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# International business cycles: Information matters <sup>\*</sup>

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## Abstract

We propose a mechanism that explains standard stylized facts in both international macroeconomics and international finance. To do so, we develop a New Keynesian DSGE model with financial frictions à la Bernanke et al. (1999), in which we depart from the full-information rational expectations (FIRE) assumption. The key ingredient is home information bias (HIB) in expectations. While the FIRE model predicts high consumption co-movements, no departure from uncovered interest parity (UIP) and procyclical trade balance, assuming HIB makes the model consistent with the data by producing low consumption correlation, solving the quantity puzzle, generating endogenous departures from the UIP and matching a countercyclical trade balance. The mechanism is empirically validated and shown to be robust to the extent of frictions in the economy.

**Keywords:** international business cycles, uncovered interest rate parity, home information bias, learning

**JEL:** D84, E44, F32, F41, F42

## 1. Introduction

Standard international macroeconomic models still have a hard time reproducing several stylized facts in the data, such as international output synchronization, and a relatively low international correlation of consumption levels (the so-called "output-consumption correlation puzzle" or "quantity anomaly"), together with the countercyclical trade balance.<sup>1</sup> Moreover, standard open-economy DSGE models are built on the uncovered interest parity (UIP) condition, while departures from the UIP have been extensively documented in the data (Engel (2016)).

We propose a model that contributes to both the international macroeconomics and international finance literature by solving the quantity anomaly, matching countercyclical trade-balance dynamics and producing endogenous departures from the UIP. To our knowledge, this is the first paper to succeed along these dimensions.

The key feature of our model is a departure from the full-information rational expectations (FIRE) approach. Deviations from FIRE include departures from both assumptions of full information (FI) and rational expectations (RE). We depart from FI and examine the macroeconomic impact of information asymmetry by introducing home information bias (HIB) in agents' expectations, in line with the empirical evidence on attention allocation and home portfolio bias.<sup>2</sup> We introduce adaptive learning (AL) à la Evans and Honkapohja (2001) and thus also deviate from RE.

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<sup>1</sup>See, for instance, Backus et al. (1994) and Corsetti et al. (2008), among many others.

<sup>2</sup>See section 2.1 for a detailed discussion on the empirical evidence on information asymmetry.

This choice seems to us particularly suited because deviations from RE in survey data have been widely documented<sup>3</sup>, and models with AL have proved to match some important characteristics of agents' expectations.<sup>4</sup> By introducing HIB in a model with AL, we use a new approach (HIB-AL) through which agents learn in an adaptive manner about the fundamentals of the economy by tracking local variables only. The main ingredient that makes the model consistent with the data turns out to be HIB.

We build a two-country DSGE model, that we enrich with New-Keynesian features and financial frictions in a realistic way.<sup>5</sup> The main mechanisms at work rely on HIB and are robust to the degree of frictions in the model. They work as follows. After a positive technology shock abroad, domestic agents focus only on local information and observe only their terms of trade improvement. They then interpret the current situation as inflationary and revise their expectations accordingly. Because of the expected increase in local inflation—and, therefore, the low expected real return on local capital—local households reduce consumption with respect to the FIRE case and seek to invest abroad. This behavior has important implications for both the trade balance and the UIP. While the FIRE model predicts high consumption co-movement, no departure from the UIP and a procyclical trade balance, HIB-AL makes the model consistent with the data with low consumption correlation, endogenous departure from the UIP of about 30%, and a countercyclical trade balance. We show that this mechanism is robust with respect to the degree of financial frictions and price rigidities.

To assess the empirical relevance of this mechanism, we match the HIB-AL model's responses to the IRFs of a structural VAR for the United States and Euro Area economies. We show that the HIB-AL model outperforms the FIRE model in reproducing the international correlation of consumption and output, trade balance dynamics, and UIP deviations. In addition to being realistic, the existence of financial frictions and price rigidities allows us to enlarge the set of macroeconomic and financial variables for which agents must form expectations. Therefore, we perform experiments in which we gradually relax the information asymmetry and highlight how observing different foreign variables affects international dynamics. As local agents learn more about foreign variables, the model's predictions get closer to their FIRE counterparts.

The paper contributes to several strands of the literature. First, we contribute to studies on international macroeconomics (Backus et al. (1992); Baxter and Crucini (1993); Obstfeld and Rogoff (2001); Corsetti et al. (2008)). Our originality lies in proposing an explanation for several puzzles in this literature based on the role of information in the form of deviations from the FIRE paradigm. In Backus et al. (1992), a positive technology shock generates a negative correlation of international output as resources are shifted to the more productive country, which reduces investments and output abroad. In addition, the international correlation of consumption is positive and high, since both domestic and foreign agents sustain an elevated consumption profile given the existence of complete markets and perfectly insurable risk. Since then, several studies have shown that financial imperfections can break this mechanism. In a model with incomplete markets, Kehoe and Perri (2002) show that when the risk is not perfectly insurable, the correlation of consumption across countries decreases. Indeed, not all resources are transferred to the most productive economy, and this determines a positive international correlation of output and investment. However, despite the much lower correlation of consumption, the synchronization of consumption remains higher than that of output. Faia (2007a) is also able to replicate the positive output correlation puzzle because of a financial spillover. However, given the international financial opportunities for risk sharing, business-cycle synchronization of consumption remains large compared with the data. Corsetti et al. (2008) study the ability of standard international business-cycle models to reproduce the low and negative correlation between relative consumption and the real exchange rate, together with a countercyclical trade balance and a lower international consumption correlation.<sup>6</sup> With a particularly low trade elasticity, strong wealth effects—in the country directly hit by a positive technology shock—push domestic demand for domestic goods above output and appreciate the real exchange rate. This dampens positive spillovers to the foreign country, eventually inducing a "negative" transmission of domestic productivity shocks. In our work, the international transmission of shocks is affected by imperfect information, which is at the core of the *endogenous* mechanisms that allows our model to match main cross-country correlations. Our mechanism goes in the same direction of that of Corsetti et al. (2008), but differs

<sup>3</sup>See Coibion et al. (2018); Manski (2018); and Pesaran and Weale (2006) for surveys.

<sup>4</sup>See, for instance, Branch and Evans (2006); Milani (2007); Pfajfar and Santoro (2010); and Markiewicz and Pick (2014). Additionally, Slobodyan and Wouters (2012) and Ormeno and Molnar (2015) show that AL is crucial in matching data in closed-economy macroeconomic models. Moreover, Pintus and Suda (2019) show that a model with learning and financial frictions captures the macroeconomic consequences of the 2008 crisis, and Winkler (2020) provides evidence on the ability of this type of model to match asset prices and business-cycle moments.

<sup>5</sup>The state-of-the-art closed-economy New Keynesian DSGE model with financial frictions à la Bernanke et al. (1999) has already proved to provide a good empirical fit for the US under FIRE (Christiano et al., 2014). We use a two-country version of this realistic DSGE framework.

<sup>6</sup>Analogously, Benigno and Thoenissen (2008) focus on the consumption-real exchange anomaly in a model with incomplete financial markets and both traded and non-traded goods. In the same spirit, Bai and Rios-Rull (2015) both solve the Kollmann-Backus-Smith puzzle (see Backus and Smith (1993) and Kollmann (1995)) and obtain a lower cross-country correlation of consumption with respect to output, by using demand shocks.

in its nature. Because of HIB, the positive effects of a local technology shock are not tracked by the foreign country and the response of foreign agents' consumption is dampened, even if their terms of trade improve. Foreign agents save more in the form of international assets, which sustains the trade deficit of domestic agents and makes the domestic trade balance countercyclical.<sup>7</sup> This allows us to match consumption correlations and trade balance dynamics with a standard trade elasticity.<sup>8</sup> Moreover, all of the above-mentioned models are built under the assumption that the UIP holds. Introducing imperfect information creates a departure from the UIP<sup>9</sup>, together with matching important stylized facts in international macroeconomics.

In international finance, the impact of expectation errors on interest rate differentials and the UIP has been examined in several papers (Lewis (1989); Gourinchas and Tornell (2004); and Ilut (2012), among others). "Ambiguity-averse agents" underestimate interest rate differentials or misperceive the source of the shock and leave arbitrage opportunities for the next periods (the UIP is not satisfied). In the same vein, Chakraborty and Evans (2008) use a simplified exchange-rate model with adaptive learning to explain the forward premium puzzle. Evans and Lyons (2002) stress the empirical relevance of financial variables—in particular, order flows—as a significant determinant of the exchange rate because of their role in conveying important information. Our mechanism works in a similar fashion. Under HIB, agents misperceive foreign dynamics and the interest rate differential across countries. Their corresponding expectations drive their international investment decisions and currency adjustments in a way that is not consistent with the actual interest rate differential: the UIP is not satisfied. To our knowledge, no one has yet examined the departure from the UIP along with international synchronization and trade balance dynamics.<sup>10</sup>

Finally, this paper is related to the growing literature that examines the macroeconomic implications of *information frictions* and *imperfect information*. The literature has focused on the closed-economy implications of different modeling approaches to agents' expectations. Gabaix (2020); Coibion and Gorodnichenko (2015); Mackowiak and Wiederholt (2015); and Reis (2006)—among others—study the closed-economy implications of agents' decisions when information is imperfect (see Coibion et al. (2018) for a detailed survey), and stress the existence of sizeable implications for the business cycle. While the literature agrees on the importance of information frictions for the business cycle, determining the best modeling process for expectations remains an open question. In a recent paper, Molavi (2019) introduces the concept of constrained rational expectations equilibrium (CREE) and shows how a wide range of deviations from FIRE in the form of adaptive learning, rational inattention, sentiments, extrapolative expectations, and the gambler's fallacy can all be nested within a CREE—under specific conditions—and that CREE dynamics differ notably from those of RE equilibria. From an empirical perspective, Coibion and Gorodnichenko (2015) show that rejection of the null of FIRE reflects deviations from full information and provide empirical evidence to support pervasive departure from it. Our paper echoes these findings and emphasizes the importance of departures from the FI paradigm in an open-economy setting, by studying the implications of HIB. In this paper, we adopt the HIB-AL approach, remaining agnostic about the sources of HIB, which we impose as a parsimonious and empirically relevant (see Section 2.1) alternative to more elaborate micro-founded theories of information choices. Although micro-founding the choices of foreign information acquisition would be important in determining the drivers of HIB, our paper suggests that our main result—in terms of international business cycle dynamics—would hold as long as there is a sufficient degree of HIB. That is to say, as long as the key information friction concerns the (non) observation of foreign variables.

