falls initially, but then rises, and nominal interest rates display positive international co-movement.

The second row of Figure 1 presents impulse responses to the preference shock. In this case, a 1 percent fall in the EU preference parameter leads to a maximum increase in the US preference parameter of 0.2 percent, after seven years. For endogenous variables, either there is no hump-shaped dynamic, or the overall movement is relatively muted. The reason is that, with a negative preference shock, households wish to work more, and so output rises, consistent with additional labor supply. The markup, however, is not directly affected by the shock (recall that the path of technology is independent of the path of preferences) and interest rates display negative international co-movement. Finally, there is negative co-movement between the terms of trade and output.

Since countries are not symmetric (the EU is more open to trade, has higher price markups, and greater price dispersion, relative to the US; see Table 2) we can ask what happens when the US is hit by a shock, as opposed to the EU. US (EU) technology shocks have a relatively larger effect on consumption and output internationally (domestically). For example, the maximum response of EU and US consumption to a US technology shock is 0.53 percent and 0.94 percent, respectively, whereas for an EU shock, these values are 1.04 percent and 0.48 percent. The interest rate (law of one price deviation) response is stronger (weaker) in both countries when the technology shock originates in the US. The same pattern holds with preference shocks.

#### *4.3. Taylor Rules*

In this section, I assume monetary policy is conducted using a Taylor-type interest rate

rule. For example, in the EU, interest rate policy targets inflation and output according to  $R_t = R (\pi_t/\pi)^{\phi_\pi} (y_t/y)^{\phi_y}$ . The parameters of the Taylor rule are assumed to be the same in each country, and are set equal to  $\phi_\pi = 1.5$  and  $\phi_y = 0.5/4$ , both of which are standard values.<sup>33</sup> Figure 2 presents the impulse responses of the same variables as Figure 1 and for the same shocks.

===== FIGURE 2 =====

In Figure 2, a positive EU technology shock generates an initial rise in both the EU and US nominal interest rate, whereas a negative EU preference shock, generates a drop in interest rates, on impact. In both cases, the response of interest rates is related to the pattern of adjustment in output, and depends on the weight attached to output in the Taylor rule.<sup>34</sup> A second difference, compared with optimal policy, is that the EU and US LOP gaps co-move more closely, which is partly explained by the closer co-movement in nominal interest rates across countries.

*4.4. International Correlations*

In this section, I calculate cross-country correlations of consumption, output, and interest rates, the correlation between EU output and the terms of trade, and correlations for the real and nominal exchange rate. Monetary policy is specified as either an interest rate peg, as optimal interest rate policy, or as a Taylor rule. Table 3 reports data and model-based correlations (with and without country heterogeneity).

===== TABLE 3 =====

Consider the case when policy is an interest rate peg (Inactive). The combination of shocks to technology and preferences imply that the cross-country correlation of consumption is higher than output and there is a negative correlation between output and the terms of trade. Both are features of the data. There is less serial correlation in the real exchange rate than in the data, but this is expected, given the relative simplicity of the model.<sup>35</sup> Under optimal policy (Optimal), nominal interest rates are positively correlated across countries, albeit by significantly less than in the data, and this cross-correlation is lower when countries are heterogeneous - the reasons for this are discussed below in the sensitivity analysis. The positive cross-country correlations of consumption and output fall under optimal policy and the correlation between output and the terms of trade rises (in absolute value).

When interest rate policy follows a Taylor rule (Taylor) the most obvious point of note is that the cross-correlation of interest rates is higher than when monetary policy is optimal. A similar point was clear from the impulse response functions reported in Figures 1 and 2. To understand the source of this difference, consider the case without preference shocks.<sup>36</sup> The cross-country correlation of interest rates is higher than for output under optimal policy, and also higher than when monetary policy is specified as a Taylor rule. However, the ranking of cross-country correlations in consumption and output is reversed, and there is a positive correlation between output and the terms of trade.

*4.5. Sensitivity Analysis*

In this section, I undertake a sensitivity analysis.<sup>37</sup> I first lower the Armington elasticity to 0.7, consistent with values reported by Lubik and Schorfheide (2006) and Drozd and Nosal (2012b).<sup>38</sup> I also reduce the imports-to-output share to 5 percent. I then raise the markup to 40 percent and search time to 33 percent. Both of these figures are discussed in Alessandria and Kaboski (2011).<sup>39</sup> Finally, I lower the share of labor in income to 55 percent and I consider the case in which labor is indivisible.<sup>40</sup> Table 4 reports international correlations under optimal interest rate policy.<sup>41</sup>

===== TABLE 4 =====

Table 4 demonstrates that lower exchange rate pass-through (higher price-markups) leads to higher cross-country correlation of nominal interest rates, even with technology and preference shocks. This is consistent with the analytical results. Second, in the benchmark calibration, the Armington elasticity (the elasticity of substitution between home and foreign goods) is set above unity. The cross-correlation of interest rates rises once this elasticity is lowered. Thus, it is quite possible for the cross-country correlation of nominal interest rates to be higher than output under optimal policy, even when there is a negative correlation between output and the terms of trade.<sup>42</sup>

*4.6. Discussion: Optimal Monetary Policy and Incomplete Exchange Rate Pass-Through*

This paper addresses an important question in international macroeconomics. Does incomplete exchange rate pass-through affect the design of monetary policy? A sizable literature

that features infrequent price adjustment suggests this is indeed the case. For example, Monacelli (2005) develops a small open economy model where exchange rate pass-through to import prices is incomplete. He shows that incomplete pass-through can generate a trade-off between stabilizing producer price inflation and either the output gap or the deviation from the law of one price. Thus, the monetary authority cannot simultaneously stabilize the LOP gap and the domestic markup (page 1058). I find a similar result. However, the trade-off identified in Monacelli disappears when  $\sigma = \omega = 1$  (my notation) and, in this case, the well-known isomorphism result of Clarida, Gali, and Gertler (2002) holds.<sup>43</sup> By contrast, for this special case, I find that each policy maker focuses on its own-good deviation from the law of one price and faces a trade-off with regard to the domestic price-markup.

