Real Exchange Rate Fluctuations and Non-Homothetic Preferences

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Abstract

This study illustrates that a dynamic and stochastic general equilibrium model with non-homothetic consumption aggregates can explain the exchange rate disconnect puzzle. Variable markups are procyclical and amplify cost responses to financial shocks but offset cost responses to productivity shocks. Consequently, a favorable financial shock creates larger real appreciation, whereas a favorable productivity shock creates smaller real depreciation than the model with CES aggregates. Combining a favorable financial shock with an adverse productivity shock increases real appreciation and weakens its comovement with relative consumption. Both shocks can generate greater volatility in the real exchange rate than the terms of trade.

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1 Introduction

A limit on international risk sharing, home bias in consumption and financial shocks in dynamic and stochastic general equilibrium (DSGE) models in Itskhoki and Mukhin (2021, 2025), Kekre and Lenel (2024), and Chien et al. (2020) generate more realistic behaviors of exchange rates than earlier studies.[1] These models assume constant-elasticity-of-substitution (CES) consumption aggregates, and unit income elasticity contradicts the micro evidence in Alessandria and Kaboski (2011). They find that prices of tradables are persistently higher in high-income countries than in low-income countries, and this pattern of pricing-to-market (PTM) is twice as important as local nontraded inputs for differences in tradable prices.

Recent explanations for PTM rely on the introduction of non-homothetic preferences for consumption aggregates, whereas early studies rely on strategic complementarity and the distribution margin.[2] Auer et al. (2018) and Macedoni and Weinberger (2022) argue that variable income elasticity of demand results from differences in quality of tradables across income levels. On the contrary, Simonovska (2015) assumes identical quality of tradables and and present micro evidence for variable income elasticity of demand. These studies, however, examine micro prices without investigating their aggregate effects.

We fill the gap in the literature by illustrating that introducing non-homothetic preferences for consumption aggregates in DSGE model can explain behaviors of RER in line with the exchange rate disconnect puzzle, as described in Backus and Smith (1993) and Atkeson and Burstein (2008). The functional form of our non-homothetic consumption aggregate is

[1] See Chari et al. (2002) for the role of nominal rigidities, Ghironi and Melitz (2005) for endogenous entries to exporting, and Naknoi (2008) for both features.

[2] See Kimball (1995) for the strategic complementarity in pricing in a closed-economy, and de Blas and Russ (2015) for this mechanism in an open-economy. See Atkeson and Burstein (2008) for the role of distribution margins in an open economy.

similar to Simonovska (2015), as we do not address quality differences. In each country, the price-setting monopolist produces a tradable good for domestic and foreign consumption, and the good price is flexible. Non-homothetic preferences cause the producer to choose markups that vary across markets due to differences in income, hence PTM emerges in equilibrium.

We derive a closed form solution for prices, the RER and the terms of trade in response to temporary financial shocks and productivity shocks. We supplement our analytical proofs with a numerical illustration and obtain three results. First, our PTM mechanism creates a 50% exchange rate pass-through and procyclical markups, which imply that consumers become increasingly willing to pay higher prices during expansionary periods. Hence, a cross-country asymmetry in consumption booms creates asymmetric increases in markups, and therefore the degree of relative risk aversion becomes important for the magnitude of markup adjustments.

Second, a combination of a temporary positive shock to financial frictions and a negative temporary productivity shock in the home country creates rising inflation, RER appreciation that is not perfectly correlated with relative consumption. Intuitively, a positive shock to financial frictions raises the relative cost of production while creating a consumption boom at home, which increases markups of both domestic and imported products in the home market. Hence, PTM amplifies inflation and RER appreciation in response to positive financial shocks. At the same time, a temporary negative shock to productivity increases the relative cost of production while having a negative effect on consumption, which offsets the expansionary effect of a positive financial shock and weakens the comovement between RER and relative consumption.

Finally, financial shocks generate greater volatility in the RER than the terms of trade,

even when the degree of relative risk aversion is as low as 1.5. This result is due to the amplifying effect of markup adjustments, and this effect is decreasing in the the degree of relative risk aversion. As for productivity shocks, they generate this volatility ranking when the degree of home bias is sufficiently high, and cause the difference in volatility of these two variables increasing in the degree of relative risk aversion. To illustrate the mechanism, we compare our results with an alternative conventional model with CES aggregates without strategic complementarity. Such a model predicts lower volatility in the RER than the terms of trade, for any degree of relative risk aversion.

We make a contribution to the theoretical literature on exchange rates and our work is closely related to Itskhoki and Mukhin (2021). They present the first study that integrates multiple shocks and a low degree of relative risk aversion in DSGE models to resolve the exchange rate disconnect puzzle. Their PTM mechanism relies on strategic complementarity, which implies countercyclical markups. Compared to their model, the strength of ours is its consistency with both micro evidence, as discussed above, and macro evidence in Nekarda and Ramey (2020). They find that markups are procyclical in US data, conditioning on productivity shocks, monetary shocks and government spending shocks, but countercyclical conditioning on investment-specific technology shocks. In theory, procyclical markups permit a positive demand shock to generate larger effects on inflation than countercyclical markups. For this reason, our model is potentially useful for studying effects of fiscal shocks on the Covid-19 pandemic inflation and their international spillovers.[3]

The other closely related work is the open economy model of markups by de Blas and Russ (2015). In their model, endogenous entries following trade liberalization generate a neg-

[3]For open economy model of the Covid-19 pandemic inflation, see di Giovanni et al. (2023).

ative relationship between the average markup and aggregate output, similar to endogenous entries under a translog demand structure in Bergin and Feenstra (2009). However, trade liberalization is a low-frequency shock, whereas shocks in our model are medium-frequency shocks over business cycles. Introducing endogenous entries in our model would weaken the positive correlation between output and markups, but favorable shocks over business cycles would likely create much smaller number of entrants than trade liberalization.

Next section presents the model and its results. Section 3 compares our results with those in the conventional model with CES preferences. Finally, we conclude our study in Section 4.

2 The Model

Consider two open economies called Home and Foreign. In each country, there is a representative household and a monopolist producing a tradable good for domestic consumption and exporting. We abstract from nontradables, which is critical in Chien et al. (2020), to highlight the PTM mechanism. Of most importance, households choose optimal demand for each product given their non-homothetic preferences, as described below.