The paper is organized as follows. In Section 2, we study HIB in a simplified model. Section 3 examines the quantitative predictions of the HIB-AL model with financial frictions, in terms of IRFs, business-cycle statistics, VAR empirical validation, and welfare analysis. Section 4 presents the sensitivity of our results to a gradual relaxation of the HIB assumption and the use of other workhorse models (RBC and New Keynesian). Section 5 concludes.

## 2. Information asymmetry

Information asymmetries are at the roots of the main mechanisms at work in our model. In what follows, we review the evidence supporting HIB. We then study its impact in a simple two-country model.

<sup>7</sup>In Corsetti et al. (2008), because of wealth effects in the country benefiting from the shock, the terms of trade of the rest of the world deteriorate together with consumption levels with respect to the high-elasticity case. In our model, because of HIB, the expansion of consumption in the rest of the world is dampened, even if their terms of trade improve, because agents do not perceive the positive spillover.

<sup>8</sup>Additionally, our mechanism helps to explain the Kollmann-Backus-Smith puzzle by lowering the correlation between relative consumption and the real exchange rate with respect to the FIRE model.

<sup>9</sup>The results of our model do not rely on exogenous disturbances such as UIP shocks, which are commonly used in the international macroeconomics literature. For some discussion see Itskhoki and Mukhin (2017).

<sup>10</sup>Gabaix and Maggiori (2015) account for the failure of the UIP in a stylized model with a focus on international financial investors. Tille and van Wincoop (2014) highlight the implications of information dispersion for international capital flows in a stylized general equilibrium setting.

## 2.1. Empirical evidence on information asymmetry

This section presents the empirical evidence supporting the HIB assumption. According to survey data, a global attitude of the public around the world is to follow national and local news more closely than international news.<sup>11</sup> Based on internet search query data, Mondria et al. (2010) measure how much information investors indeed decide to process. They find that investors are more attentive to news about familiar countries. In addition, Cziraki et al. (2019) provide a direct measure of attention allocation by local investors relative to non-locals using aggregate search volume from Google. They find evidence that locals process more information about local assets relative to non-locals. The HIB in information processing has also been studied extensively in the finance literature, especially in relation with the home portfolio bias. Using data on cross-border equity flows, Portes and Rey (2005) provide empirical support for the existence of information asymmetry between domestic and foreign investors. Using a variable measuring directly the degree of asymmetry between domestic and foreign investors (an index of insider trading), equity bilateral trade shows evidence of information asymmetry. Empirical studies by Bae et al. (2008) (using data on earnings forecasts by local and foreign analysts) and Leuz et al. (2009) (using data on firms' portfolio investment) reach a similar conclusion. Huang (2015) finds evidence of investors' lack of understanding of foreign information, which slows the incorporation of new information from more linguistically and culturally distant countries into US stock prices. Van Nieuwerburgh and Veldkamp (2009) provide a rationale behind the information asymmetry by stressing that investors who know more about local economic environment want to exploit this particular informational advantage and specialize in collecting domestic information in order to achieve higher excess returns. In light of the above considerations, we introduce HIB as a realistic assumption and study its implications for the international business cycle.

## 2.2. Information asymmetry in a simple two-country model

To provide an intuitive explanation of our mechanism, we study the implications of information asymmetry in a textbook model à la Obstfeld and Rogoff (1996), chapter 1. We consider a two-period two-good two-country deterministic model with exogenous endowments.<sup>12</sup> We incorporate information asymmetries by assuming that domestic agents have an imperfect knowledge of foreign variables. In this basic framework, this assumption implies that foreign interest rates are not known by domestic agents.<sup>13</sup> Indeed, foreign returns depend on foreign endowments and consumption levels, and knowing them would require domestic agents to acquire information on the foreign country.

We follow Gabaix (2020) in introducing deviations from FIRE through a "cognitive" parameter on agents' expectations.<sup>14</sup> We borrow the same logic and use the cognitive parameter  $M \in (0, 1]$  to capture the extent of agents' inattention to foreign variables as a way to introduce HIB in this simple framework. In our setting,  $M$  brings agents to perceive the foreign interest factor as  $MR_1^*$ . When  $M = 1$ , we recover the FI model. When  $0 < M < 1$ , domestic agents do not correctly perceive the foreign interest factor and there is HIB. This paper stresses the importance of HIB for the international dynamics, while not studying the sources of HIB (i.e., the reasons why  $M < 1$ ). Models of information choice could provide some micro-foundation for  $M$ . Our paper suggests that—for any possible micro-foundation of  $M$ —what matters for the model to match the data is a sufficient level of HIB ( $M < 1$ ).

Because of the cognitive parameter, agents have an information home bias towards the local interest rate with respect to the interest rate abroad and this affects local saving-investment choices. The intertemporal budget constraint now reads<sup>15</sup>:  $C_1 + \frac{e_1}{e_2} \frac{C_2}{MR_1^*} = Q_1 + \frac{e_1}{e_2} \frac{Q_2}{MR_1^*}$  where  $R_1^*$  is the foreign interest rate factor at period 1;  $C_1(C_2)$  denotes domestic consumption levels,  $e_1(e_2)$  denotes the exchange rate,  $Q_1(Q_2)$  denote the exogenous output endowment in period 1 (period 2).

*Departure from UIP..* By calculating the first order conditions of both domestic and foreign agents with respect to foreign bonds, we obtain a modified UIP condition:

$$R_1 = \frac{e_2}{e_1} MR_1^*. \quad (1)$$

<sup>11</sup>PEW Research Center, Spring 2017, Global attitudes. <https://www.pewresearch.org/global/2018/01/11/publics-around-the-world-follow-national-and-local-news-more-closely-than-international/>

<sup>12</sup>The full model is reported in Appendix A.

<sup>13</sup>This assumption follows Grossman and Stiglitz (1980) and Dziuda and Mondria (2012) where there is a component of returns that is observable by some agents at an information cost. Analogously, Barron and Ni (2008) also assume that there is a component of domestic (foreign) interest rates that can be observed without costs by domestic (foreign) agents only.

<sup>14</sup>In Gabaix (2020), agents react myopically to events that are too far in the future. Expectations of the behavioral agent on the vector of forward variables,  $X_{t+k}$  are defined as:  $E_t^{BR}[X_{t+k}] = m^k \cdot E_t[X_{t+k}]$ , where  $E_t^{BR}$  are behavioral expectations featuring inattention,  $E_t$  are rational expectations and  $0 < m < 1$  is the scaling—cognitive—parameter.

<sup>15</sup>There is no money and all variables are expressed in real terms of the domestic consumption good.

145 When  $M = 1$ , UIP holds under FI. When  $0 < M < 1$ , the foreign interest rate is not perfectly known and this can lead to unexplored investment opportunities. HIB can therefore entail departures from UIP, consistently with data.

*Consumption co-movement..* By substituting interest rates in equation (1) with consumption choices, we obtain:

$$\left(\frac{C_2}{C_1}\right) = \frac{e_2}{e_1} M \left(\frac{C_2^*}{C_1^*}\right). \quad (2)$$

When  $M = 1$ , for a given value of  $\frac{e_2}{e_1}$ , changes in  $\frac{C_2^*}{C_1^*}$  in equation (2) are fully transmitted to country  $H$ . This entails a high consumptions co-movement across countries. In contrast, when agents have limited information on foreign variables (0 < M < 1), HIB breaks this proportionality: lower perceived returns determine a lower consumption growth path. Therefore, the international correlation of consumption under HIB is expected to be lower than under FI. By lowering consumption co-movement, HIB is thus key in solving the quantity anomaly.

155 This very stylized model provides the basic intuitions on the way HIB alters intertemporal consumption and saving decisions. In a general equilibrium model, changes in savings and consumption choices will affect output and trade balance dynamics with respect to the FIRE case. In what follows, we show how HIB is a key element in letting our model match the data on international co-movements and trade balance dynamics in a general equilibrium framework.

### 3. A two-country New-Keynesian model with financial frictions

To the purpose of tracking general-equilibrium feedback effects of shocks, we develop a DSGE version of the simple model.<sup>16</sup> The main economic mechanisms at work do rely on HIB and are thus robust to our model's specifications (see Section 4.2). Our full benchmark model is featured by nominal rigidities and financial frictions. These realistic features<sup>17</sup> are useful to check the empirical performance of our framework (see Section 3.3). Moreover, with frictions in the economy, agents need to form expectations about inflation and financial variables. By enlarging the set of variables for which agents form expectations, a model with frictions provides a particularly suitable framework for analyzing the role of information asymmetries in macroeconomic dynamics.