Engel (2011) also considers the role of deviations from the law of one price (a currency misalignment) for the conduct of monetary policy. He utilizes a second-order approximation of the utility function around the efficient steady state of a two-country economy. Engel demonstrates that the objective function of the monetary authority depends on a currency misalignment if price differences arise from local-currency price-stickiness or from price discrimination.<sup>44</sup> This means welfare costs arise not specifically from price-stickiness, but rather, from prices that do not deliver efficient allocations. In my analysis, price differences arise because there are search frictions, and price-markups depend on conditions in the local labor market. I also use the utility function as the metric for policy decisions, but I study non-cooperative policy under commitment in a model with monetary frictions.

Finally, there is a parallel between my results and those presented in Corsetti and Pesenti (2005). They derive a utility-based loss function that can be expressed in terms of output gaps, in the home and foreign economy, and deviations from the law of one price in each market, for differing degrees of exchange rate pass-through. In their analysis, however, with prices set one period in advance, inflation does not lead to price dispersion within countries.<sup>45</sup> Coenen *et al.* (2010) provide a numerical analysis of the welfare implications of monetary policy when exchange rate pass-through is incomplete, and there are multiple sources of aggregate uncertainty. Exogenous markup shocks play a prominent role in their analysis, whereas in this paper, changes in markups reflect the optimal response of firms and households to technology and preference shocks.

## 5. CONCLUSION

This paper studies utility-maximizing monetary policy in a two-country economy with consumer search frictions. The main result is that monetary policy should target deviations from the law of one price. This suggests the exchange rate has an important role to play in the design of monetary policy in open economies. Whilst this has been established in the sticky-price literature - incomplete exchange rate pass-through, with sticky local currency prices, reduces the extent to which exchange rate movements are desirable - search frictions deliver a similar result. Since the policy implications of incomplete exchange rate pass-through arising from real and nominal frictions point in the same direction, an assessment of the normative implications of these two types of rigidities for the open economy could



be a promising direction for future research. The real-world implications of such findings also highlight the potential of international monetary policy coordination - a topic which has seen renewed interest in recent years.<sup>46</sup> In practice, however, competing objectives at the domestic level, and disagreement about the extent of international spillovers from policy, means that such coordination has been difficult to achieve.

## APPENDIX

The Appendix presents proofs for Propositions 1, 2, and 4, omitted from the main text, and the details of the autoregressive processes for technology and preferences used for the quantitative analysis.

### A.1 Proof of Proposition 1

Consider the home good, sold in the home market, at price  $p_{h,t}$ . Firms are indifferent between charging any price on the support  $p_{h,t} \in [\underline{p}_{h,t}, \bar{p}_{h,t}]$ . The following indifference condition is used to solve for the distribution of prices:  $\pi_{h,t}(p_{h,t}) = \pi_{h,t}(\bar{p}_{h,t})$ , where  $\pi_{h,t}$  is defined in equation (9) in the main text,  $F(\bar{p}_{h,t}) = 1$ , and  $d_{h,t} = q$ , when  $p_{h,t} = \bar{p}_{h,t}$ . The CDF of price quotes is given by  $F(p_{h,t}) = 1 - \mathbf{b} [(\bar{p}_{h,t} - p_{h,t}) / (p_{h,t} - x_t)]$ , where  $\mathbf{b} \equiv z/2(1 - z)$ . Since  $F(\underline{p}_{h,t}) = 0$ , we can express the lower-bound of the price distribution as a function of upper-bound,  $\bar{p}_{h,t}$ , such that,  $\underline{p}_{h,t} = [1/(1 + \mathbf{b})]x_t + [\mathbf{b}/(1 + \mathbf{b})]\bar{p}_{h,t}$ . Following Burdett and Judd (1983), the reservation price of the household is equal to the upper-bound of the distribution, and  $\tilde{p}_{h,t} = \bar{p}_{h,t}$ .

The optimal condition for consumer search is generated by combining the second condition in equation (7) -  $W_t/\tilde{p}_{h,t} = R_t l_t^v [\theta_t/u_{c_h}(t)]$  - with equation (8) -  $\eta [\theta_t/u_{c_h}(t)] = (1 - P_{h,t}/\tilde{p}_{h,t}) J(\tilde{p}_{h,t})$ . This implies,  $\eta W_t/R_t l_t^v = (\tilde{p}_{h,t} - P_{h,t}) J(\tilde{p}_{h,t})$ , which is discussed in the main text, and can be written as,

$$\eta W_t/R_t l_t^v = \int_0^{\tilde{p}_{h,t}} (\tilde{p}_{h,t} - p_{h,t}) dJ(p_{h,t}) = |(\tilde{p}_{h,t} - p_{h,t}) J(p_{h,t})|_0^{\tilde{p}_{h,t}} + \int_0^{\tilde{p}_{h,t}} J(p_{h,t}) dp_{h,t} \quad (\text{A1})$$

where the expected purchase price is,  $P_{h,t} = \left[ \int_0^{\tilde{p}_{h,t}} p_{h,t} dJ(p_{h,t}) \right] / J(\tilde{p}_{h,t})$ . Using  $J(p_{h,t}) = zF(p_{h,t}) + (1-z) \{1 - [1 - F(p_{h,t})]^2\}$ , substituting  $F(p_{h,t})$  into this condition, and then rearranging,

$$\eta W_t / R_t l_t^v = \int_{\underline{p}_{h,t}}^{\tilde{p}_{h,t}} \left\{ 1 + (\mathbf{b}z/2) \left[ 1 - \left( \frac{\tilde{p}_{h,t} - x_t}{p_{h,t} - x_t} \right)^2 \right] \right\} dp_{h,t} \quad (\text{A2})$$

where  $\mathbf{b} \equiv z/2(1-z)$ . Evaluating this expression,

$$\eta W_t / R_t l_t^v = (\tilde{p}_{h,t} - \underline{p}_{h,t}) (1 + \mathbf{b}z/2) + \mathbf{b}z (\tilde{p}_{h,t} - x_t)^2 \left( \frac{1}{\tilde{p}_{h,t} - x_t} - \frac{1}{\underline{p}_{h,t} - x_t} \right) / 2 \quad (\text{A3})$$

