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Abstract

In this paper, we examine the current state of the international macroeconomic literature, focusing specifically on international spillovers and the international transmission of country-specific shocks. Using a general equilibrium framework, we analyze the standard two-country RBC model and its ability to replicate empirical evidence on international correlation of output, consumption, and international risk sharing. We then survey attempts in the literature to address the limitations of the model, including incorporating nominal rigidities and financial frictions, as well as recent contributions bridging the gap between open-economy macroeconomics and international finance. These works have the potential to explain the international transmission of shocks among advanced countries by accounting for factors affecting international risk sharing.

JEL Classification : E44, F41, F42, F44.

Keywords: international business cycles, cross-country co-movement, quantity puzzle.

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1 Introduction

Even if a rich literature has studied them for decades, the state of the art of international macroeconomics is still featured by several open questions. Scholars commonly refer to them as "puzzles" (see Obstfeld & Rogoff (2001) among others). In this chapter, we analyze the recent international macroeconomic literature with a specific focus on explaining *international spillovers* and the *transmission* of disturbances among countries. We will introduce a unifying framework to discuss the underlying mechanisms and point to promising avenues for future research.

To the purpose of accounting for agents' interactions and feedback effects, we will consider a general equilibrium framework. This is particularly important as shocks are transmitted among countries via international goods and asset prices. Because it is the (underlying) benchmark model for dynamic macroeconomic analysis in open economy, we introduce the standard two-country RBC model. We highlight its structure and the implied dynamics. For a matter of simplicity, we focus on the response of the model to standard productivity shocks. This choice has the advantage to provide an unified framework in line with the literature. We then confront it with the standard stylized facts on international transmission in advanced countries. We will discuss in particular the (in)ability of the model to reproduce the empirical evidence on international correlation of output, inputs, consumption and international risk sharing. We then survey the attempts of the literature to overcome the structural limits of the model. We will then enrich the RBC framework so as to account for nominal rigidities and financial frictions. As this is not sufficient to reproduce the data, we will then analyze recent contributions trying to bridge the open-economy macroeconomic literature with international finance, beyond the traditional interest of the literature into sovereign default and overborrowing[1]. Indeed, by incorporating (financial) factors affecting international risk sharing, these recent works have the potential of explaining the international transmission of shocks among advanced countries.

This chapter is organized as follows. Section 2 discusses stylized facts on international comovement. Section 3 introduces the standard two-country RBC model. Section 4 surveys the literature focusing on inputs and the production structure, to the purpose of overcoming the limits of the RBC model. Section 5 studies the ability of the standard framework to reproduce data once enriched with nominal rigidities and variable markups. In section 6 we further modify the standard framework so as to account for financial frictions; we also

[1]See Mendoza (2002), Mendoza (2010), Uribe (2006), Jeanne & Korinek (2010), Bianchi (2011), Benigno et al. (2013) among others.

discuss promising works further improving the performance of the model by accounting for information and other factors affecting the financial side of the model. Section 7 concludes.

2 Stylized facts: International co-movement

The originality of our survey with respect to existing work consists in laying stress on international spillovers. This explains the choice of the stylized facts we discuss in this section and the focus on international co-movement of key macroeconomic aggregates. Not surprisingly, we discuss the international correlation of output and consumption. Moreover, as international capital flows play a key role in driving international spillovers, we also look at investment synchronization and the behavior of the trade balance. We will also point out to departures from the Uncovered Interest rate Parity (UIP). In fact, this condition represents the trade-off investors are facing when they choose to invest in the domestic country or in the rest of the world. International consumption(investment) decisions in response to local shocks eventually determine how risk is shared among countries.[2]

The comparison of model allocations with data is performed in order to evaluate the ability of our framework to account for the data. There are many dimensions along which one can perform this comparison. In this section, we focus on stylized facts at business cycle frequency, as it is standard in the international macroeconomic literature (Backus et al. (1992)). Moreover, we provide evidence on international departures from UIP based on Iliopulos et al. (2021).[3]