165 Even though the calibration is symmetric (to make the economic mechanisms transparent) and based on US data, we need to refer to a large country with floating exchange rate with the US when we compare the model to the data. We choose the Euro Area. For simplicity, starred variables refer to the United States while variables without stars refer to the Euro Area.

#### 3.1. Model

170 Each country is populated by representative households whose members receive both revenues arising from labor work in wholesale firms and profits coming from their retail activity. Households have access to international markets where they can invest in international bonds (or get indebted); they can also lend their savings to domestic (foreign) banks. Each economy is also populated by entrepreneurs, who produce capital and decide over investment and labor inputs so as to produce wholesale goods. Capital production is affected by capital adjustment costs. To finance their production activity domestic (foreign) entrepreneurs have access to loans from domestic (foreign) banks. This lending contract is subject to a financial friction à la Bernanke et al. (1999). Once all production uncertainty is solved, retailers aggregate wholesale goods and sell (export) the final good to domestic (foreign) consumers. Retailers are monopolistic competitors, and their activity is affected by price rigidities à la Rotemberg. In each country, rigidities affect the domestic retailing activity only (i.e. domestic retailers in the domestic country and foreign retailers in the foreign country, respectively). 175 The exchange-rate pass through between countries is complete.

##### 3.1.1. Households

Households in the EA maximize the following flow of expected utilities  $E_0 \sum_{t=0}^{\infty} \beta^t U(C_t, N_t)$  where  $\beta$  is the discount rate,  $C_t$  denotes aggregate consumption and  $N_t$  labor. The utility function  $U(C_t, N_t)$  verifies the standard properties,  $U'_C > 0, U''_C < 0, U'_N < 0$ , where  $U'_C$  is the marginal utility of consumption and  $U'_N$  is the marginal (dis)utility of labor effort. Aggregate consumption includes domestically produced goods and foreign ones, i.e.:  $C =$  185

<sup>16</sup>We refer to Appendix C for all details.

<sup>17</sup>This framework has already provided a good fit for the US economy under FIRE in a closed-economy setting (Christiano et al., 2014) and is commonly used in international macroeconomic models under FIRE (Faia (2007a) and Faia (2007b) among others).

$\left[ (1 - \gamma)^{\frac{1}{\eta}} C_{EA}^{\frac{\eta-1}{\eta}} + \gamma^{\frac{1}{\eta}} C_{US}^{\frac{\eta-1}{\eta}} \right]^{\frac{\eta}{\eta-1}}$ , with  $\gamma < 0.5$  as agents prefer domestically produced goods.  $\eta > 1$  is the elasticity of

substitution between domestic and foreign goods. The CES-related CPI price index is:  $P = \left[ (1 - \gamma) P_{EA}^{1-\eta} + \gamma P_{US}^{1-\eta} \right]^{\frac{1}{1-\eta}}$  where  $P_{EA}$  is the price of domestically-produced goods and  $P_{US}$  the one of foreign ones (in domestic currency). Agents' budget constraint can be written in real terms of domestic goods as:

$$C_t + d_t + b_t^* \leq R_{t-1} \frac{d_{t-1}}{\pi_t} + R_{t-1}^F \frac{b_{t-1}^*}{\pi_t} \frac{e_t}{e_{t-1}} + \frac{W_t}{P_t} N_t + \frac{\Pi_t}{P_t} \quad (3)$$

where  $d$  are households' deposits in the local bank,  $R$  is the deposit rate factor,  $R^F$  is the return factor received (paid) on foreign-denominated international bonds (debt)  $b^*$  and  $\frac{W}{P}$  are real wages. We denote by  $e$  the nominal exchange rate (ie, the price of 1 unit of US currency).  $\pi$  is CPI inflation. Households' resources come from labor activity in wholesale firms and profits arising from the retailing activity. Households consume, lend funds to (perfectly competitive) banks and invest in international imperfect markets.

The standard Euler equation associated to domestic deposits is  $U'_{ct} = \beta E_t \left[ \frac{R_t}{\pi_{t+1}} U'_{ct+1} \right]$  and the optimality equation associated to international bonds is  $U'_{ct} = \beta E_t \left[ R_t^F U'_{ct+1} \frac{e_{t+1}}{\pi_{t+1} e_t} \right]$ .

Due to a risk premium associated to debt accumulation, there is a spread between the return on international securities received (paid) by domestic agents and the one paid (received) by foreign ones. In particular, following Schmitt-Grohe and Uribe (2003), the spread is a function of the (real) value of the country's net external debt so that the interest rate on international bonds is defined as  $R_t^F = R_t^* + p(-b_t^*)$  where  $R^*$  is the foreign nominal interest rate and  $p(-b_t^*) = -\zeta (exp^{b_t^* - b^*} - 1)$  a country-specific interest rate premium with  $\zeta > 0$ . Foreign households face the same optimization problem as domestic households except for the fact that international bonds are denominated in their own currency. By combining agents' Euler equations, we obtain the following uncovered interest parity condition:

$$U'_{ct} = \beta E_t \left[ \left( \frac{U_{ct}^*}{\beta E_t \left[ \frac{U_{ct+1}^*}{\pi_{t+1}^*} \right]} + p(-b_t^*) \right) U'_{ct+1} \frac{e_{t+1}}{\pi_{t+1} e_t} \right] \quad (4)$$

so that marginal utilities across countries are equalized up to a spread for the country risk. Notice finally that terms of trade for EA are the ratio of the price of EA goods over the price of US goods,  $tot_t = \frac{P_{EA,t}}{e_t P_{US,t}} = \frac{f_t}{e_t^* f_t^*}$ , where  $f_t \equiv \frac{P_{EA,t}}{P_t} = f_{t-1} \frac{\pi_{EA,t}}{\pi_t}$  and  $f_t^* \equiv \frac{P_{US,t}^*}{P_t^*} = f_{t-1}^* \frac{\pi_{US,t}^*}{\pi_t^*}$ . The real exchange rate is defined as  $e_t^r = e_t \frac{P_t}{P_t^*}$ , where  $P_t^*$  is the price index of US.

### 3.1.2. Entrepreneurs

We now focus on local entrepreneurs. As in Bernanke et al. (1999), entrepreneurs are risk neutral and choose the optimal level of both capital and labor inputs to be used for wholesale production. Once idiosyncratic uncertainty is solved, wholesale output is:  $Y_t = A_t F(K_{t-1}, N_t)$ ,  $\log A_t = \rho_A \log A_{t-1} + \varepsilon_t^{as}$ , where  $K$  denotes capital,  $N$  labor and  $A$  the exogenous total factor productivity, with  $0 < \rho_A < 1$  and  $\varepsilon_t^{as}$  the productivity shock with standard deviation  $\sigma_A$ . Capital evolves as  $K_t = (1 - \delta)K_{t-1} + I_t$ , where  $\delta$  is the depreciation rate and  $I$  investment. The standard optimality condition with respect to labor entails  $f_t \frac{Y_{N,t}}{X_t} = \frac{W_t}{P_t}$  where  $Y_{N,t}$  denotes the first derivative of output w.r.t. labor and  $X_t$  the gross markup of retail goods over wholesale goods (i.e.  $\frac{1}{X_t} = \frac{P^w}{P_{EA}}$  where, in turn,  $P^w$  is the wholesale output price and  $P_{EA}$  is the price of the domestic production). The optimal investment decision verifies:  $Q_t = \left[ 1 + \Phi' \left( \frac{I_t}{K_{t-1}} \right) K_{t-1} \right]$  where  $Q_t$  is the (real) price of capital and it is different from one around the steady-state because of capital adjustment costs. The mean return from holding one unit of capital is:

$$R_t^k = \frac{\pi_t}{Q_{t-1}} \left[ \frac{Y_{K,t-1}}{X_t} f_t + \Phi' \left( \frac{I_t}{K_{t-1}} \right) \frac{I_t}{K_{t-1}} - \Phi \left( \frac{I_t}{K_{t-1}} \right) + Q_t (1 - \delta) \right] \quad (5)$$

where the first term in the brackets represents the domestic-currency yields of one unit of capital,  $\frac{Y_{K,t-1}}{X_t} f_t$  (where  $Y_{K,t-1}$  is the derivative of output w.r.t. capital); the second one is the reduction in adjustment costs,  $\Phi' \left( \frac{I_t}{K_{t-1}} \right) \frac{1}{K_{t-1}} - \Phi \left( \frac{I_t}{K_{t-1}} \right)$ ; and the third term captures the returns from selling that unit of non-depreciated capital,  $Q_t (1 - \delta)$ . Entrepreneurs finance the purchase of new capital partly with external funding. The credit conditions are the result of an optimal loan contract established by the bank implying the existence of an external finance premium, that the entrepreneur needs to pay to have access on external funds.