Eliminating the lower bound, and collecting terms,

$$\eta W_t / R_t l_t^v = \{ [1/(1+\mathbf{b})] (1 + \mathbf{b}z/2) - z/2 \} (\tilde{p}_{h,t} - x_t) \quad (\text{A4})$$

which can be equivalently expressed as,  $\tilde{p}_{h,t} = x_t + \eta W_t / (1-z) R_t l_t^v$ . Applying the definition  $\mu_{h,t} \equiv [z\eta / (1-z)] W_t / R_t l_t^v x_t$  generates the first equation in Proposition 1. To determine the export price,  $p_{h,t}^*$ , I use  $\eta^* W_t^* / R_t^* l_t^{*v} = \int_0^{\tilde{p}_{h,t}^*} J(p_{h,t}^*) dp_{h,t}^*$ , and the CDF of price quotes,  $F(p_{h,t}^*)$ . This implies  $\tilde{p}_{h,t}^* = (x_t/e_t) + \eta^* W_t^* / (1-z^*) R_t^* l_t^{*v}$ , which generates the second equation in Proposition 1. ■

## A.2 Proof of Proposition 2

I measure price dispersion by the coefficient of variation in posted prices. Denote the posted price of the home good, in the home market, by  $\mathbf{p}_{h,t}$ , and the coefficient of variation by  $cv_t \equiv \sigma(\mathbf{p}_{h,t}) / E(\mathbf{p}_{h,t})$ , where  $E(\cdot)$  is the mean and  $\sigma(\cdot)$  the standard deviation of  $\mathbf{p}_{h,t}$ .

Inserting the expression for the reservation price into the CDF for price quotes, I generate  $F(\mathbf{p}_{h,t})$ . The mean posted price is given by  $E(\mathbf{p}_{h,t}) = \int_{\underline{\mathbf{p}}_{h,t}}^{\bar{\mathbf{p}}_{h,t}} \mathbf{p}_{h,t} f(\mathbf{p}_{h,t}) d\mathbf{p}_{h,t}$ . Using  $F(\mathbf{p}_{h,t}) =$

0 to determine  $\underline{p}_{h,t}$ , and noting  $\bar{p}_{h,t} = \tilde{p}_{h,t}$ , the mean posted price can be written as,

$$E(\mathbf{p}_{h,t}) = [1 + \Sigma(\eta W_t/R_t l_t^\nu x_t)] x_t \quad ; \quad \Sigma \equiv (1/2) [z/(1-z)^2] \ln(2/z-1) \quad (\text{A5})$$

The variance of posted prices is  $E[(\mathbf{p}_{h,t})^2] - [E(\mathbf{p}_{h,t})]^2$  and  $E[(\mathbf{p}_{h,t})^2] = \int_{\underline{p}_{h,t}}^{\bar{p}_{h,t}} \mathbf{p}_{h,t}^2 f(\mathbf{p}_{h,t}) d\mathbf{p}_{h,t}$ .

Integrating this expression,  $E[(\mathbf{p}_{h,t})^2] = x_t^2 + 2\eta\Sigma(x_t W_t/R_t l_t^\nu) + Z(\eta W_t/R_t l_t^\nu)^2$ , where  $Z \equiv z/[(1-z)^2(2-z)]$ . By substitution:

$$cv_t = \frac{\{x_t^2 + 2x_t\Sigma(\eta W_t/R_t l_t^\nu) + Z(\eta W_t/R_t l_t^\nu)^2 - [x_t + \Sigma(\eta W_t/R_t l_t^\nu)]^2\}^{1/2}}{x_t + \eta\Sigma(W_t/R_t l_t^\nu)} \quad (\text{A6})$$

Defining  $\phi \equiv (Z - \Sigma^2)^{1/2}$  and applying  $\mu_{h,t} = [z\eta/(1-z)] W_t/R_t l_t^\nu x_t$  (defined in Proposition 1) to equation (A6), generates the equation in Proposition 2. ■

### A.3 Proof of Proposition 4

Assume  $\alpha = 0$  and  $\nu = 0$ . The home policy problem is to maximize the lifetime utility of the representative household,  $\sum_{t=0}^{\infty} \beta^t [u(c_t) - \theta_t(l_t + \eta s_t)]$ , subject to the equilibrium conditions of the world economy, as presented in Table 1, with the foreign interest rate,  $R_t^*$ , taken as given. I take advantage of the definitions of international relative prices to simplify the problem. For given policies, I express the world economy as a 15 variable system in:  $\{c_t, c_{h,t}, c_{f,t}, l_t, s_t, \gamma_t\}$ , foreign equivalents, and relative prices  $\{\psi_{h,t}, \psi_{f,t}, (e_t W_t^*/W_t)\}$ . I treat the terms-of-labor as a choice variable, and replace  $R_t$  with  $e_t W_t^*/W_t$ , using the international risk-sharing condition. With  $\alpha = 0$  and  $\nu = 0$ , the foreign resource constraint is not relevant for the home policy problem, and since  $\psi_{h,t}$  only appears once, the home LOP gap does not constrain the home policy decision. Finally, since  $R_t$  now only appears once, we can drop

home labor supply as a constraint, and use it to determine an explicit expression for the interest rate.

With  $s_t = c_{h,t} + c_{f,t}$  (and foreign equivalent) and consumption indexes, the objective function of the monetary authority can be written as,

$$\begin{aligned}
U_t = & u(c_t) - \theta_t(l_t + \eta s_t) + \lambda_1(a_t l_t - c_{h,t} - c_{h,t}^*) + \lambda_2[\phi \psi_{f,t}^\omega (c_{f,t}^*/c_{f,t}) - (c_t/c_t^*)^\kappa] \\
& + \lambda_3[c_{h,t}^* - \phi^*(\gamma_t^*)^\omega c_{f,t}^*] + \lambda_4\left\{(c_t^*)^{-\kappa/\omega} - \theta_t^*[(R_t^*/a_t^*) + G](c_{f,t}^*)^{1/\omega}\right\} \\
& + \lambda_5\left[\psi_{f,t} \frac{R_t^*/a_t^* + G(\theta_t/\theta_t^*)}{R_t^*/(ToL_t a_t) + G(\theta_t/\theta_t^*)} - (c_{h,t}/c_{f,t}^*)^{1/\omega} (c_t/c_t^*)^{\kappa/\omega}\right] \\
& + \lambda_6\left[\gamma_t^* - \frac{R_t^*/a_t^* + G}{R_t^*/(ToL_t a_t) + G}\right] + \lambda_7\left[\frac{R_t^*/a_t^* + G}{R_t^*/a_t^* + G(\theta_t/\theta_t^*)} - \psi_{f,t}\right]
\end{aligned}$$

where  $G \equiv \eta/(1-z)$ ,  $c_t$  is determined by equations (17), and  $ToL_t \equiv e_t W_t^*/W_t$ . The choice variables are relative prices  $\{\gamma_t^*, ToL_t, \psi_{f,t}\}$  and allocations  $\{l_t\}$  and  $\{c_{h,t}, c_{f,t}, c_{h,t}^*, c_{f,t}^*\}$ . The 7 constraints are on home resources, home and foreign (relative) demand functions, foreign labor supply, and appropriate definitions of relative prices.