2.1 The Household's Intratemporal Problem

Let c_{it} denote consumption of product i, where $i \in \{h, f\}$ denotes home and foreign products, respectively. Final consumption exhibits non-homothetic preferences over home

and foreign products as follows:

$$c_t = (c_{ht} + \gamma)^{\alpha}(c_{ft} + \gamma)^{1-\alpha}$$

where $\gamma > 0$ and $0.5 < \alpha < 1$, indicating a home bias towards the domestic product. Solving a cost minimization problem subject to unit consumption gives the optimal allocation as a function of its own price (p_{it}) and the unit cost (P_t):

$$c_{ht} = \alpha \left(\frac{P_t}{p_{ht}} \right) c_t - \gamma \tag{1}$$

$$c_{ft} = (1 - \alpha) \left(\frac{P_t}{p_{ft}} \right) c_t - \gamma \tag{2}$$

$$P_t = \frac{p_{ht}^{\alpha} p_{ft}^{1-\alpha}}{\alpha^{\alpha}(1-\alpha)^{1-\alpha}}. \tag{3}$$

Let the superscript * denote foreign variables, and the foreign final consumption aggregate takes a similar form:

$$c_t^* = (c_{ht}^* + \gamma)^{1-\alpha}(c_{ft}^* + \gamma)^{\alpha}$$

Likewise, we obtain the foreign optimal demand for each product and the foreign unit cost

from a cost minimization problem:

$$c_{ht}^* = (1-\alpha)\left(\frac{P_t^*}{p_{ht}^*}\right)c_t^* - \gamma \tag{4}$$

$$c_{ft}^* = \alpha\left(\frac{P_t^*}{p_{ft}^*}\right)c_t^* - \gamma \tag{5}$$

$$P_t^* = \frac{p_{ht}^{*1-\alpha}p_{ft}^{*\alpha}}{\alpha^\alpha(1-\alpha)^{1-\alpha}} \tag{6}$$

2.2 The Household's Intertemporal Problem

Consider an incomplete asset market in which money and a foreign-currency bond are available. Let $\mathcal{E}_t$ denote the nominal exchange rate defined as units of the home currency per foreign currency. Real balances held by home residents at the end of period t are $m_t = M_t/P_t$ and $b_t = B_t\mathcal{E}_t/P_t$, where M_t and B_t denote nominal values, respectively. Let i_t^* be the nominal interest rate on the bond between periods $t-1$ and t. There exist financial frictions that increase the cost of borrowing above the nominal interest rate, and we denote financial frictions with $\phi_t > 1$. Let gross inflation from $t-1$ to t be $\pi = P_t/P_{t-1}$. Then, real values of asset holdings in the beginning of period t are m_{t-1}/π_t and $b_{t-1}\mathcal{E}_t/(\pi_t\mathcal{E}_{t-1})$, respectively. Let β be the discount factor, where $\beta \in (0,1)$.

The utility function exhibits separability with money and labor supply (l_t), a constant degree relative risk aversion ($\sigma > 0$) and Frisch elasticity of labor supply ($1/\kappa$). A representative household chooses final consumption, labor supply and real money balance to maximize the expected lifetime utility:

$$\max_{\{c_t,l_t,m_t\}} E_0 \sum_{t=0}^{\infty} \beta^t \frac{1}{1-\sigma}c_t^{1-\sigma} - \frac{l_t^{1+\kappa}}{1+\kappa} + \ln m_t$$

subject to the intertemporal budget constraint:

$$c_t + m_t + b_t = w_t l_t + \frac{m_{t-1}}{\pi_t} + \frac{\Pi_t}{P_t} + \phi_t(1 + i_t^*)\frac{b_{t-1}\mathcal{E}_t}{\pi_t \mathcal{E}_{t-1}},$$

where w_t denotes the real wage rate, and Π_t denotes dividends. The first order conditions (FOCs) for consumption and labor supply give labor income that is positively correlated with consumption:

$$w_t l_t^{\kappa} = c_t^{\sigma} \tag{7}$$

The FOCs with respect to consumption and bond give the Euler equation:

$$1 = \beta E_t \left[\frac{\phi_{t+1}(1 + i_{t+1}^*)\mathcal{E}_{t+1}}{\pi_{t+1}\mathcal{E}_t} \left(\frac{c_{t+1}}{c_t} \right)^{-\sigma} \right]$$

A similar optimization problem exists for foreign households, and we obtain a similar the Euler equation for them:

$$1 = \beta E_t \left[\frac{\phi_{t+1}^*(1 + i_{t+1}^*)}{\pi_{t+1}^*} \left(\frac{c_{t+1}^*}{c_t^*} \right)^{-\sigma} \right]$$

2.3 The Real Exchange Rate

The RER is defined as the relative price levels, $q_t = P_t^* \mathcal{E}_t / P_t$. Then, its movements are identical to domestic-foreign inflation differentials adjusted by the depreciation rate of the home currency. Let $\hat{x}_t$ denote a percentage deviation of variable x_t from its steady state

$\bar{x}$. For analytical tractability, we assume $\bar{b} = 0$ in the steady state. The difference in the linearized versions of the two Euler equation above gives the expected rate of change in the RER:

$$E_t[\Delta \hat{q}_{t+1}] = \sigma E_t[\Delta \hat{c}_{t+1} - \Delta \hat{c}^*_{t+1}] - E_t[\hat{\phi}_{t+1} - \hat{\phi}^*_{t+1}] \tag{8}$$

The last term depends on the stochastic process of shocks to financial frictions, as in Itskhoki and Mukhin (2021, 2025).

2.4 The Monopolist Producer

The production function of the home monopolist is linear: $Y_t = A_t l_t$, where A_t is total factor productivity. The home monopolist takes its local demand in (1) and export demand in (4) as given, and sets market-specific home-currency price p_{ht} and foreign-currency price p^*_{ht} to maximize profits:

$$\max_{\{p_{ht}, p^*_{ht}\}} \Pi_t = \left(p_{ht} - \frac{W_t}{A_t}\right) c_{ht} + \left(p^*_{ht}\mathcal{E}_t - \frac{W_t}{A_t}\right) c^*_{ht}$$

The optimal prices are obtained from the FOCs as:

$$p_{ht} = \left(\frac{\alpha W_t P_t c_t}{\gamma A_t}\right)^{0.5} \tag{9}$$

$$p^*_{ht} = \left(\frac{(1-\alpha) W_t P^*_t c^*_t}{\gamma A_t \mathcal{E}_t}\right)^{0.5} \tag{10}$$

The power 0.5 indicates the elasticity of exchange rate pass through to local-currency price of exported product. In addition, these optimal prices are positively influenced by aggregate consumption in the destination market. When aggregate consumption in the domestic market and that in the foreign market are different, the firm sets different prices for each locations. For this reason, PTM emerges in equilibrium. These prices also suggest that the optimal price is positively correlated with income.