### 225 3.1.3. Final good production

As in Bernanke et al. (1999), local retailers aggregate wholesale goods to the purpose of producing final goods  $X^c$  according to the following Dixit-Stiglitz aggregator,  $X^c = \left( \int_0^1 X^c(i)^{\frac{v-1}{v}} di \right)^{\frac{v}{v-1}}$ , with  $v > 0$  the elasticity of substitution between domestic varieties. They operate in a monopolistic competition framework and price setting is affected by nominal rigidities à la Rotemberg with quadratic price-adjustment costs  $\frac{\omega_P}{2} (\pi_{EA} - 1)^2$ , where  $\pi_{EA}$  denotes producer price inflation in the EA and  $\omega_P > 0$  is the Rotemberg parameter for price rigidity. Retailers' optimization problem leads to the following Phillips curve:

$$(\pi_{EA} - 1) \pi_{EA} = Y_t \frac{v}{\omega_P} \left[ \frac{1}{X_t} - \frac{(v-1)}{v} \right] + \beta E_t \left[ \frac{U'_{ct+1}}{U'_{ct}} (\pi_{EA} - 1) \frac{f_{t+1}}{f_t} \pi_{EA} \right] \quad (6)$$

### 3.1.4. Monetary policy

We suppose that in each country the monetary policy follows a Taylor rule:

$$R_t = (R_{t-1})^\chi \left( \bar{R}^n \left( \frac{\pi_t}{\bar{\pi}} \right)^{b_\pi} \left( \frac{Y_t}{y} \right)^{b_y} \right)^{1-\chi} \quad (7)$$

### 3.1.5. Calibration

In order to be as straightforward as possible on the economic mechanisms at work, the calibration is symmetric and based on the US. Each period corresponds to one quarter. To pin down parameter values, we look at studies with modeling features close to ours (namely, Faia (2007a), Christiano et al. (2010), Christiano et al. (2014), Kolasa and Lombardo (2014)). Parameter values lie thus within the range found in the literature. Table 1 summarizes the calibration.

We let the instantaneous utility function be  $U_t = \frac{C_t^{1-\sigma}}{1-\sigma} + \Psi \log(1 - N_t)$ . The inverse of the intertemporal elasticity of substitution for consumption is set equal to 2, consistently with the literature. The disutility of the labor parameter is set equal to 2.6 so as to insure that labor is normalized to 1/3 at steady state. The discount factor is equal to 1/1.01147, consistently with Christiano et al. (2014) (hereafter, CMR) annual interest rate. The elasticity of substitution between foreign vs domestic goods is 1.5<sup>18</sup> and the share of foreign goods into the domestic basket,  $\gamma$ , is equal to 0.3 consistently with Faia (2007a). The elasticity of substitution among varieties  $v$  is set equal to 6 as in CMR (among others).

The wholesale production function is a Cobb-Douglas,  $Y_t = A_t K_t^\alpha N_t^{1-\alpha}$  where  $\alpha$  is set to 0.40 and the capital depreciation rate is 0.025 as in CMR among others. The capital adjustment costs parameter  $\Phi$  is set to 5.2 in line with Kolasa and Lombardo (2014) and so as to ensure that the volatility of consumption is lower than the one of investment in both countries, as Faia (2007a).

The monitoring cost parameter  $\mu$  is set equal to 0.21, based on Christiano et al. (2014), which is in the range of the values chosen by Faia (2007a) (between 0.07 and 0.3). The interest rate premium parameter,  $\zeta$ , is 0.000742 as in Schmitt-Grohe and Uribe (2003). The share of surviving entrepreneurs lies between 0.97 in Faia (2007a) and 0.985 in CMR. We set  $\varsigma = 0.978$  as in Kolasa and Lombardo (2014), which provides a middle point among the values in the literature. The steady-state standard deviation of idiosyncratic productivity is  $\sigma_\omega = 0.26$ , which is consistent with Kolasa and Lombardo (2014); Christiano et al. (2014); Faia (2007a).

We consider Christiano et al. (2010)'s estimates of Calvo adjustment parameter for the US and use this value to infer Rotemberg adjustment parameter following Monacelli (2009). As for Taylor rules, we choose a calibration with standard values. The policy smoothing parameter is  $\chi = 0.8$  in both countries, as in Faia (2007a) and in line with Christiano et al. (2010) among others. The weight on inflation,  $b_\pi = 2.6$ , and on output  $b_y = 0.36$ , lie within the range from the literature, consistently with Christiano et al. (2010)'s estimates. Technological shocks are calibrated following Faia (2007a).

### 3.1.6. Introducing HIB into a DSGE model with adaptive learning

The DSGE model is approximated at order one, as in Evans and Honkapohja (2001). The corresponding reduced form is:

$$k_t = a_1 E_t k_{t+1} + a_2 k_{t-1} + b_1 z_t + b_2 z_{t-1} \quad (8)$$

$$z_t = \rho z_{t-1} + \varepsilon_t \quad (9)$$

<sup>18</sup>The key role of this parameter has been discussed by a rich literature (see, for instance, Corsetti et al. (2008)). We use the standard calibration of this parameter as in Backus et al. (1994) among many others.



Table 1: Calibration

Parameter		Value	Reference
$\beta$	discount factor	0.9887	CMR (2014)
$\sigma$	elasticity of intertemporal substitution	2	KL (2014)
$\Psi$	disutility of labor	2.6	Labor normalized at 1/3 at ss
$\gamma$	share of foreign goods in domestic basket	0.3	KL (2014)
$\eta$	elasticity of substitution home-foreign goods	1.5	Faia (2007a)
$\nu$	elasticity of substitution between varieties	6	CMR (2014)
$\alpha$	production function	0.4	CMR (2014)
$\delta$	capital depreciation	0.025	CMR (2014)
$\phi$	capital adjustment costs	5.2	KL (2014)
$\omega_p$	Rotemberg parameter	35.84	CMR (2014), Monacelli (2009)
$\mu$	monitoring cost	0.21	CMR (2014)
$\sigma_\omega$	sd idiosyncratic productivity	0.26	CMR (2014), KL (2014)
$\zeta$	interest rate premium parameter	0.000742	SGU (2003)
$b^*$	steady state Net Foreign Asset	0	SGU (2003)
$\varsigma$	share of surviving entrepreneurs	0.978	KL (2014)
$\chi$	weight on lagged int. rate into Taylor Rule	0.8	Faia (2007a)
$b_\pi$	weight on inflation into Taylor Rule	2.6	KL (2014), CMR (2014)
$b_y$	weight on output gap into Taylor Rule	0.36	KL (2014), CMR (2014)
$\rho_A$	persistence technology shock	0.9	Faia (2007a)
$\sigma_A$	standard deviation technology shock	0.008	Faia (2007a)
$corr(\epsilon^a, \epsilon^{a*})$	cross-correlation technology shocks	0.30	Faia (2007a)

CMR(2014) refer to Christiano et al. (2014), KL(2014) to Kolasa and Lombardo (2014), SGU (2003) to Schmitt-Grohe and Uribe (2003). Symmetric calibration: all parameter are set at the same value for the two countries.

with  $z_t$  the vector of shocks and  $k_t$  a vector of all endogenous variables in the model. HIB affects the dynamics of the economy through terms with expectations,  $E_t k_{t+1}$ , in equation (8) of the AL algorithm, as agents need to forecast economic variables given their information set. Notice that, when the economy faces more frictions, agents need to make choices by formulating anticipations on a higher number of variables as there are more equations with  $E_t k_{t+1}$  in the reduced form. HIB is then expected to matter more in a model with more frictions. Private agents have beliefs on the evolution of macroeconomic variables in the economy, based on their Perceived Law of Motion (PLM):

$$k_t = \phi_{k,t-2} x_{t-1} + \phi_{z,t-2} z_{t-1} \quad (10)$$

Private agents think that endogenous variables  $k_t$  are a function of a set of observed variables  $x_{t-1}$  and exogenous shocks  $z_{t-1}$ . Private agents use the PLM to forecast economic variables.

$$E_t k_{t+1} = \phi_{k,t-1} x_t + \phi_{z,t-1} z_t \quad (11)$$

The actual evolution of macroeconomic variables in the economy is obtained by replacing the expected value from equation (11) into the reduced form (equation (8)). In doing so, it becomes clear that beliefs affect the actual dynamics of the economy, which in turn affect beliefs. This is the so-called "self-referentiality" in models with learning (Eusepi and Preston (2018)).

It is thus necessary to define: *i*) the set of observed variables  $x$  included in the PLM (equation (10)); *ii*) the methodology used to update time-varying coefficients  $\phi$  in the PLM and *iii*) the initialization of  $\phi$ . We now discuss *i*) as it relates to HIB. We refer to Appendix F.2 for *ii*) and *iii*) and the associated sensitivity analysis.

The information set involves choosing the variables included in  $x$  in the PLM (equation (10)). Under FIRE,  $x$  includes EA and US variables as all agents in the two countries observe all economic variables in the world. They use this wide information set in their PLM and forecasting model.

In contrast, under HIB, agents have an imperfect knowledge of their economic environment. They then use a reduced information set when forming their expectations. We start with a case in which, in each country, private agents base their PLM only on *local* variables, including *local* shocks, together with international bonds  $b^*$  and terms of trade. Agents do not observe macroeconomic variables abroad.<sup>19</sup> We refer to this assumption as home information bias (HIB) and to the

<sup>19</sup>As only the US bond (denominated in US currency) is available in the model, only EA households forecast the nominal exchange rate.

corresponding PLM as the HIB-PLM. In section 4.1, we perform a sensitivity analysis on the choice of information set.