The first 4 first-order conditions are:

$$\lambda_3(\omega c_{h,t}^*) = \lambda_6 \gamma_t^* \quad ; \quad \lambda_5(\gamma_t \psi_{h,t}) = \lambda_6 \gamma_t^* \quad ; \quad \lambda_2[\omega \phi (c_{f,t}^*/c_{f,t})] = \lambda_7 \psi_{f,t} - \lambda_5 \gamma_t \quad (\text{A7})$$

where  $\lambda_1 = \theta_t/a_t$ . The remaining 4 first-order conditions are:

$$0 = [c_t u'(c_t)] \mu_{hh} - \lambda_1 c_{h,t} - \lambda_2 \kappa \mu_{hh} [\phi (c_{f,t}^*/c_{f,t})] - \lambda_5 \gamma_t (1 + \kappa \mu_{hh})/\omega - \theta_t \eta c_{h,t} \quad (\text{A8})$$

$$0 = [c_t u'(c_t)] \mu_{hf} - \lambda_2 (1 + \kappa \mu_{hf}) [\phi (c_{f,t}^*/c_{f,t})] - \lambda_5 \gamma_t (\kappa \mu_{hf}) \omega - \theta_t \eta c_{h,t} \quad (\text{A9})$$

$$0 = -\lambda_1 c_{h,t}^* + \lambda_2 (\kappa \mu_{fh}) [\phi (c_{f,t}^*/c_{f,t})] - \lambda_4 (c_t^*)^{-\kappa/\omega} (\kappa \mu_{fh})/\omega + \lambda_5 \gamma_t (\kappa \mu_{fh})/\omega + \lambda_4 c_{h,t}^* \quad (\text{A10})$$

$$0 = \lambda_2 (1 + \kappa \mu_{ff}) [\phi (c_{f,t}^*/c_{f,t})] - \lambda_4 (c_t^*)^{-\kappa/\omega} (1 + \kappa \mu_{ff}) / \omega + \lambda_5 \gamma_t (1 + \kappa \mu_{ff}) / \omega - \lambda_3 c_{h,t}^* \quad (\text{A11})$$

where,

$$\mu_{hh} = 1 - \mu_{hf} = 1 / (1 + \phi \gamma_t^{1-\omega}) \quad \text{and} \quad \mu_{ff} = 1 - \mu_{fh} = 1 / [1 + \phi^* (\gamma_t^*)^{\omega-1}]$$

I use equations (A8)-(A11) and  $\lambda_3 (\omega c_{h,t}^*) = \lambda_5 (\gamma_t \psi_{h,t})$  to generate,

$$[c_t u' (c_t)] \mu_{hh} = (1 + \kappa \mu_{hf}) (\theta_t \eta + \lambda_1) c_{h,t} - \theta_t \eta c_{f,t} \kappa \mu_{hh} + \lambda_5 \gamma_t (1 + \kappa) / \omega \quad (\text{A12})$$

and,

$$\lambda_5 \gamma_t (1 + \kappa) \psi_{h,t} = \lambda_1 c_{h,t}^* (1 + \kappa \mu_{ff}) \omega \quad (\text{A13})$$

Eliminating  $\lambda_5$  from (A12) and (A13), and noting  $R_t = (a_t / \theta_t) (\mu_{hh} / c_{h,t}) [c_t u' (c_t)] - G a_t$ ,

generates Proposition 4 in the text, where  $\chi_t = \mu_{hf}$  and  $\chi_t^* = \mu_{ff}$ . ■

#### A.4 Technology and Preference Processes

The autoregressive process for technology and preferences is,

$$\lambda_{t+1} = A_0 + A \lambda_t + \varepsilon_{t+1} \quad ; \quad \varepsilon_{t+1} \sim N(0, V) \quad (\text{A14})$$

where  $\lambda_t = [\ln(a_t), \ln(\theta_t), \ln(a_t^*), \ln(\theta_t^*)]^T$ ,  $A_0 = [a, \theta, a^*, \theta^*]^T$ , and  $\varepsilon = [\varepsilon^a, \varepsilon^\theta, \varepsilon^{a^*}, \varepsilon^{\theta^*}]^T$ .

The coefficient matrix for the autoregressive terms is,

$$A = \begin{bmatrix} 0.88 & 0 & 0.06 & 0 \\ -0.45 & 0.96 & -0.18 & -0.02 \\ 0.06 & 0 & 0.88 & 0 \\ -0.18 & -0.02 & -0.45 & 0.96 \end{bmatrix}$$

Innovations are such that  $\text{corr}(\varepsilon^a, \varepsilon^{a^*}) = 0.385$ ,  $\text{corr}(\varepsilon^\theta, \varepsilon^{\theta^*}) = 0.48$ ,  $\text{corr}(\varepsilon^a, \varepsilon^\theta) = \text{corr}(\varepsilon^{a^*}, \varepsilon^{\theta^*}) = -0.54$ , and  $\text{corr}(\varepsilon^a, \varepsilon^{\theta^*}) = \text{corr}(\varepsilon^{a^*}, \varepsilon^\theta) = -0.34$ . Finally,  $\text{var}(\varepsilon^a) = \text{var}(\varepsilon^{a^*}) = 0.0061^2$  and  $\text{var}(\varepsilon^\theta) = \text{var}(\varepsilon^{\theta^*}) = 0.03^2$ .

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# Notes

<sup>1</sup>Monacelli (2005) shows that incomplete exchange rate pass-through can introduce a trade-off between stabilizing producer price inflation and either the output gap or deviations from the law of one price. Engel (2011) shows that incomplete pass-through generates a trade-off among inflation, output gap, and currency misalignment objectives, the latter of which is a weighted average of deviations from the law of one price across countries. A further discussion of these points is contained in section 4.6.