Stylized facts are calculated on US and Euro Area (hereafter EA) data between 1973Q1 and 2014Q4.[4] The quarterly series are logged (with the exception of net exports which are expressed relative to GDP) and HP filtered. Table 1 reports the cross-country correlations of output, private consumption and investment. There is clear evidence of business cycle synchronization, as all correlations are positive. In particular, output international co-movement is greater than that of consumption and investment, as in other OECD countries (Backus et al. (1992)). The fact that the international correlation of consumption is

[2]In what follows, we will analyze how risk sharing conceptually links consumption co-movement among countries with international capital flows (see Section 3).

[3]In this chapter, we will not assess the ability of international macro models to match the Impulse Response Functions (IRFs) from a 2-country VAR. The reader can refer to Iliopulos et al. (2021).

[4]Appendix A provides a detailed description of the data. We choose the US and the Euro Area for several reasons. First, to the purpose of being consistent with the structure of our model, we need two advanced large countries with floating exchange rates. Second, stylized facts on the US and the EA are consistent with the ones computed on a large set of OECD countries (see Backus et al. (1992), among others).

lower than the one of output[5] suggests that consumers do not seize enough opportunities to diversify their portfolio of assets. With a fully diversified asset portfolio, consumption would be more synchronized than output. We will get back to this point in section 3.2.

Table 1: International business cycles: Stylized facts

	Cross-country correlations			net exports	UIP	BS
	y,y*	c,c*	i,i*	TB*/y*,y*	β^{UIP}	c-c*,e^r
	(1)	(2)	(3)	(4)	(5)	(6)
Data	0.53	0.38	0.38	-0.56	-0.006	-0.19

"Data": AWM data, 1973Q1-2014Q4 for the Euro Area; US FRED for the US. See Appendix A. "UIP" presents the coefficient of the estimation in equation (1). "Cross-country correlations" presents the international correlation of investment i, output y, consumption c and the cyclicality of the trade balance over GDP tb^*/y^*. "BS": Backus & Smith (1993*a*) correlation between relative consumption across countries and real exchange rate e^r.

Column (4) in Table 1 shows that the trade balance is countercyclical. This fact is particularly interesting in the study of international synchronization because of the linkage between trade flows and capital flows. Investment booms can in fact lead to a countercyclical trade balance.

The UIP states that the return of a domestic asset (i.e., a risk-free interest rate) should equal the expected return of a foreign asset once we account for expected changes in foreign-currency spot exchange rates. Indeed, without restrictions to international capital flows, deviations from the UIP imply that there are opportunities to make risk-free profit by using financial arbitrage. In order to gauge departures from UIP in the data, we follow the literature (Engel (2014)) and regress nominal exchange-rate changes on the nominal interest rates differential for US and EA:

$$log(e_{t+1}) - log(e_t) = \beta^{constant} + \beta^{UIP}(R_t - R_t^F) + \epsilon_t \tag{1}$$

If UIP holds, $\beta^{UIP} = 1$, because the country with the higher interest rate or risk-free money market yield will experience depreciation of its domestic currency relative to the foreign currency. Table 1 shows that the estimated coefficient β^{UIP} is actually zero. There is strong departure from UIP in the data.[6] Opportunities for risk-free profit are thus not seized, which echoes our discussion on the low consumption co-movement.

[5] Notice also that consumption in each country is highly correlated with local output. See Backus et al. (1992).

[6] We do not report the constant $\beta^{constant}$ as it is zero in the data and in all models. Strong departure from UIP has been extensively documented, see Engel (2014).

Column (6) in Table 1 shows that, in the data, the correlation between relative consumption and the real exchange rates is negative, which was first pointed out by Backus & Smith (1993a). This suggests that risk sharing is not efficient. Indeed, efficient risk sharing calls for allocating higher rates of consumption growth to countries where it becomes cheaper. Under full risk sharing, if the euro depreciates in real terms, EA households shall receive wealth transfers to enjoy low EA prices, and vice versa when the US dollar is weak. This is not the case in the data.