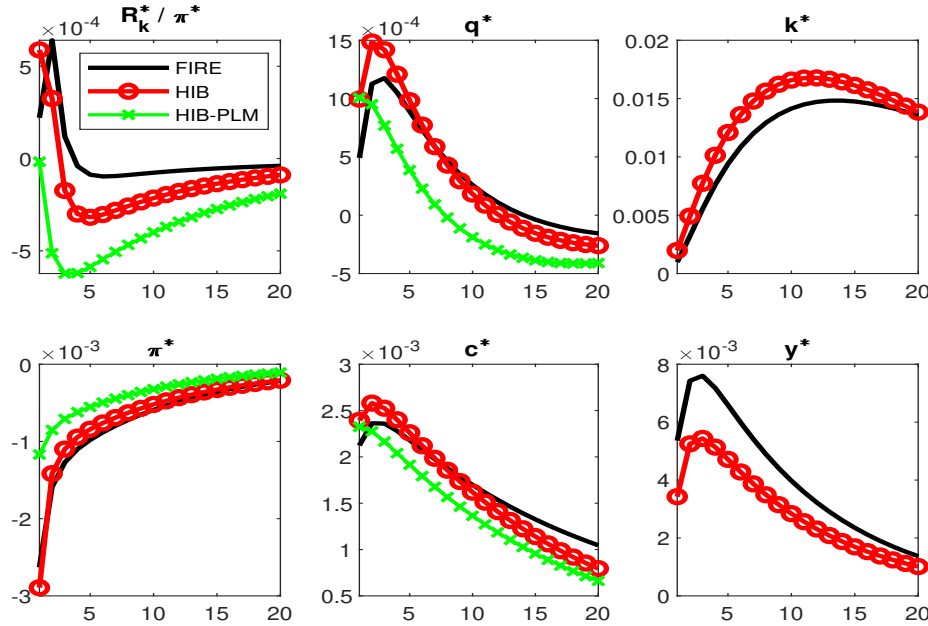
### 3.2. Economic mechanisms

We analyse the transmission mechanisms in response to a positive technology shock in the US. To understand the evolution of the economy, we focus on the formation of expectations in the two countries and show how these shape the dynamics. Therefore, we present below the responses of the economy under FIRE (solid line), under HIB-AL (dotted line) and agents' expectations for the forward variables of the HIB-AL model (crossed line).

#### 3.2.1. Local response to a local shock: IRF in the US

In Figure 1, a positive US technology shock generates an increase in the marginal return of capital ( $R_k^*$ ), which increases the demand for capital, and the price of capital ( $q^*$ ). Investment expands (capital accumulation,  $k^*$ ). The positive technology shock also generates a fall in the production price of US goods and—via home bias in consumption—a decrease in the US CPI index ( $\pi^*$ ). The expansionary effects of the shock boost US consumption ( $c^*$ ) that—together with higher investments—further raises output ( $y^*$ ).

Figure 1: Local response to local shock: US response to US technological shock



$x^*$ : starred variable refer to the US. Solid line: FIRE. "o" line: HIB-AL. "+" line: HIB-AL PLM,  $E_t[x_{t+1}^*]$ : US agents' forecast of variable  $x^*$  based on their HIB-PLM. Only for forward-looking variables. Deviation from steady state after one-sd positive shock.

In Figure 1, the responses of the model under FIRE and HIB-AL are very close. US agents do not observe EA variables. Therefore, US expectations do not take into account the possible reaction of the EA to the US shock.

In particular, US agents do not expect the positive spillover effect towards the EA to eventually stimulate EA consumption and investment. As a consequence, US expectations are more conservative under HIB: US agents think that the macroeconomic effects of the supply shock are smaller than they actually are. However, for US agents, the information on US variables after a US shock is sufficient to make their behavior close to the one under FIRE.<sup>20</sup>

<sup>20</sup>The overall effect of the local shock in the local economy under HIB-AL is not very far from the one under rational expectations. This is consistent with Carceles-Poveda and Giannitsarou (2007)'s findings in a closed-economy RBC model. As in their model, agents form their 1-step ahead expectations based on the observation of all the domestic variables, including domestic shocks and initializing their beliefs at rational expectations. Quantitatively, for US agents, the information on the US shock is sufficient to make their behavior close to the one under FIRE. The learning algorithm affects the speed of convergence to the steady state through the adaptive process in the update of beliefs. In fact, what amplifies the effect of learning in our model is the interaction with imperfect information. The part of information the agents miss is the one coming from the other country: EA agents do not observe US shocks and US agents do not take into account feedback effects coming from the EA country. As the domestic variables contain the majority of the relevant information after a US shock, the US dynamics are generally not far from the ones under FIRE.

### 3.2.2. International spillover: IRFs in the Euro Area

In our framework with HIB, EA (US) households do not track the impact of US (EA) variables on EA (US) dynamics. In particular, EA (US) agents update their expectations reacting only to the observed international capital inflows, terms of trade and local macroeconomic changes. Therefore, agents in each region do not take into account the possibility that the other country's variables could react to the shock. The international transmission of shocks can thus significantly differ from the one under FIRE. This is also at the roots of quantitatively significant deviations from the UIP.

Let us now focus on the HIB-PLMs displayed in Figure 2. After a US productivity shock, EA agents observe an improvement in their terms of trade ( $tot$ ) and review their expectations without tracking the source of the shock. Because of the terms of trade increase, they interpret the shock as an inflationary shock. They expect thus EA inflation ( $\pi$ ) to increase, the real return on capital ( $R_k/\pi$ ) to decrease and the EA real exchange rate ( $rer$ ) to appreciate little, in line with terms-of-trade expectations.

As EA agents with HIB-AL do not perceive the positive nature of the spillover from the shock, its expansionary effect on EA consumption is much more dampened with respect to the FIRE framework. With respect to FIRE, HIB-AL triggers indeed in the EA a substitution effect in favor of current saving. Consequently, actual consumption increases much less than in the case of FIRE, entailing a lower consumption correlation among countries, that is crucial to solve the quantity puzzle. Moreover, as the expected returns on EA capital investment are negative (because of the high inflation expectations) and the real exchange rate is expected to appreciate by a smaller amount (with respect to FIRE), they prefer to invest abroad ( $b^*$ ) where the return on US assets is expected to be high.

However, because of the lower price of US goods and its impact on the Phillips curve, actual inflation in the EA country falls in equilibrium (see the red dotted line, Figure 2). This eventually generates a small increase in the real return on capital, which triggers a positive (but much smaller with respect to FIRE) accumulation of EA capital ( $k$ ).

Notice that EA investments in US assets ( $b^*$ ) increase, instead of falling as in the FIRE case. This investment behavior is key in tilting the trade balance: as EA agents accumulate international assets rather than consuming and investing domestically, the US experience a trade deficit ( $tb^*/y^*$ ) instead of a trade surplus as under FIRE. HIB-AL is thus crucial in allowing us to match the countercyclical behavior of the trade balance, as in the data. Our mechanism is similar to the one emphasized by Corsetti et al. (2008), in that it dampens the expansion of EA consumption in response to a US technology shock, but differs in its nature. In fact, in Corsetti et al. (2008), strong wealth effects in the domestic country (US here)—associated to low trade elasticity and persistent shocks—push up aggregate demand. This appreciates the domestic terms of trade (and the real exchange rate) and dampens foreign (EA here) consumption. In contrast, in our work, HIB-AL entails a wrong perception in the EA country of the US shock, which dampens EA consumption even if the EA terms of trade do not deteriorate.

Moreover, thanks to greater exports to the US<sup>21</sup>, the EA eventually benefits from positive spillovers that push up output more than under FIRE (see Figure 3). In contrast, in the US, the impact of the shock under HIB-AL is eventually less expansionary in terms of output ( $y^*$ ) because of greater imports. Output under HIB-AL is therefore less synchronized than under FIRE but the two cycles remain highly correlated.

Finally, Figure 4, shows the implications of the previous dynamics for the UIP condition. Under FIRE, UIP holds. In contrast, under HIB, EA agents do not observe the US interest rate response. They see the improvement of terms of trade and the fall in the EA interest rate. These considerations, together with the above-discussed mechanisms, make EA households eager to invest in US bonds. This further boosts the demand for US currency, thereby leading to an initial large equilibrium nominal depreciation of the euro under HIB-AL. This larger depreciation of the euro under HIB-AL is inconsistent with the UIP.

### 3.3. Quantitative predictions

In what follows, we explore the quantitative predictions of the model under FIRE and under HIB-AL.

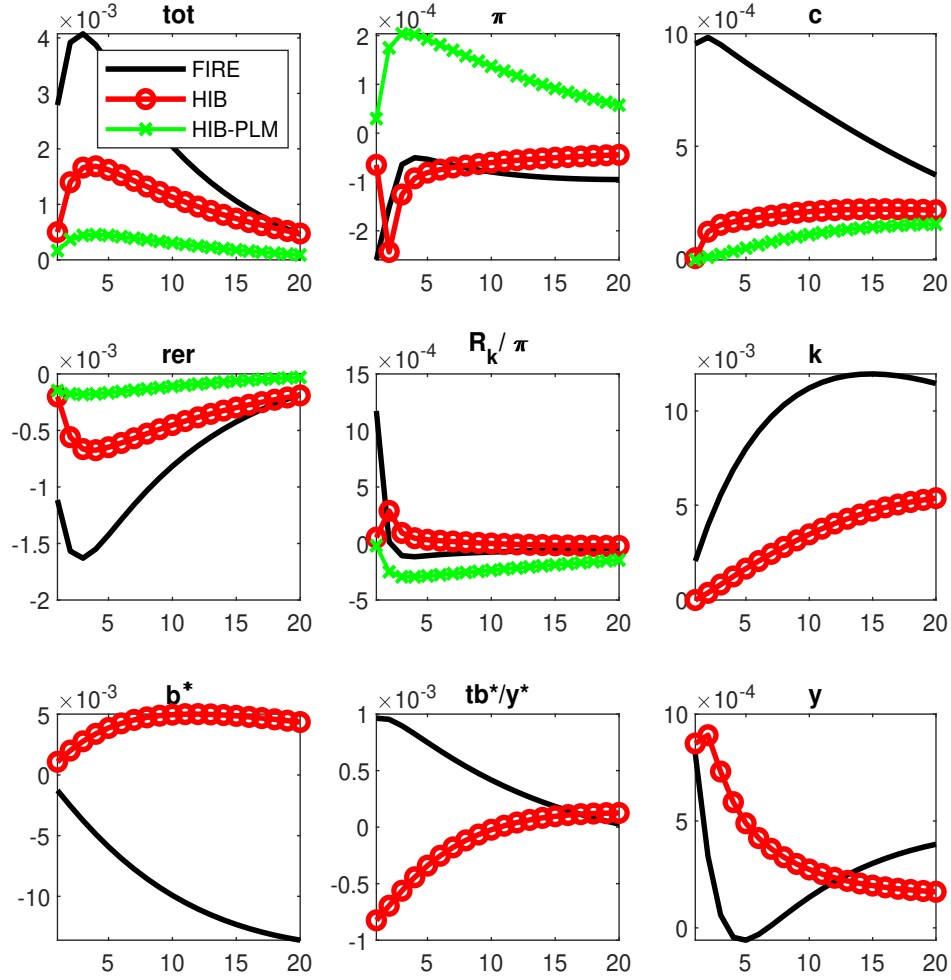
#### 3.3.1. Simulations

We now focus on the quantitative predictions of our FIRE model using data from the US and the Euro Area. To this aim, we first regress nominal exchange rate changes on the nominal interest rates differential by using simulated data in response to technology shocks:

$$\log(e_{t+1}) - \log(e_t) = \beta_1 + \beta_2(R_t - R_t^F) + \epsilon_t \quad (12)$$