To demonstrate the key mechanism, we derive the endogenous markup as the ratio of optimal price in each location to the marginal cost, conditioning on the optimal demand:

$$\mu_{ht} = \frac{c_{ht} + \gamma}{\gamma} \tag{11}$$

$$\mu^*_{ht} = \frac{c^*_{ht} + \gamma}{\gamma} \tag{12}$$

Proposition 1 *Variable markups are procyclical in each location.*

Proof. Let $corr(\cdot, \cdot)$ denote time series correlation of two random variables. According to (11), $corr(\hat{\mu_{ht}}, \hat{c}_{ht}) > 0$. From (1) and (7), $corr(\hat{c}_{ht}, \hat{w}_t + \hat{l}_t) > 0$. From the production function, $corr(\hat{w}_t + \hat{l}_t, \hat{Y}_t) > 0$, thus $corr(\hat{\mu}_{ht}, \hat{Y}_t) > 0$. Likewise, according to (12), $corr(\hat{\mu}^*_{ht}, \hat{c}^*_{ht}) > 0$. In addition, (4) and the foreign counterpart of (7) imply that $corr(\hat{c}^*_{ht}, \hat{w}^*_t + \hat{l}^*_t) > 0$. From The foreign production function, $corr(\hat{w}^*_t + \hat{l}^*_t, \hat{Y}^*_t) > 0$, thus $corr(\hat{\mu}^*_{ht}, \hat{Y}^*_t) > 0$.

Proposition 1 is consistent with the effect of price elasticity of demand, denoted by θ_{ht} in the home market and θ^*_{ht} in the foreign market. To see why, we write the markup in (11) as $\theta_{ht}/(\theta_{ht} - 1)$ where $\theta_{ht} = (c_{ht} + \gamma)/c_{ht}$. Likewise, the markup abroad in (12) is equivalent

to $\theta^*_{ht}/(\theta^*_{ht}-1)$, where $\theta^*_{ht} = (c^*_{ht}+\gamma)/c^*_{ht}$. Intuitively, an expansion in demand reduces the price elasticity and therefore raises the markup. In short, consumers' increasing willingness to pay during an expansionary period enables the producer to raise markups.

However, our prediction in Proposition 1 is opposite from that in de Blas and Russ (2015). Their open economy model with Bertrand competition illustrates that bilateral trade liberalization creates new exporters and decreases the markups of domestic firms, while increasing markups of incumbent exporters. Hence, their work predicts a negative correlation between the average markup and aggregate output. This mechanism is also similar to endogenous entries in Bergin and Feenstra (2009), who assume a translog demand structure. Compared to their models, ours is abstract from endogenous entries in the export market. Introducing endogenous entries in our model would intuitively weaken the correlation between markups and aggregate output, as new exporters would increase price elasticity of demand. However, medium-frequency shocks over business cycles would likely generate much smaller number of new entrants than low-frequency trade shocks in their studies.

We obtain similar properties of markups chosen by the foreign firm. In particular, the foreign monopolist chooses market-specific home=currency price p_{ft} and foreign-currency price p^*_{ft} to maximize profits, taken as given its export demand in (2) and local demand in (5):

$$\max_{\{p_{ft},p^*_{ft}\}} \Pi^*_t = \left(\frac{p_{ft}}{\mathcal{E}_t} - \frac{W^*_t}{A^*_t}\right) c_{ft} + \left(p^*_{ft} - \frac{W^*_t}{A^*_t}\right) c^*_{ft}$$

The optimal prices for foreign monopolist become:

$$p_{ft} = \left(\frac{(1-\alpha) W_t^* P_t c_t \mathcal{E}_t}{\gamma A_t^*} \right)^{0.5} \tag{13}$$

$$p_{ft}^* = \left(\frac{\alpha W_t^* P_t^* c_t^*}{\gamma} A_t^* \right)^{0.5} \tag{14}$$

Again, the power 0.5 indicates the degree of exchange rate pass-through to local-currency price of exports to the home country. Alternatively, we write endogenous markups as:

$$\mu_{ft} = \frac{c_{ft} + \gamma}{\gamma} \tag{15}$$

$$\mu_{ft}^* = \frac{c_{ft}^* + \gamma}{\gamma} \tag{16}$$

Similar to Proposition 1, it is straightforward that price markups for foreign products in (15) and (16) are also procyclical in each location.

2.5 The Monetary Rule

The monetary rule of the central bank pins implicitly determines the nominal exchange rate. We consider the Taylor rule:

$$\hat{i}_t = \xi \hat{\pi}_t,$$

where $\xi > 0$ and the nominal interest rate is defined as $i_t = \beta(c_{t+1}/c_t)^{\sigma}\pi_t - 1$. This rule and the definition of the RER determine the nominal exchange rate:

$$\hat{\mathcal{E}}_t = \hat{q}_t + \frac{\hat{\pi}_t - \hat{\pi}_t^*}{\xi}$$

As pointed out by Itskhoki and Mukhin (2021, 2025), this rule creates strong correlation between nominal exchange rate and the RER when the central bank targets inflation rate that is close to the foreign central bank. The foreign central bank is assumed to follow a similar rule.

2.6 Shock Processes

Financial frictions in each country follow the following AR(1) process:

$$\hat{\phi}_t = \rho_\phi \hat{\phi}_{t-1} + z_t, \text{ and } \hat{\phi}_t^* = \rho_\phi \hat{\phi}_{t-1}^* + z_t^*,$$

with a degree of persistence $\rho_\phi \in (0, 1)$. The random shocks z_t and z_t^* are identically and independently distributed (iid) and follow $\mathcal{N}(0, \sigma_z^2)$.

The stochastic processes for productivity at home and abroad are described by:

$$\hat{A}_t = \rho_A \hat{A}_{t-1} + v_t, \text{ and } \hat{A}_t^* = \rho_A \hat{A}_{t-1}^* + v_t^*,$$

where $\rho_A \in (0, 1)$l. The random shocks v_t and v_t^* are iid and follow $\mathcal{N}(0, \sigma_v^2)$.

To close the model, all markets must clear in every period. The goods market clears at equilibrium prices, and the labor market clears at equilibrium wages. In the asset market, there is has net zero supply of bonds in equilibrium.

2.7 The Equilibrium Real Exchange Rate

To obtain the effect of PTM on the RER, we substitute wages from (7) into optimal PTM conditions (9) and (13), and then substitute these prices into the price index (3) to obtain the equilibrium domestic price level. Likewise, the foreign counterpart of (7), optimal PTM conditions (10) and (14), and the foreign price index (6) give the equilibrium foreign price level. Assume that the size of population is identical in the two countries. Then, the RER deviation from the symmetric steady state becomes:

$$\hat{q}_t = -\frac{\sigma(2\alpha-1)+1}{2(1-\alpha)}(\hat{c}_t - \hat{c}_t^{\star}) + \frac{2\alpha-1}{2(1-\alpha)}(\hat{A}_t - \hat{A}_t^{*} - \kappa(\hat{l}_t - \hat{l}_t^{*}))$$

The elasticity of the relative consumption is negative, given that $\alpha \in (0.5, 1)$. It illustrates the role of non-homothetic preferences in PTM. When home consumption expands and the marginal cost declines in response to positive productivity shocks at home, both foreign and home monopolists raise markups in the home market. Such a PTM pattern offsets the direct impact of productivity improvements on prices. As a result, PTM weakens the degree of RER depreciation. As for the elasticity of the relative productivity, it is positive as long as the Frisch elasticity of labor supply is sufficiently small.