<sup>2</sup>I focus on Ramsey-optimal monetary policy. A Ramsey-optimal policy is one which maximizes the lifetime utility of the representative agent, subject to the equilibrium conditions of the economy. An extensive discussion of Ramsey-optimal monetary policy is contained in Schmitt-Grohe and Uribe (2010).

<sup>3</sup>I consider economies with complete international asset markets and no physical capital. See Heathcote and Perri (2002) on the transmission of real shocks with physical capital and the role of international financial markets.

<sup>4</sup>The Taylor rule is a useful benchmark for two reasons. First, a large class of DSGE models in international macroeconomics build on this framework. Second, modeling monetary policy as a Taylor rule follows an empirical literature that suggests the policy of many central banks is well approximated by such a rule. See Clarida, Gali, and Gertler (2000).

<sup>5</sup>Kaplan and Menzio (2015) assess the relative importance of four explanations for the existence of price dispersion in product markets: (i) amenities; (ii) heterogeneous costs; (iii) intertemporal price discrimination; (iv) search frictions. The latter two appear to be the most important quantitatively.

<sup>6</sup>Aguiar and Hurst (2005) focus on retirees. Kaplan and Menzio (2016) find that employed people spend between 24 and 33 percent less time shopping than non-employed people and between 13 and 20 percent less than unemployed people.

<sup>7</sup>A large literature provides empirical evidence for pricing-to-market. See Engel (1999), Atkeson and Burstein (2008), Gopinath and Itskohki (2010) and Fitzgerald and Haller (2014).

<sup>8</sup>If pass-through has fallen over time, as suggested by Marazzi and Sheets (2007), increased correlation

in nominal interest rates appears more likely.

<sup>9</sup>Sectoral aggregation (Atkeson and Burstein 2008), inventory considerations (Alessandria, Kaboski, and Midrigan 2010), and Kimball consumption aggregation (Gust, Leduc, and Vigfusson 2010) have also been shown to limit exchange rate pass-through. The quantitative implications of such rigidities are studied in Drozd and Nosal (2012a).

<sup>10</sup>The study of (optimal) monetary policy with search frictions typically focuses on the labor market, features infrequent price adjustment, and is set within a closed economy. See Blanchard and Gali (2010) and Ravenna and Walsh (2011) and references contained therein. I abstract from unemployment and inflation dynamics and study the implications of search frictions in the product market for monetary policy in the open economy.

<sup>11</sup>A household is a family comprised of three members associated with particular activities: shopping, working, or taking leisure.

<sup>12</sup>Holland and Scott (1998) present a quantitative analysis of shocks to this parameter using a Real Business Cycle model (without search frictions), which, in general, is part of the labor wedge, as stressed by Chari, Kehoe, and McGratten (2007). Nakajima (2005) presents a micro-foundation motivated by a heterogeneous-agents economy with incomplete markets.

<sup>13</sup>As in Burdett and Judd (1983), some shoppers contact multiple firms simultaneously, and other shoppers contact only one firm. For a further discussion, see Menzio and Trachter (2015).

<sup>14</sup>Both conditions are standard. They are intertemporal conditions for state contingent and non-contingent assets, expressed in terms of the reservation price of the home good.

<sup>15</sup>Total profit is  $\Phi_t \equiv s_t \pi_t = s_{h,t} \pi_{h,t} + s_{h,t}^* \pi_{h,t}^*$ . Demand curves are derived in the following way. A fraction  $z/[z + 2(1 - z)]$  of households receive one quote and a fraction  $2(1 - z)/[z + 2(1 - z)]$  receive two quotes. Combining these expressions, the probability that a household purchases from a firm charging  $p_{i,t}$  is,  $\{z + 2(1 - z)[1 - F(p_{i,t})]\}/(2 - z)$  for  $p_{i,t} \leq \tilde{p}_{i,t}$ , and 0 otherwise.

<sup>16</sup>Nekada and Ramey (2013) have recently argued that monetary shocks cause markups and output to co-



move positively, and Banerjee and Russell (2001) provide evidence that higher long-run inflation is associated with lower markups. Both are consistent with the first equation in Proposition 1.

<sup>17</sup>Deviations from the law of one price arise if prices are assumed to be sticky (i.e., set in advance) in local currency terms. However, once prices are adjusted, the law of one price holds.

<sup>18</sup>Proposition 2 is consistent with Gerardi and Shapiro (2009), who provide industry-level evidence for a negative relationship between competition and price dispersion, and the industry-level evidence in Cornia, Gerardi, and Shapiro (2012), which implies price dispersion is pro-cyclical.

<sup>19</sup>This expression is equivalent to the representation of international risk-sharing that requires the ratio of the marginal utility of total consumption across countries -  $u_{c^*}(t)/u_c(t)$  - equal the consumption-based real exchange rate.

<sup>20</sup>It should be clear that we can write  $\psi_{h,t} = \left[1 + (\theta_t^*/\theta_t) \frac{\eta^* z(1-z)}{\eta z^*/(1-z^*)} \mu_{h,t}/z\right] / (1 + \mu_{h,t}/z)$ , such that, for example,  $\eta > \eta^*$  translates into  $\psi_{h,t} < 1$ . I do not interpret my model as a theory of international deviations from the law of one price based on search considerations. See Alessandria and Kaboski (2011).

<sup>21</sup>Currency misalignments are a weighted average of deviations from the law of one price, where the weights are an average of the home and foreign weights in the consumer price index.

<sup>22</sup>This is emphasized in many studies on monetary policy in open economies - such as Corsetti and Pesenti (2001) - because substitutability affects how real shocks are transmitted through the economy, via movements in the terms of trade.

<sup>23</sup>Throughout the analysis I study non-cooperative monetary policy.

<sup>24</sup>In the closed economy ( $\phi \rightarrow 0$ ), the policy maker would like to set  $R_t = 1 - \eta\delta_t$ , where  $\delta_t = a_t / (\frac{1}{z} - 1)$ , and simultaneously eliminate monetary and search frictions. This is not possible, and the optimal interest rate is zero, with deflation at the rate of time preference (Friedman rule). In the open economy ( $\phi, \phi^* > 0$ ), it can be optimal to raise the nominal interest rate above the Friedman rule because the policy maker faces an incentive to influence the terms of trade.