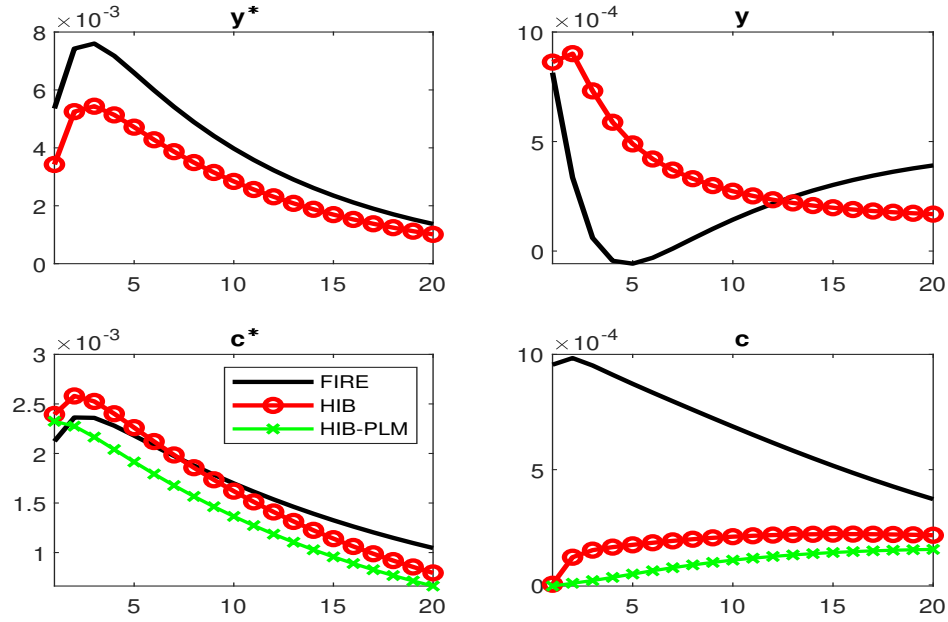
<sup>21</sup>This compensates the lower increase in consumption and investment with respect to FIRE.

Figure 2: International spillover: response of the Euro Area to the US technological shock



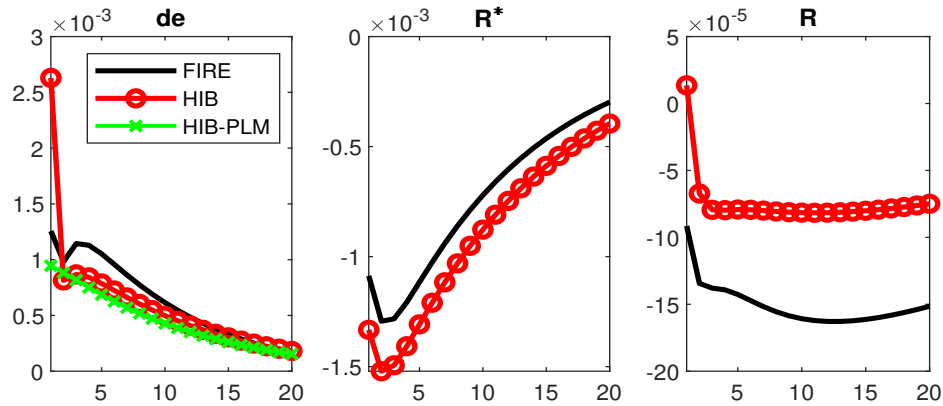
$x^*$ : starred variables refer to US variable,  $x$ : non-starred variables refer to EA variable. Solid line: FIRE. "o" line: HIB-AL. "+" line: HIB-AL PLM,  $E_t[x_{t+1}]$ : EA agents' forecast of variable  $x$  based on their HIB-PLM. Only for forward-looking variables. Deviation from steady state after one-sd positive shock.  $rer_t < 0$  is an appreciation of the EA real exchange rate.

Figure 3: US technological shock and the quantity puzzle



$x^*$ : starred variables refer to the US,  $x$ : non-starred variables refer to the EA. Solid line: FIRE. "o" line: HIB-AL. "+" line: HIB-AL PLM,  $E_t[x_{t+1}^*]$ : US agents' forecast of variable  $x^*$  based on their HIB-PLM,  $E_t[x_{t+1}]$ : EA agents' forecast of variable  $x$  based on their HIB-PLM. Only for forward-looking variables. Deviation from steady state after one-sd positive shock.

Figure 4: US technological shock and the UIP



$x^*$ : starred variables refer to the US,  $x$ : non-starred variables refer to the EA. Solid line: FIRE. "o" line: HIB-AL. "+" line: HIB-AL PLM,  $E_t[x_{t+1}^*]$ : US agents' forecast of variable  $x^*$  based on their HIB-PLM,  $E_t[x_{t+1}]$ : EA agents' forecast of variable  $x$  based on their HIB-PLM. Deviation from steady state after one-sd positive shock.  $de_t = e_t - e_{t-1}$  is the first difference of the nominal exchange rate.  $de_t > 0$  is the magnitude of the depreciation of the EA currency.

Table 2, panels 1 and 2, show that the estimated coefficient is very close to 1, as UIP holds in the FIRE model, while it is not the case in the data ( $\beta = -0.006$ ).<sup>22</sup> The FIRE model fails to account for departures from UIP. Table 2 panel 2, also displays the model's predictions regarding the output-consumption co-movement puzzle. As in Faia (2007a, 2007b), the model under FIRE is characterized by a strong positive output co-movement (0.56) consistent with the business cycle synchronization observed between the US and the Euro Area data since the early 1970s (0.53). However, international risk sharing is too large in the FIRE model, leading to high international correlations of consumption (0.82) compared to the data (0.38). Notice finally that the model is characterized by a too large cross-country correlation of investments (0.95 in the FIRE model versus 0.38 in the data). Finally, under FIRE, trade balance appears procyclical (with a correlation with output of 0.18), which is counterfactual.

HIB-AL improves the model's performances along several dimensions. First, under HIB-AL we obtain a UIP coefficient of 0.70. Given that the estimated coefficient hovers around zero in the data and around 1 under FIRE, we consider that our model can explain approximately 30% of departure from UIP. Second, the match of simulated international cross-country correlations improves significantly. Consumption co-movement is positive (0.39) and consistent with data (0.38). Notice that it lies well below its predicted value under FIRE (0.82) and is consistent with the economic mechanisms in Section 2. Output co-movement under HIB-AL (0.43) is slightly below the empirical counterpart (0.56), but remains within the range found in G7 data (Backus et al. (1992)). The international correlation of consumption (0.39) is now lower than the one of output (0.43), consistently with data, thus solving the quantity anomaly. In addition, because of the dampened financial spillover analyzed in Section 3.2, the cross-country correlation of investment is much closer to the data (0.47 in the HIB-AL model versus 0.38 in the data) than the FIRE model (0.95). Finally, the trade balance under HIB-AL appears countercyclical (with a correlation of output of -0.58), which is consistent with US data (-0.56).

### 3.3.2. VAR Evidence

In this section, we show that the HIB-AL model outperforms the FIRE model when we compare the models' IRFs to their empirical counterpart from a structural VAR. The VAR evidence draws from Corsetti et al. (2014), who investigate the international transmission of shocks. We follow their VAR identification scheme and estimate several specifications of the following VAR model (omitting the constant):  $\mathcal{Y}_t = B(L)\mathcal{Y}_{t-1} + \mathcal{U}_t$ , where  $\mathcal{Y}_t$  denotes a vector of 3 variables in levels and  $B(L)$  a lag polynomial of order  $p$ .<sup>23</sup> Open-economy VAR papers face the curse of dimensionality as they deal with many variables in relatively short samples. Following the literature, we deal with this issue by: *i*) specifying  $\mathcal{Y}_t$  as the US variable in level, minus its EA counterpart and *ii*) keeping the first two variables fixed and changing the third one. The first 2 variables in  $\mathcal{Y}_t$  are, along the lines of Corsetti et al. (2014): 1) the log of labor productivity in the US minus its EA counterpart, 2) the logged CPI US inflation factor minus its EA counterpart. The third variable is in turn: 1) the log of real US private consumption minus its EA counterpart or 2) the log of real US GDP minus the EA counterpart or 3) the departure from UIP<sup>24</sup> or 4) US trade balance over US GDP.