Next, we further rewrite the expression above using the production function, $\hat{l}_t = \hat{Y}_t - \hat{A}_t$:

$$\hat{q}_t = -\frac{\sigma(2\alpha-1)+1}{2(1-\alpha)}(\hat{c}_t - \hat{c}_t^{\star}) + \frac{2\alpha-1}{2(1-\alpha)}((1+\kappa)(\hat{A}_t - \hat{A}_t^{*}) - \kappa(\hat{Y}_t - \hat{Y}_t^{*})) \tag{17}$$

where $-\eta^j \hat{\phi}_t + \eta^j \hat{A}_t = \hat{Y}_t$, and $\eta^j \in (d, s)$ is the elasticity of output in response to positive

shocks to financial frictions and productivity, respectively. By construction, $\eta^j \in (d, s) > 0$.

To obtain the equilibrium RER, we iterate the supply side in (17) forward for one period, take the first difference and equate with the demand side in (8). In addition, we use the stochastic process of shocks to obtain the expectations $E_t[\Delta\hat{A}_{t+1} - \Delta\hat{A}^*_{t+1}] = -(1-\rho_A)(\hat{A}_t - \hat{A}^*_t)$ and $E_t[\hat{\phi}_{t+1} - \hat{\phi}^*_{t+1}] = \rho_\phi(\hat{\phi}_t - \hat{\phi}^*_t)$.

$$
\begin{aligned}
E_t[\Delta\hat{q}_{t+1}] = &-\frac{((\sigma - \kappa\eta^d)(2\alpha - 1) + 1)}{1+\sigma}\rho_\phi(\hat{\phi}_t - \hat{\phi}^*_t) \\
&- \frac{(\sigma + \kappa - \kappa\eta^s)(2\alpha - 1)}{1+\sigma}(1-\rho_A)(\Delta\hat{A}_t - \Delta\hat{A}^*_t)
\end{aligned} \tag{18}
$$

When $d(E_t[\Delta\hat{q}_{t+1})/d(\hat{\phi}_t))] < 0$ and $d(E_t[\Delta\hat{q}_{t+1})/d(\hat{A}_t))] < 0$), the RER is expected to be mean-reverting. Given that $\alpha \in (0.5, 1)$, $2\alpha - 1 > 0$ and thus this is the case when κ is sufficiently small that $\sigma > \kappa\eta^j$. To put differently, this condition requires that a small increase in employment enables households to enjoy a consumption boom. Quantitative studies typically choose a small parameter value for κ to satisfy this condition; otherwise the economy will not converge to the steady state in the long run. Then, the RER follows the following stochastic process: $\hat{q}_{t+1} = \delta\hat{q}_t + u_t$, where and u_t is white noise. As a result, $E_t[\Delta\hat{q}_{t+1}] = -(1-\delta)\hat{q}_t$. Substituting this expectation into (18) gives the following.

$$
\hat{q}_t = \frac{((\sigma - \kappa\eta^d)(2\alpha - 1) + 1)\rho_\phi}{(1+\sigma)(1-\delta)}(\hat{\phi}_t - \hat{\phi}^*_t) + \frac{(\sigma + \kappa - \kappa\eta^s)(2\alpha - 1)(1-\rho_A)}{(1+\sigma)(1-\delta)}(\hat{A}_t - \hat{A}^*_t)
$$

This expression is not exactly a closed form solution of $\hat{q}_t$, because we know only $\eta^d > 0$ and $\eta^j > 0$ without a prediction about how they are determined by other parameters.

For this reason, we consider a special case in which labor supply is restricted by the size

of population, and so $\kappa = 0$, to analytically illustrate the key mechanism.

$$\hat{q}_t = -\frac{(\sigma(2\alpha-1)+1)\rho_\phi}{(1+\sigma)(1-\delta)}(\hat{\phi}_t - \hat{\phi}_t^*) - \frac{\sigma(2\alpha-1)(1-\rho_A)}{(1+\sigma)(1=\delta)}(\hat{A}_t - \hat{A}_t^*) \tag{19}$$

2.7.1 Persistence of the Real Exchange Rate

To solve for the first-order autocorrelation δ, we consider one shock at a time. Suppose $\hat{\phi}_t \neq 0$, and $\hat{\phi}_t^* = \hat{A}_t = \hat{A}_t^* = 0$. Then, the home demand shock generates the following first-order autocorrelation:

$$\delta = corr\left(\frac{(\sigma(2\alpha-1)+1)\rho_\phi}{(1+\sigma)(1-\delta)}(\rho_\phi\hat{\phi}_{t-1} + z_t), \frac{(\sigma(2\alpha-1)+1)\rho_\phi}{(1+\sigma)(1-\delta)}\hat{\phi}_{t-1}\right) = \rho_\phi$$

We can generalize this result for other shock variables.

Proposition 2 *RER responses to AR(1) shocks follow an AR(1) process of which persistence is identical to the persistence of underlying shocks.*

Proof. We can write (19) as $y_t = \hat{q}_t$, x_t is a shock variable, and k_x is the elasticity associated with the shock. Hence, $y_t = k_x x_t$, $k \neq 0$, and x_t is governed by the following mean-reverting process: $x_t = \rho_x x_{t-1} + n_t$, where $0 < \rho_x < 1$ and n_t is an iid white noise. Multiplying x_t with k_x gives $k_x x_t = k\rho_x x_{t-1} + k_x n_t$. This process is identical to the stochastic process of $y_t = \rho_x y_{t-1} + k n_t$. Given that n_t is an iid white noise, kn_t is also an iid white noise. Hence, $corr(y_t, y_{t-1}) = \rho_x = corr(x_t, x_{t-1})$.

The prediction in Proposition 2 is intuitive, given that our model is highly stylized and abstract from capital accumulation and investment adjustment costs, unlike full-fledged international real business cycle models.