<sup>25</sup>In this knife-edge case, the marginal utility of one good is independent of the consumption of the other

good.

<sup>26</sup>With search frictions, optimal interest rate policy is closely tied to the real exchange rate, which, in this example, is equal to the average of the LOP gaps,  $\psi_{h,t}^{1/2}\psi_{f,t}^{1/2}$ . Absent search frictions, when pass-through is complete, optimal interest rate policy is a constant, and so is the real exchange rate. With home-bias in consumption, optimal interest rates remain independent of the business cycle, despite movements in the real exchange rate.

<sup>27</sup>Throughout this section I assume symmetry across countries. Since this requires  $a = a^*$ , then  $R = R^*$ , which further implies  $\hat{\psi}_{h,t} = \hat{\psi}_{f,t}$ . A currency misalignment is the weighted sum of LOP gaps, so  $\hat{\psi}_{h,t}$  is also the currency misalignment.

<sup>28</sup>This is true for changes in the preference parameter when the net markup is higher than the parameter  $z$  (see Proposition 2). This restriction always holds in the quantitative analysis below.

<sup>29</sup>Data is taken from the World Bank (indicator code: FP.CPI.TOTL.ZG).

<sup>30</sup>Employment is percentage of total working age population and labor-income share is for the total economy.

<sup>31</sup>A previous version of the paper also introduced cross-country heterogeneity in consumption and labor-income taxes based on Coenen, McAdam, and Straub (2008). These taxes had little impact quantitatively.

<sup>32</sup>Publicly available data is provided by Sweden Statistics (<https://www.h6.scb.se/tus/tus/>).

<sup>33</sup>The inflation rate in these interest rate rules is the consumer price index for posted prices.

<sup>34</sup>Similar results are reported in Henriksen, Kydland, and Sustek (2013). They develop a flexible-price model and study technology shocks when there are interest rate rules.

<sup>35</sup>Model-based correlations are usually reported for models with physical capital. Throughout the paper, I have abstracted from physical capital to focus on the normative implications of search frictions for the conduct of monetary policy.

<sup>36</sup>The results are available on request.

<sup>37</sup>Throughout this section, the two countries are symmetric, and there are technology and preference

shocks.

<sup>38</sup>Lubik and Schorfheide (2006) report estimates below one using a small-scale, two-country DSGE model. Drozd and Nosal (2012b) report a median value of 0.71 using cross-country data.

<sup>39</sup>Alessandria and Kaboski (2011) use data from the Harmonized European Time Use Survey and the Multinational Time Use Survey. Across both sets of data, shopping-to-work time is over 30 percent, and the average markup of firms from the richest country is, on average, 40 percent.

<sup>40</sup>As regards labor share, a value of 55 percent is reported in Gali and Monacelli (2016) for Greece, Ireland, Portugal and Spain. Alessandria and Kaboski (2011) reduce the labor share to 50 percent in their sensitivity analysis.

<sup>41</sup>The Taylor rule economy is not very sensitive to different parameter values. Results with a Taylor rule are available on request.

<sup>42</sup>Table 4 also explains why the results from the heterogeneous and homogenous-countries calibrations in Table 3 appear similar. Moving away from homogenous countries requires changing markups and search time simultaneously.

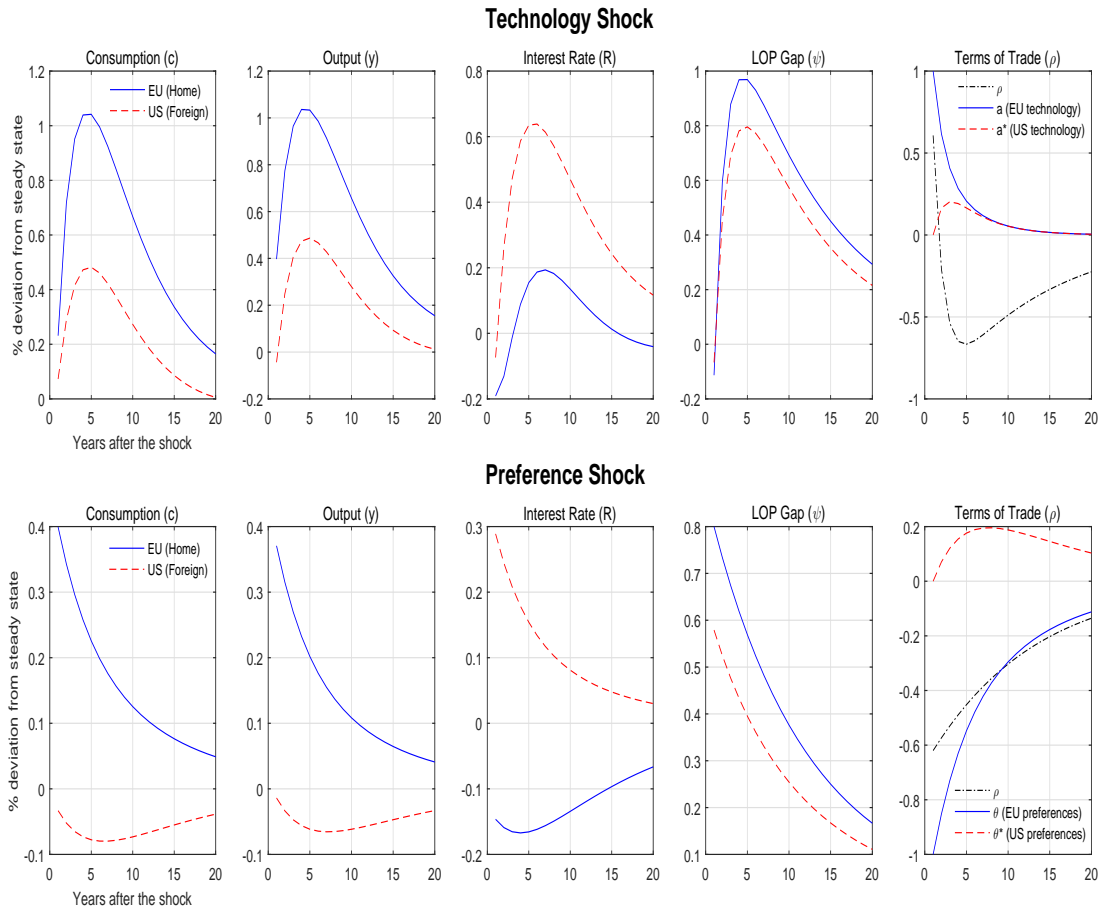
<sup>43</sup>The isomorphism result states that adding openness results only in a modification of the slope coefficients of the aggregate demand and supply relationships of the closed economy.