We follow Corsetti et al. (2014) in that we use sign restrictions to identify technological shocks.<sup>25</sup> The theoretical foundation for the restriction lies in the simple idea that supply shocks move relative prices and quantities in opposite directions: the US technological shock raises US labor productivity, relative to the EA labor productivity, *and* lowers US inflation relative to its EA counterpart. The sign restriction is assumed to hold for up to 4 quarters in all VARs.<sup>26</sup> The third variable is left unconstrained.

In Figure 5, we plot the theoretical impulse responses together with their empirical counterparts. The US supply shock lowers inflation in the US data (that remains significantly different from zero, see panel b). The models' IRFs, both under HIB-AL and FIRE, are consistent with the magnitude and persistence of relative inflation from the VAR, which suggests that the theoretical inflation dynamics are empirically relevant. The third variable is the log of real US private consumption in deviation from its EA counterpart (panel c), which is left unconstrained in the VAR. The data predicts a significant positive response to the US supply shock. The theoretical HIB-AL IRFs fall within the 95% confidence band of the structural VAR, while the FIRE IRF lies outside the confidence band in the first 4 quarters.

<sup>22</sup>We do not report the constant  $\beta_1$  as it is zero in the data and in all models. Additional moments from the models are reported in Appendix E.

<sup>23</sup> $p$  is determined using a test based on LR ratio. See Appendix B for data sources.

<sup>24</sup>Departure from UIP is denoted  $duip = R_t - R_t^F - (\log(e_{t+1}) - \log(e_t))$  following equation (12).

<sup>25</sup>Technological shocks are identified using sign restrictions rather than long run restrictions. Corsetti et al. (2014) argue that it provides intuitive and clean theory-based restrictions. Dedola and Neri (2007) also advocate the use of sign restrictions rather than long-run restrictions in the study of the macroeconomic impact of technological shocks. They find that, unlike long-run restrictions, results from sign restrictions are robust to specification assumptions.

<sup>26</sup>Corsetti et al. (2014) consider sign restrictions from 8 to 20 quarters. We consider a horizon of 1 year, which is less restrictive than Corsetti et al. (2014).

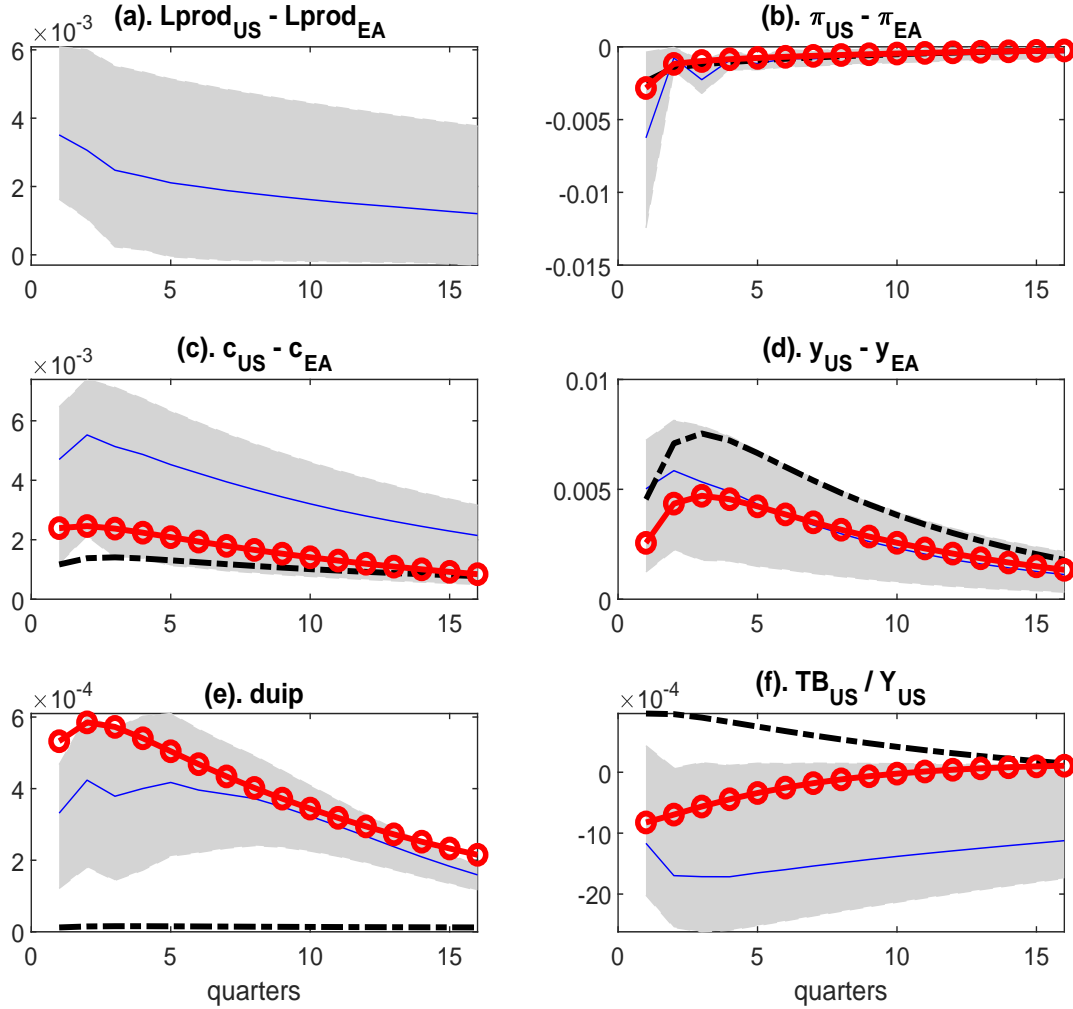
Table 2: Simulations: output-consumption anomaly and departure from UIP

		Co-movements				UIP
		$i, i^*$	$y, y^*$	$c, c^*$	$TB^*/y^*, y^*$	$\beta$
1. Data		0.38	0.53	0.38	-0.56	-0.006
2. Baseline	FIRE	0.95	0.56	0.82	0.18	0.97
	<b>HIB-AL</b>	<b>0.47</b>	<b>0.43</b>	<b>0.39</b>	<b>-0.58</b>	<b>0.70</b>
3. Info. set	HIB+q	0.53	0.47	0.46	-0.53	0.71
	HIB+R	0.61	0.48	0.39	-0.49	0.77
	HIB+R+q	0.66	0.51	0.46	-0.43	0.77
	HIB+FI	0.87	0.55	0.82	0.17	0.97
4. NK	FIRE	0.75	0.65	0.79	0.13	0.95
	HIB-AL	0.37	0.58	0.36	-0.61	0.72
5. BKK	FIRE	0.70	0.28	0.76	0.08	-
	HIB-AL	0.43	0.40	0.42	-0.26	-

"Data": AWM data, 1973Q1–2014Q4 for the Euro Area; US FRED for the US. See Appendix B. "HIB-AL": Predictions from model with Home information bias and adaptive learning. "FIRE": Predictions from model with full information and rational expectations. "UIP" presents the coefficient of the estimation in equation (12). "Co-movements" presents the international correlation of investment  $i$ , output  $y$ , consumption  $c$  and the cyclicalit of the trade balance over GDP  $tb^*/y^*$ . "HIB+q:" Information set includes local variables and other country's price of capital. "HIB+R:" Information set includes local variables and other country's interest rate. "HIB+R+q:" Information set includes local variables and other country's interest rate and price of capital. "HIB+FI:" Full Information set, it includes local variables and all foreign variable (same information set as under rational expectations). "NK" stands for the New Keynesian model (with nominal rigidities but without financial frictions). "BKK" is the two-country Walrasian model with incomplete markets (without financial frictions and without nominal rigidities). Results are provided after technology shocks. Results are based on 1000 simulations of the model of 100 periods' length.

Therefore, the HIB-AL specification improves the empirical performance of the model in the short run regarding the cross-country consumption correlation (in response to a technological shock). This is a key feature of our work stressed in Section 2. Figure 5, panel (d), reports the IRFs when the 3rd variable is relative real output. Theoretical IRFs fall within the 95% confidence band suggesting that both models are empirically relevant to explain the output cross-country correlation, with a slight advantage for the HIB-AL model (the HIB-AL IRF is closer to the median). Thus, HIB-AL plays a key role in solving the quantity puzzle through cross-country consumption correlation. Finally, in panel (e) and (f), the VAR evidence suggests that the US technological shock generates a significant departure from UIP and a negative response of the US trade balance (over US GDP), consistently with the empirical evidence in Corsetti et al. (2014). In both cases, the FIRE IRFs lie outside the VAR 95% confidence band whereas the IRFs of the HIB-AL model are significant, implying that HIB-AL does improve the empirical relevance of the model.

Figure 5: US positive technological shock



Solid line: VAR Median IRF. Light-shaded area: 95% confidence band. "o" line: Theoretical response from HIB-AL model. Dash Line: Theoretical response from FIRE model. " $Lprod_{US} - Lprod_{EA}$ ": log of US labor productivity - log of EA labor productivity. " $\pi_{US} - \pi_{EA}$ ": log of US inflation factor - log of EA inflation factor. " $c_{US} - c_{EA}$ ": log of US real private consumption - log of EA real private consumption. " $y_{US} - y_{EA}$ ": log of US real GDP - log of EA real GDP. " $duip$ ": departure from UIP,  $duip = R_t - R_t^F - (\log(e_{t+1}) - \log(e_t))$  with notations as in equation (12). See Appendix B for the data sources.