2.7.2 Volatility of the Real Exchange Rate

Demand-Driven Volatility. We substitute the persistence parameter, $\delta = \rho_\phi$, and shock variables, $\hat{\phi}_t \neq 0, \hat{\phi}^*_t = \hat{A}_t = \hat{A}^*_t = 0$, into (19) to obtain the closed form solution for the RER response to a home financial shock:

$$\hat{q}^d_t = \frac{(\sigma(2\alpha - 1) + 1)\rho_\phi}{(1+\sigma)(1-\rho_\phi)}\hat{\phi}_t \tag{20}$$

We obtain the standard deviation of the home financial shock from its stochastic process. Consequently, the standard deviation of RER is:

$$std(\hat{q}^d_t) = \frac{(\sigma(2\alpha - 1) + 1)\rho_\phi \sigma_z}{(1+\sigma)(1-\rho_\phi)\sqrt{1-\rho^2_\phi}} \tag{21}$$

Proposition 3 *Favorable financial shocks appreciate the RER, and the degree of RER appreciation is decreasing in the degree of relative risk aversion.*

Proof. From (20), $d\hat{q}^d_t/d\hat{\phi}_t > 0$ for $\alpha \in (0.5, 1)$. From (21), $d(std(\hat{q}^d_t))/d\sigma = -2(1-\alpha)\rho_\phi\sigma_z/((1+\sigma)^2(1-\rho_\phi)\sqrt{1-\rho^2_\phi})$. Since $\alpha \in (0.5, 1)$ and $\rho_\phi \in (0, 1)$, then $d(std(\hat{q}^d_t))/d\sigma < 0$.

Understanding the intuition for Proposition 3 requires understanding how the RER adjusts to financial shocks. According to (20), a reduction in financial frictions appreciates the RER by raising the value of home product, while increasing consumption with a home bias. Then, the PTM mechanism suggests that the home monopolist raises the local markup and lowers the export markup. On the contrary, the foreign monopolist raises the export

markup and lowers the local markup. For this reason, markups for both products increase in the home market and decrease in the foreign market, reinforcing the rising home-foreign wage differential. The price and RER adjustments cause home consumers to decrease exports and increase imports. Hence, this expenditure switching causes the home country to run a trade deficit and become a debtor.

Proposition 3 implies that a low degree of risk aversion amplifies RER responses to financial shocks. Intuitively, increasing risk aversion implies declining intertemporal elasticity of substitution and decreasing adjustments in relative consumption growth. Then, the positive impact of consumption growth on markup adjustments declines and diminishes the amplification effect of procyclical markups. However, RER volatility in (21) will reach its lower bound if $\alpha = 0.5$, implying that the home bias is critical for our result. The importance of the home bias in consumption has been emphasized in previous studies under CES preferences including Itskhoki and Mukhin (2021, 2025) and Chien et al. (2020).

Supply-Driven Volatility. Substituting the persistence parameter, $\delta = \rho_A$, and shock variables, $\hat{A}_t \neq 0, \hat{\phi}_t = \hat{\phi}_t^* = \hat{A}_t^* = 0$, into (19) gives us the closed form solution for the RER response to a home productivity shock:

$$\hat{q}_t^s = \frac{\sigma(2\alpha - 1)}{1 + \sigma} \hat{A}_t \tag{22}$$

Next, we obtain the standard deviation of the home productivity shock from its stochastic process to derive the standard deviation of RER responses to productivity shocks:

$$std(\hat{q}_t^s) = \frac{\sigma(2\alpha - 1)\sigma_v}{1 + \sigma\sqrt{1 - \rho_A^2}} \tag{23}$$

Proposition 4 *Favorable productivity shocks depreciate the RER, and the degree of RER depreciation is increasing in the degree of relative risk aversion.*

Proof. From (22), $d\hat{q}_t^s/d\hat{A}_t > 0$ for $\alpha \in (0.5.1)$. From (23), $d(std(\hat{q}_t^s))/d\sigma = (2\alpha - 1)\sigma_v/((1+\sigma)^2\sqrt{1-\rho_A^2})$. Since $\alpha \in (0.5.1)$ and $\rho_A \in (0,1)$, then $d(std(\hat{q}_t^s))/d\sigma > 0$.

To understanding Proposition 4, we have to understand how the RER adjusts to a productivity shock in (22). An improvement in home productivity depreciates the RER by lowering the value of the home product, while creating an expansion in relative consumption. The PTM mechanism suggests that the home monopolist raises the local markup and lowers the export markup. On the contrary, the foreign monopolist raises the export markup and lowers the local markup. For this reason, markups for both products increase in the home market and decrease in the foreign market, offsetting the decline in relative cost of production. The price and RER adjustments cause home consumers to increase exports and decrease imports. Hence, this expenditure switching causes the home country to run a trade surplus and become a creditor.

According to Proposition 4, increasing risk aversion implies declining intertemporal elasticity of substitution and decreasing adjustments in relative consumption growth. As a result, the offsetting effect of procyclical markups diminishes and increases the influence of relative cost on inflation and RER. Once again, the solution in (22) highlights the importance of the home bias. If $\alpha = 0.5$, the RER will not respond to productivity shocks.

2.8 Exchange Rate Disconnect

2.8.1 Comovement between RER and Consumption Growth

To illustrate the mechanism that generates exchange rate disconnect, we derive correlation of the solution of RER with relative consumption for each type of shocks. First, we revisit from (17), (20) and (22):

$$corr(\hat{q}_t^d, \hat{c}_t - \hat{c}_t^*) = -1, \ corr(\hat{q}_t^s, \hat{c}_t - \hat{c}_t^*) \in (0, 1) \tag{24}$$

These statistics imply that a positive financial shock and an adverse productivity shock both create RER appreciation, while creating opposite adjustments in consumption. For this reason, the combined effect of both shocks can weaken the comovement of RER with relative consumption. In this case, the closed form solution of RER responses becomes:

$$\hat{q}_t^{ds} = \hat{q}_t^d + \hat{q}_t^s = \frac{(\sigma(2\alpha - 1) + 1)\rho_\phi}{(1 + \sigma)(1 - \rho_\phi)}\hat{\phi}_t + \frac{\sigma(2\alpha - 1)}{1 + \sigma}\hat{A}_t \tag{25}$$

Proposition 5 *Combining a favorable financial shock with an adverse productivity shock, or an adverse financial shock with a positive productivity shock, increases RER volatility while creating imperfect correlation in RER and relative consumption.*

Proof. Consider $\hat{A}_t = \hat{\phi}_t \neq 0$ and $\hat{A}_t^* = \hat{\phi}_t^* = 0$. From (25), $std(\hat{q}_t^{ds}) = \sqrt{(std(\hat{q}_t^d))^2 + (std(\hat{q}_t^s))^2} > std(\hat{q}_t^d)$. From (17), $corr(\hat{q}_t^{ds}, \hat{c}_t - \hat{c}_t^*) = corr(\hat{q}_t^s, \hat{c}_t - \hat{c}_t^*)$ and thus (24) gives $corr(\hat{q}_t^{ds}, \hat{c}_t - \hat{c}_t^*) \in (-1, 0)$.