<sup>44</sup>With producer currency pricing, only the variance of producer prices appears in the loss function. Dispersion in consumer prices can be eliminated if producer price dispersion (of home and foreign goods) is eliminated. With local currency pricing, the variance of each type of good can be different in the two countries, and each variance term appears in the loss function.

<sup>45</sup>Devereux and Engel (2003) also analyze a model with one period preset prices. Once prices are adjusted infrequently, Engel (2011) shows that deviations from the law of one price matter for welfare, as well as output gaps and inflation rates. Deviations from the law of one price are therefore a separate source of loss in the model when prices are set in local currency terms.

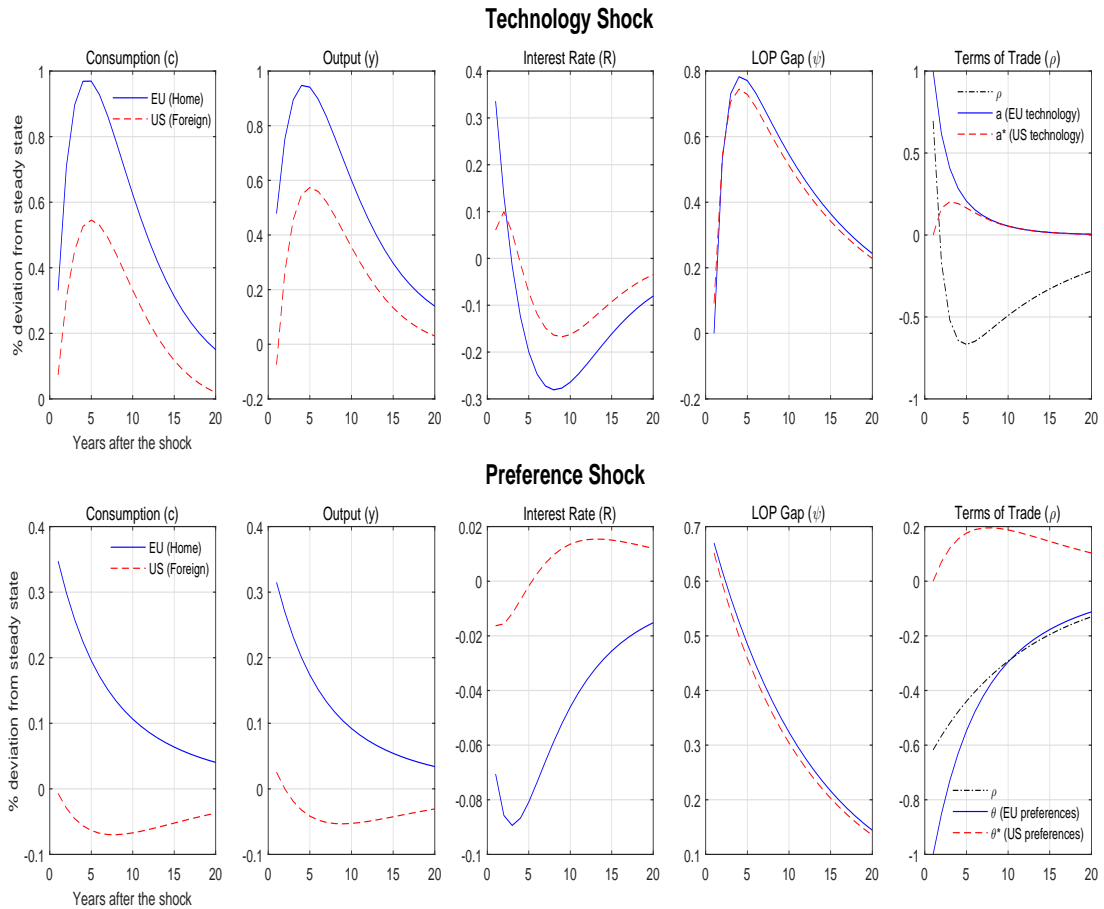
<sup>46</sup>Engel (2016) surveys the literature on international monetary policy coordination.

FIGURE 1: Impulse Responses to a Home Technology and Preference Shock (Optimal Policy)<sup>†</sup>



<sup>†</sup>Figure 1 notes: The top (bottom) panel reports impulse responses for a one-time positive (negative) shock to home technology,  $a_t$  (preferences,  $\theta_t$ ) of 1 percent, under optimal interest rate policy. The home (foreign) country is calibrated to the EU (US) economy. One period corresponds to one year on the horizontal axis and the percentage deviation from the steady-state is reported on the vertical axis.

FIGURE 2: Impulse Responses to a Home Technology and Preference Shock (Taylor Rule)<sup>‡</sup>



<sup>‡</sup>Figure 2 notes: The top (bottom) panel reports impulse responses for a one-time positive (negative) shock to home technology,  $a_t$  (preferences,  $\theta_t$ ) of 1 percent, when interest rates follow a Taylor rule. The home (foreign) country is calibrated to the EU (US) economy. One period corresponds to one year on the horizontal axis and the percentage deviation from the steady-state is reported on the vertical axis.