### 3.3.3. Welfare impact of HIB

We look at the conditional welfare cost of HIB-AL. We compute welfare as a 2nd order approximation of the discounted stream of consumers' utility. In each country, it is given by:

$$W_0 \cong \frac{1}{1-\beta} \left\{ \left[ \frac{C^{1-\sigma}}{1-\sigma} + \Psi \log(1-N) \right] + \left[ C^{1-\sigma} E_0(\hat{c}_t) - \frac{\Psi N}{1-N} E_0(\hat{n}_t) \right] - \frac{\sigma}{2} C^{-(\sigma+1)} C^2 \text{var}(\hat{c}_t) - \frac{\Psi}{2(1-N)^2} N^2 \text{var}(\hat{n}_t) \right\} \quad (13)$$

where  $C$  and  $N$  denote steady-state values, hatted variables refer to variables expressed in % deviations from the steady-state, i.e.,  $\hat{c}_t = \frac{C_t - C}{C}$  and  $\hat{n}_t = \frac{N_t - N}{N}$  and  $\text{var}$  denotes the variance operator.  $W_0$  is calculated with the FIRE model and falls when the volatility of consumption increases. We then compute the cost of living in the HIB-AL economy with respect to the FIRE one. We calculate it in terms of percentage of steady-state consumption as in Schmitt-Grohe and Uribe (2001).<sup>27</sup>

The welfare cost of HIB-AL appears very small. Consumers in the US are willing to pay  $5.9e - 5$  per cent of their steady-state consumption to obtain the FIRE welfare. IRFs in Section 3.2 provide the intuition for this result: under HIB-AL, US consumers are more responsive to local shocks, which tends to increase consumption volatility, thereby, decreasing welfare under HIB-AL. However, US consumers are also less responsive to shocks from the EA, which tends to lower consumption volatility, thereby increasing welfare under HIB-AL. All in all, the welfare cost of HIB-AL tends to be small, which rationalizes the fact that, in the data, agents do focus more on local information.<sup>28</sup>

## 4. Sensitivity

In this section, we illustrate how our results change with the information set (Section 4.1) and are robust to the extent of frictions in the model (Section 4.2). Additional sensitivity to the learning parameters and the results from a monetary policy shock are reported in Appendix F.1 and F.2.

### 4.1. Information set

In the previous sections, we assumed a complete Home Information Bias. We examine now the macroeconomic consequences of gradually relaxing this assumption. We allow the EA (US) agents' information set to include more US (EA) variables. We choose to focus on financial variables as they are more likely to be observed worldwide and characterize our model. We enlarge agents' information set with the other country's nominal interest rate,  $R$ , or/and price of capital,  $q$ . We proceed step by step in order to highlight the importance of the information set for the international transmission.

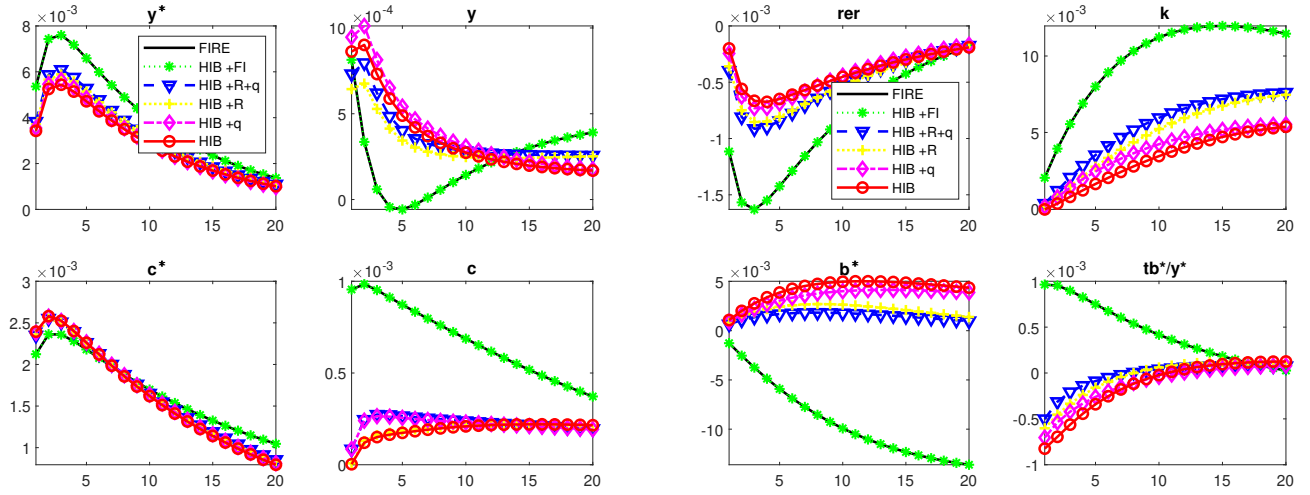
We can see in Figure 6 that, after a US technological shock, the information set greatly affects international spillovers. The more information is known by the agents, the more it is incorporated into prices and the more the EA real exchange rate appreciates. EA agents substitute less domestic for foreign investments and the model behaves closer to FIRE.

The graphical intuitions are confirmed by simulation results. Panel 3 in Table 2 shows that the greater the information set, the lower the information asymmetry, the closer the moments are to the FIRE case. In particular, the inclusion of the other country's interest rate  $R$  in the information set matters for UIP dynamics as the agents consider the possible behavior of the other country's monetary policy when making their international financial investments. Departure from UIP is then smaller ( $\beta = 0.77$ ) than under complete HIB and output correlation is slightly higher (0.48) as  $R$  indirectly determines credit costs. However, observing the foreign interest rate alone is not sufficient to align on the UIP equilibrium condition as the agents still have an imperfect knowledge of the foreign factors that determine the other country's monetary policy reaction. The inclusion of the price of capital  $q$  plays instead an important role for the synchronization of the cycles as the agents have a key information on the financial cycle abroad. Finally, under AL and with the full information set ("HIB+FI"), the model's predictions are similar to the results under FIRE for all our statistics of interest. With the same information set as in the FIRE case and agent's beliefs initialized at RE, the

<sup>27</sup>See Appendix D for further details and the computation of conditional and unconditional welfare. Welfare cost of HIB-AL also remains small when we consider unconditional welfare.

<sup>28</sup>In Section 4 and Appendix F, we perform sensitivity to the information set and learning parameters. When the information set expands, welfare costs decrease, as expected, although changes remain small. For instance, when agents know the other country's Tobin's  $q$ —which is critical in the financial accelerator mechanism—the welfare cost of HIB-AL reduces to  $5.8e - 5$  per cent of US steady-state consumption. The welfare results are slightly modified when learning parameters are changed. The change in the gain barely affects the welfare results ( $5.9e - 5$  per cent of steady state consumption). As for initialization, the welfare cost of HIB is slightly larger ( $7.1e - 5$  per cent of steady state consumption) when international risk sharing is less prevalent (cross-country consumption correlation is lower when initialization under HIB lies above RE). However, the welfare changes remain small.

Figure 6: IRFs with alternative information sets. Positive US technology shock.



(a) The quantity puzzle

(b) Trade balance dynamics

$x^*$ : starred variables refer to the US,  $x$ : non-starred variables to the EA. Solid line: FIRE. "o" line: HIB-AL. "diamond" line: HIB-AL +  $q$  other country's price of capital in the information set. "+" line: HIB-AL +  $R$  other country's interest rate in the information set. "triangle" line: HIB-AL +  $R$  +  $q$  other country's interest rate and price of capital in the information set. "asterisk" line: HIB + FI is AL with Full Information. Deviation from steady state after one-sd positive shock.

only difference between FIRE and HIB-AL lies in the update of beliefs based on the learning algorithm. Our results (Appendix F) suggest that the learning algorithm alone does not quantitatively alter the magnitude of international spillovers.

#### 4.2. Role of frictions

In order to illustrate the robustness of our economic mechanism, we have reported in Table 2 the simulation results for models without financial frictions, namely a two-country two-goods RBC model with incomplete markets ("BKK": no financial frictions nor price rigidity) and a two-country two-goods New Keynesian model ("NK", which is the "BKK" model enriched with price rigidities but no financial frictions). As these models are well-known, their full presentation is reported in Appendix C.

Panels 4 and 5 in Table 2 show that the HIB mechanism is at work whatever the nature of frictions in the economy. For each model, whether BKK, NK or our baseline model, HIB makes the model correctly predict a countercyclical trade balance and lowers the consumption and investment international correlation with respect to the FIRE model, which brings each model closer to the data regarding i) the level of consumption and investment co-movements and ii) the quantity puzzle. While it is not possible to compute the UIP coefficient for the BKK model (it is a pure RBC model that does not include nominal exchange and interest rates), the NK model also features departure from UIP. The economic mechanisms at work based on HIB (described in Sections 2 and 3.2) apply whatever the nature and degree of frictions in the economy.

### 5. Conclusion

We propose a mechanism that succeeds in solving the quantity anomaly, matching countercyclical trade balance dynamics and producing endogenous departures from the UIP of about 30%. To our knowledge, this is the first paper that succeeds along these dimensions. The key feature of our model is the departure from the full-information rational expectations (FIRE) approach. The key ingredient that makes the model successful in matching the data is home information bias, which is more crucial than learning or the extent of nominal and financial frictions in the economy. Coibion and Gorodnichenko (2015) provide empirical evidence of pervasive departure from full information. Our paper echoes this finding by stressing the importance of departure from FI in an open-economy setting. The results suggest that information frictions and imperfect information provide interesting insights for the understanding of the international business cycle, calling for a re-thinking of policy design in open economies.

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