Proposition 5 and (25) suggest that a favorable financial shock and an adverse pro-

ductivity shock at the same time ($\hat{q}_t^{ds} < 0$) creates RER appreciation with a small impact on relative output. The reason is that the two shocks have opposite impacts on output, while having positive impacts on the relative cost of production. Although this productivity shock puts a downward pressure on markup, the pressure is dominated by rising cost and an upward pressure on markup from the financial shock.

Combining different types of shocks to weaken the comovement between RER and real allocation is also how Itskhoki and Mukhin (2021) resolve the exchange rate disconnect puzzle. Our contribution is the illustration that we can achieve a similar mechanism underlying a macro fact in an environment that is supported by micro evidence.

2.8.2 Volatility of the Terms of Trade

An alternative way to address the exchange rate disconnect puzzle is to illustrate that our model can generate greater volatility in the RER than the terms of trade, as documented in the literature (Atkeson and Burstein (2008); de Blas and Russ (2015)). We define the terms of trade as $\omega_t = p_{ht}^* \mathcal{E}_t / p_{ft}$. Thus, $\hat{\omega}_t = \hat{p}_{ht}^* + \hat{\mathcal{E}}_t - \hat{p}_{ft}$. The equilibrium prices in (10) and (13), the demand-side in (8), and the solution of RER in (20) and (22) give the solution of terms of trade responses to each shock:

$$\hat{\omega}_t^j = -\tau^j \hat{q}_t^j, \tag{26}$$

where $j \in \{d, s\}$ and

$$\tau^j = \begin{cases} \frac{(1-\alpha)(\sigma-1)}{1+\sigma(2\alpha-1)} & \text{for } j = d \\ \frac{(1-\alpha)\sigma+\alpha}{\sigma(2\alpha-1)} & \text{for } j = s \end{cases}$$

Proposition 6 *Financial shocks always generate greater volatility in the RER than the terms of trade when the relative risk aversion is 3 or below 3. Productivity shocks will generate this result over the same range of relative risk aversion if the degree of home bias is sufficiently high.*

Proof From (40), $std(\hat{\omega}_t^j) < std(\hat{q}_t^j)$ if $\tau^j < 1$. This is the case when $\alpha > \underline{\alpha}^j$ where $\bar{\alpha}^d = 2(\sigma-1)/(2\sigma-1)$ and $\underline{\alpha}^s = 2\sigma/(2\sigma-1)$. For $1 < \sigma \leq 3$, $\underline{\alpha}^d \leq 0.5$ and $\bar{\alpha}^s > 0.75$.

The numerical illustration of Proposition (6) is in Table 1. Column 1 displays the degree of relative risk aversion, and the other two columns display the corresponding minimum threshold level of home bias that generates greater volatility in the RER than the terms of trade for each type of shocks. The threshold for financial shocks is lower than 0.5 for the risk aversion at 1.5 and 2. For any degree of relative risk aversion, the threshold level for productivity shocks is much higher than that for financial shocks. This result reflects the amplification effect of markup adjustments to financial shocks and the mitigating effect of markup adjustments to productivity shocks. This difference in effects of PTM across types of shocks is decreasing in the degree of risk aversion, as described in Propositions 3 and 4.

Figure 1 provides a numerical illustration of the ratio $std(\hat{\omega}_t^j)/std(\hat{q}_t^j)$, which is below 1 in the empirical literature. Panel 1a displays the result for financial shocks and Panel 1b display the result for productivity shocks. In both panels, we vary the degree of relative risk aversion, while keeping the home bias parameter constant. The solid line without markers

Table 1: Minimum degree of home bias required for std(RER)>std(terms of trade)

Risk aversion σ	Financial shocks $\underline{\alpha}^d$	Productivity shocks $\underline{\alpha}^s$
1.5	0.286	0.857
2	0.400	0.800
3	0.500	0.750
4	0.545	0.727
5	0.571	0.714
6	0.588	0.706

corresponds to a low degree of home bias ($\alpha = 0.6$), the solid line with circle markers corresponds to a moderate degree of home bias ($\alpha = 0.75$), and the solid line with asterisk markers corresponds to a high degree of home bias ($\alpha = 0.9$).

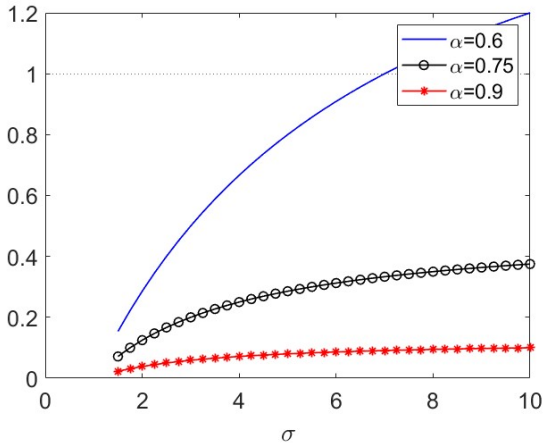
In Panel 1a, financial shocks remarkably match this fact when the risk aversion is low, for all values of the home bias parameter. The lower it is, the stronger the PTM mechanism that amplifies RER movements. When $\sigma = 1.5$ and $\alpha = 0.6$, the volatility of the terms of trade is only 15% of the volatility of the RER. When $\sigma = 2$ and $\alpha = 0.6$, the volatility of the terms of trade accounts for 29% of the volatility of the RER.

In contrast, in Panel 1b, productivity shocks do not match well when the risk aversion is low. When $\sigma = 1.5$ and $\sigma = 2$, productivity shocks replicate the empirical fact when the home bias parameter is 0.9. This level of home bias is extremely high, and results in lower import share in the steady state than that in Itskhoki and Mukhin (2021) and Chien et al. (2020).

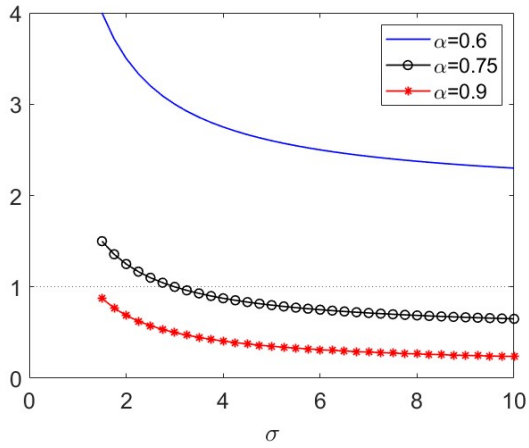
To further highlight the mechanism, we compare the prediction of our model with the alternative model with CES consumption aggregates in the next section.