TABLE 1: Model Summary

	Home country	Foreign country
Output (resources)	$a_t l_t^{1-\alpha} = c_{h,t} + c_{h,t}^*$	$a_t^* (l_t^*)^{1-\alpha} = c_{f,t}^* + c_{f,t}$
Shopping (resources)	$s_t = c_{h,t} + c_{f,t}$	$s_t^* = c_{f,t}^* + c_{h,t}$
Consumption	$u_c(t) c_t = u_{c_h}(t) c_{h,t} + u_{c_f}(t) c_{f,t}$	$u_{c^*}(t) c_t^* = u_{c_h^*}(t) c_{h,t}^* + u_{c_f^*}(t) c_{f,t}^*$
Labor-leisure	$W_t / \tilde{p}_{h,t} = R_t \theta_t l_t^v / u_{c_h}(t)$	$W_t^* / \tilde{p}_{f,t}^* = R_t^* \theta_t^* l_t^{*v} / u_{c_f^*}(t)$
Int'l relative prices	$\tilde{p}_{h,t} / \tilde{p}_{f,t} = u_{c_h}(t) / u_{c_f}(t)$	$\tilde{p}_{f,t}^* / \tilde{p}_{h,t}^* = u_{c_f^*}(t) / u_{c_h^*}(t)$
Domestic price (reserv'n)	$\tilde{p}_{h,t} = (1 + \mu_{h,t}/z) x_t$	$\tilde{p}_{f,t}^* = (1 + \mu_{f,t}^*/z^*) x_t^*$
Export price (reserv'n)	$e_t \tilde{p}_{h,t}^* = [1 + (\mu_{h,t}^*/z^*) (e_t x_t^* / x_t)] x_t$	$\tilde{p}_{f,t} = [1 + (\mu_{f,t}/z) (x_t / e_t x_t^*)] e_t x_t^*$
Int'l risk sharing	$u_{c_f^*}(t) / u_{c_h}(t) = e_t \tilde{p}_{f,t}^* / \tilde{p}_{h,t}$	

TABLE 2: Calibration<sup>§</sup>

Parameters set exogenously				
Statistic	Parameters	Values	Sources	
Discount factor	$\beta$	0.99	$(\beta^{-4} - 1) \times 100 = 4.1\%$	
CRRA parameter	$\sigma$	2	Drozd and Nosal (2012b)	
Armington elasticity	$\omega$	1.2	Ruhl (2008)	
Frisch elasticity	$\nu$	0.5	Christoffel, Coenen, and Warne (2008)	
Calibrated parameters				
Statistic	Parameters	Values	Targets (%)	Sources
Employment rate	$\{\theta, \theta^*\}$	{2.36, 3.66}	{64, 67}	OECD
Labor-income share	$\{\alpha, \alpha^*\}$	{0.10, 0.21}	64	-
Price markup	$\{\eta, \eta^*\}$	{7.80, 3.79}	{35, 23}	Bayoumi, Laxton, and Pesenti (2004)
Import share	$\{\phi, \phi^*\}$	{0.23, 0.15}	{18, 13}	-
Price dispersion	$\{z, z^*\}$	{0.10, 0.15}	{35, 21}	see text
Search time	$\{a, a^*\}$	{0.17, 0.19}	{18, 21}	see text

<sup>§</sup>Table 2 notes: The parameters set exogenously are common across countries. The remaining parameters are calibrated to EU (home) and US (foreign) steady-state targets. The parameters with a  $\star$  refer to the foreign country.

TABLE 3: International Correlations<sup>¶||</sup>

		Technology and preference shocks					
		Heterogeneous (EU, US)			Homogenous (US)		
Correlations	Data	Inactive	Optimal	Taylor	Peg	Optimal	Taylor
$\text{corr}(c, c^*)$	0.53	0.53	0.46	0.54	0.55	0.48	0.55
$\text{corr}(y, y^*)$	0.69	0.66	0.52	0.66	0.62	0.50	0.61
$\text{corr}(R, R^*)$	0.46	–	0.13	0.61	–	0.27	0.60
$\text{corr}(\rho, y)$	-0.11	-0.31	-0.41	-0.32	-0.37	-0.41	-0.38
$\text{corr}(\Delta e, \Delta q)$	0.99	–	–	0.99	–	–	0.99
s. $\text{corr}(q)$	0.82	0.71	0.72	0.72	0.70	0.71	0.71

<sup>¶</sup>Table 3 notes on column *Data*: The output and consumption values are from Alessandria (2009) for 1980.1 to 2002.4 using US and (weighted) G7 data;  $\text{corr}(\rho, y) = -0.11$  is the average across countries. Interest rate correlation is from Henriksen, Kydland, and Sustek (2013) for 1984.1 to 2006.4. The serial correlation in the real exchange rate and the correlation between the real and nominal exchange rate are reported in Chari, Kehoe, and McGratten (2002).

<sup>||</sup>Table 3 notes on specifications: Columns *Heterogeneous (EU, US)* and *Homogenous (US)* refer the case in which the two countries are calibrated as the EU and US, with values reported in Table 2, and the case in which both countries are treated as the US, with steady-state targets  $\{67, 64, 23, 13, 21, 21\}$  (ordered as in Table 2) and calibrated parameters  $\{\theta, \alpha, \eta, \phi, z, a\} = \{3.57, 0.21, 3.71, 0.15, 0.14, 0.19\}$ . Columns *Inactive*, *Optimal*, *Taylor*, refer to an interest rate peg, optimal interest rate policy, and when interest rates follow a Taylor rule. All model-based statistics have been HP-filtered with a smoothing parameter of 1,600.



TABLE 4: Variations on Benchmark Economy\*\*

		Variations on benchmark economy (optimal policy)					
		Open economy		Consumer search		Labor supply	
Correlations	Benchmark	Armington	Closed	Markup	Search	Share	Indivisible
$\text{corr}(c, c^*)$	0.48	0.49	0.51	0.50	0.51	0.49	0.59
$\text{corr}(y, y^*)$	0.50	0.56	0.54	0.48	0.50	0.50	0.38
$\text{corr}(R, R^*)$	0.27	0.56	0.94	0.63	0.17	0.19	0.62
$\text{corr}(\rho, y)$	-0.41	-0.35	-0.40	-0.40	-0.39	-0.38	-0.41
s. $\text{corr}(q)$	0.71	0.70	0.68	0.72	0.71	0.70	0.73

\*\*Table 4 notes: Column *Benchmark* reproduces the specification *Homogenous (US)-Optimal* reported in Table 3. In the subsequent columns, only one target is changed relative to the benchmark case. Column *Armington* lowers the Armington elasticity to 0.7, *Closed* reduces the imports-to-output share to 5 percent, *Markup* raises the markup to 40 percent, *Search* raises search time is 33 percent, *Share* raises the share of labor in income to 55 percent, and *Indivisible* is the case in which labor is indivisible. All statistics have been HP-filtered with a smoothing parameter of 1,600.