Figure 1: Volatility of terms of trade relative to volatility of real exchange rate

(a) Financial shocks



(b) Productivity shocks



Note: α denotes the home bias; and σ denotes the intertemporal elasticity of substitution.

3 Comparison with CES Preferences

Let θ be the elasticity of substitution between varieties and $\theta > 1$. We define the CES final consumption as:

$$c_t = \left(\alpha^{\frac{1}{\theta}} c_{ht}^{\frac{\theta-1}{\theta}} + (1-\alpha)^{\frac{1}{\theta}} c_{ft}^{\frac{\theta-1}{\theta}}\right)^{\frac{\theta}{\theta-1}}$$

The household's intertemporal choice involves solving the same utility maximization problem as in our model. The difference from our model originates in the household's intratemporal choice. In particular, a cost minimization problem subject to unit consumption gives the

optimal demand and the CPI as:

$$c_{ht} = \alpha \left(\frac{p_{ht}}{P_t} \right)^{-\theta} c_t \tag{27}$$

$$c_{ft} = (1-\alpha) \left(\frac{p_{ft}}{P_t} \right)^{-\theta} c_t \tag{28}$$

$$P_t = \left(\alpha p_{ht}^{1-\theta} + (1-\alpha) p_{ft}^{1-\theta} \right)^{\frac{1}{1-\theta}} \tag{29}$$

The foreign monopoly producer faces a similar cost minimization. The optimal allocation and the CPI in the foreign country are:

$$c_{ft}^* = \alpha \left(\frac{p_{ft}^*}{P_t^*} \right)^{-\theta} c_t^* \tag{30}$$

$$c_{ht}^* = (1-\alpha) \left(\frac{p_{ht}^*}{P_t^*} \right)^{-\theta} c_t^* \tag{31}$$

$$P_t^* = \left((1-\alpha) p_{ht}^{*1-\theta} + \alpha p_{ft}^{*1-\theta} \right)^{\frac{1}{1-\theta}} \tag{32}$$

Differences in the product-level demand above from that in our model lead to differences on the supply side. In particular, the home monopoly producer, who faces demand in (27) and (28), chooses p_{ht} and p_{ht}^* to maximize profits. The foreign monopoly producer, who faces demand in (30) and (31), chooses p_{ft} and p_{ft}^* to maximize profits. As a result, both monopoly producers choose the same optimal markup over the marginal cost:

$$\mu_{jt} = \mu_{jt}^* = \frac{\theta}{\theta - 1} \quad j \in \{h, f\} \tag{33}$$

Clearly, aggregate consumption does not appear in the constant markup in (33), unlike optimal markups with PTM in (11), (12), (15) and (16).

Substituting the optimal markup and wage into the price indices in (29) and (32) and using the definition of RER gives the expected future RER adjustments:

$$E_t\Delta\hat{q}_{t+1} = -\frac{\sigma(2\alpha-1)}{2(1-\alpha)}E_t[\Delta\hat{c}_{t+1} - \Delta\hat{c}^{\star}_{t+1}] - \frac{2\alpha-1}{2(1-\alpha)}(1-\rho_A)(A_t - A^*_t) \tag{34}$$

3.1 Volatility of the Real Exchange Rate under CES Preferences

Equating the supply side in (34) with the demand side in (8) results in the expected RER depreciation as a function of exogenous shocks:

$$E_t\Delta\hat{q}_{t+1} = -(2\alpha-1)\left[\rho_\phi(\hat{\phi}_t - \hat{\phi}^*_t) - (1-\rho_A)(\hat{A}_t - \hat{A}^*_t)\right] \tag{35}$$

As in our baseline model, to solve for the persistence of RER, we equate $E_t\Delta\hat{q}_{t+1}$ in (35) to $-(1-\delta)\hat{q}_t$, where δ is the first-order autocorrelation of $\hat{q}_t$. Similar steps arrive at the same result; the first-order autocorrelation of $\hat{q}_t$ is identical to the first-order autocorrelation of underlying shocks.

Then, the closed form solution of the RER in response to the home financial shock ($\hat{\phi}_t \neq 0, \hat{\phi}^*_t = \hat{A}_t = \hat{A}^*_t = 0$) and its standard deviation are the following:

$$\hat{q}^{d,ces}_t = (2\alpha-1)\frac{\rho_\phi}{1-\rho_\phi}\hat{\phi}_t \tag{36}$$

$$std(\hat{q}^{d,ces}_t) = \frac{(2\alpha-1)\rho_\phi\sigma_z}{(1-\rho_\phi)\sqrt{1-\rho^2_\phi}} \tag{37}$$

Next, the closed form solution of the RER in response to the home productivity shock

$(\hat{A}_t \neq 0, \hat{\phi}_t = \hat{\phi}_t^* = \hat{A}_t^* = 0)$ and its standard deviation are the following:

$$\hat{q}_t^{s,ces} = (2\alpha - 1)\hat{A}_t \tag{38}$$

$$std(\hat{q}_t)^{s,ces} = \frac{(2\alpha - 1)\sigma_v}{\sqrt{1 - \rho_A^2}} \tag{39}$$

The solutions in both (36) and (38) reflect only adjustments of relative costs, because prices of both home and foreign products are subject to a constant markup. For this reason, the degree of relative risk aversion does not matter to RER standard deviations in (37) and (39). The home bias parameter continues to play an essential role and has a positive impact on RER volatility generated by both types of shocks.

3.2 Volatility of the Terms of Trade under CES Preferences

We obtain the terms of trade from the equilibrium prices and the solution of the RER responses to shocks:

$$\hat{\omega}_t^j = -\frac{1}{2\alpha - 1}\hat{q}_t^j, \tag{40}$$

for $j \in \{d, s\}$.

Proposition 7 *Volatility of the terms of trade is always greater than volatility of the RER when the consumption aggregate exhibits a constant elasticity of substitution.*

Proof. From (40), $std(\hat{\omega}_t^j) = 1/(2\alpha - 1)std(\hat{q}_t^j)$. Since $2\alpha - 1 > 1$, $std(\hat{\omega}_t^j) > std(\hat{q}_t^j)$.

Proposition 7 suggests that the CES preferences specification cannot replicate the exchange rate disconnect puzzle. This is because optimal prices under this specification lacks

PTM mechanism, unlike the nested CES aggregates in Atkeson and Burstein (2008) and CES aggregates with heterogeneous producers in de Blas and Russ (2015).

3.3 Comparison with the Baseline Model

The rankings of volatility of the terms of trade and that of the RER in Proposition 6 and Proposition 7 clearly suggest that our model performs better than the alternative model with CES preferences. The ranking is, however, does not necessarily implies that the absolute size of RER volatility in our model is always larger than that in the alternative model. For this reason, it is useful to compare volatility of the RER across models.

Lemma 1 *Demand-driven RER volatility is greater under non-homothetic preferences than CES preferences, whereas supply-driven RER volatility is smaller under non-homothetic preferences than CES preferences.*

Proof. From (21) and (37), $std(\hat{q}_t^d) - std(\hat{q}_t^{d,ces}) = 2(1-\alpha)\rho_\phi\sigma_z/((1+\sigma)(1-\rho_\phi)\sqrt{1-\rho_\phi^2}) > 0$ for $\alpha < 1$. From (23) and (39), $std(\hat{q}_t^s) - std(\hat{q}_t^{s,ces}) = -(2\alpha-1)\sigma_v/(1+\sigma)\sqrt{1-\rho_A^2}) < 0$ for $0.5 < \alpha < 1$.

According to Lemma 1, the ranking of RER volatility driven by the two types of shocks are reverse. As discussed earlier, PTM under non-homothetic preferences creates procyclical markup adjustments that offset the effect of productivity shocks on costs but such an offsetting effect does not exist under CES preferences. In contrast, the volatility of RER responses to financial shocks in our baseline model is greater than that in the standard model under CES preferences, thanks to the amplifying effect of procyclical markups.

Lemma 2 *For both type of shocks, the difference in RER volatility under non-homothetic preferences and that under CES preferences is decreasing in the degree of relative risk aversion.*

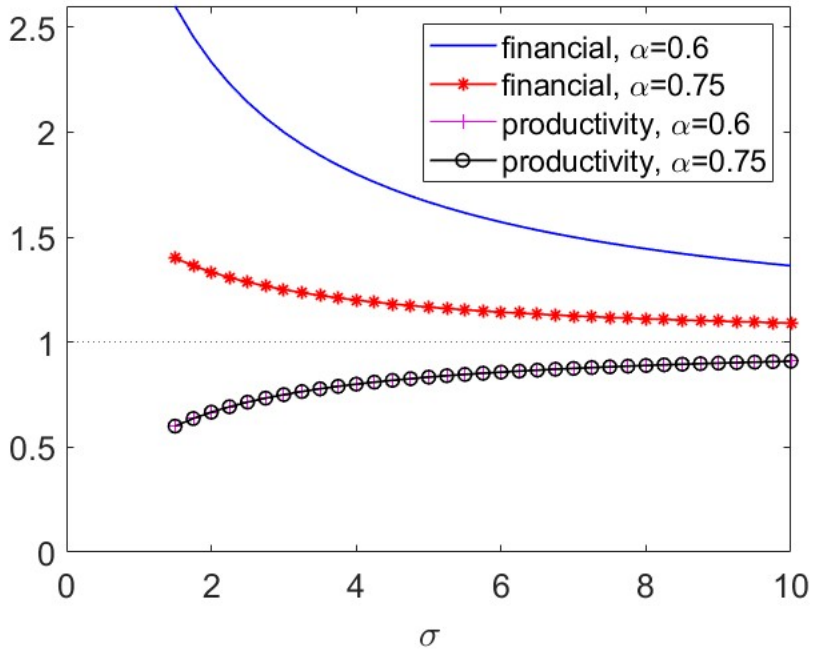
Proof. For demand-driven RER, (21) and (37) give $d|std(\hat{q}_t^d) - std(\hat{q}_t^{d,ces})|/d\sigma = -2(1-\alpha)\rho_\phi\sigma_z/((1+\sigma)^2(1-\rho_\phi)\sqrt{1-\rho_A^2}) < 0$. For supply-driven RER, (23) and (39) give $d|std(\hat{q}_t^s) - std(\hat{q}_t^{s,ces})|/d\sigma = -(2\alpha-1)\sigma_v/((1+\sigma)^2\sqrt{1-\rho_A^2}) < 0$.

Lemma 2 further highlights the importance of our PTM mechanism. To be precise, the quantitative difference in RER volatility obtained from the two models is decreasing in the degree of relative risk aversion or increasing in the intertemporal elasticity of substitution. Intuitively, declining intertemporal elasticity of substitution reduces relative consumption responses to shocks, and thus markup adjustments in our baseline model also become less responsive to shocks. Then, both the amplification effect of markups in response to financial shocks and the offsetting effect of markups in response to productivity shocks in our model become weakened. Consequently, as the degree of relative risk aversion increases, RER volatility generated by financial shocks under non-homothetic preferences falls toward the level under CES preferences, while RER volatility generated by productivity shocks under non-homothetic preferences rises toward the level under CES preferences.

Figure 2 provides the numerical illustration for predictions in Lemmas 1 and 2. We plot the volatility ratio $std(\hat{q}_t^d)/std(\hat{q}_t^{d,ces})$ and $std(\hat{q}_t^s)/std(\hat{q}_t^{s,ces})$ against the risk aversion, for two home bias parameter values: 0.6 and 0.75. The higher value of home bias accentuates the PTM mechanism in response to financial shocks and yields larger differences in the two models, for any value of the risk aversion. However, supply-driven volatility in the two

models is equally affected by the home bias, and thus their difference is not sensitive to the degree of the home bias.

Figure 2: Volatility of RER with non-homothetic aggregate/Volatility of RER with CES aggregate



4 Concluding Remarks

We demonstrate that our DSGE model with non-homothetic demand structure can explain the exchange rate disconnect puzzle. Specifically, the terms of trade in our model is substantially less volatile than the RER. Furthermore, financial shocks generate this result even when the degree of relative risk aversion is as low as 1.5. For this reason, the PTM mechanism in our model is an alternative to strategic complementary in Itskhoki and Mukhin (2025) and de Blas and Russ (2015), and distribution margins in Atkeson and Burstein (2008). Still, we have to combine financial shocks with productivity shocks in the opposite

direction to weaken the correlation of RER with relative consumption. Thus, both type of shocks are necessary for explaining the exchange rate disconnect puzzle.

Our work also has implication for the literature on cyclicality of markups. The novel mechanism in our model is procyclical markups, which are supported by micro evidence in the trade literature and macro evidence in Nekarda and Ramey (2020). In particular, they emphasize the importance of the type of shocks, and employ US data to estimate markups conditioning on shocks. They find that markups are procyclical in response to productivity shocks, monetary shocks and government spending shocks. However, markup adjustments in response to investment-specific technology shocks is found to be countercyclical. Their finding implies that our model is potentially useful for studying international spillovers of fiscal shocks during and after the Covid-19 recession. For that purpose, it is important to introduce investment in the model and solving it requires numerical solution.

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