3 The performance of the standard 2-country model

We now introduce the benchmark model on which we will build on for the rest of the analysis. We will then analyze the underlying mechanisms driving its dynamics in response to technological disturbances.

3.1 A standard two-country RBC model

The model is a standard two-country RBC model where, differently from Backus et al. (1994), markets are incomplete.[7] We assume a bond economy so that households in both countries can trade non-contingent assets, one domestic good and one foreign produced good. Each country, Home (H) and Foreign (F), is inhabited by households, wholesalers and retailers-exporters. Capital is internationally mobile, which is not the case for labor. Foreign variables are denoted with a " * ". For the sake of brevity, we present here the key equations of the model for the Home country. Foreign country's country problem is symmetrical.

3.1.1 Households

In country H, households maximize the flow of expected utilities $E_0 \sum_{t=0}^{t=\infty} U\left(C_t, N_t\right)$ subject to a budget constraint. N_t represents labor and C_t is the final consumption basket incorporating the consumption of both the domestic and the foreign-produced good (C_{Ht} and C_{Ft}, respectively), via an aggregate CES function. Preferences are defined as follows: $C_t = \left[(1-\gamma)^{\frac{1}{\eta}} C_{Ht}^{\frac{\eta-1}{\eta}} + \gamma^{\frac{1}{\eta}} C_{Ft}^{\frac{\eta-1}{\eta}}\right]^{\frac{\eta}{\eta-1}}$, where $\eta > 0$ is the elasticity of substitution between

[7] Indeed, while the assumption of complete markets is useful as a benchmark for analytical purposes, it has been strongly criticized in the aftermath of the financial crisis (see among many others, Caballero (2010)). The bond-economy assumption is representative of the recent literature in open-economy macroeconomics (see Uribe & Schmitt-Grohe (2017)).

Home and Foreign produced goods. Moreover, $\gamma < 1/2$ implies home bias. The corresponding price index is $P_t^c = \left[(1-\gamma) P_{Ht}^{1-\eta} + \gamma P_{Ft}^{1-\eta}\right]^{\frac{1}{1-\eta}}$. In real terms of the Home consumption basket, the budget constraint reads:

$$C_t + e_t^r b_t^* + b_t + I_t + \frac{\varpi}{2}\left(\frac{I_t}{K_t} - \delta\right)^2 K_t \leq R_{t-1} b_{t-1} + R_{t-1}^F b_{t-1}^* e_t^r + \frac{W_t}{P_t^c} N_t + \frac{\Pi_t}{P_t^c} + r_t K_{t-1} \quad (2)$$

where e_t^r is the real exchange rate, i.e. $e_t^r \equiv \frac{e_t P_t^{c*}}{P_t^c}$ (with P_t^c being the domestic CPI, P_t^{c*} the foreign one and e_t the nominal exchange rate), b_t^* are Foreign bonds, that are here issued in Foreign currency[8] (with R_t^F being the associated real interest-rate factor). b_t are domestic bonds (with R_t being the real domestic interest-rate factor), I_t investment in capital and $\frac{\varpi}{2}\left(\frac{I_t}{K_t} - \delta\right)^2 K_t$ (with $\varpi > 0$) represent capital adjustment costs, which are a common feature in standard RBC models. Finally, r_t is the real return on capital, $\frac{\Pi_t}{P_t^c}$ are real profits received by the household from firms in the monopolistic sector and $\frac{W_t}{P_t^c}$ real wages. The first order conditions of this problem read:

$$\frac{U'_{Nt}}{U'_{ct}} + \frac{W_t}{P_t^c} = 0 \quad (3)$$

$$U'_{ct} = \beta E_t \left[R_t U'_{ct+1}\right] \quad (4)$$

$$U'_{ct} = \beta E_t \left[R_t^F U'_{ct+1} \frac{e_{t+1}^r}{e_t^r}\right] \quad (5)$$

$$U'_{ct}\left(\frac{I_t}{K_t} - \delta\right)\frac{\varpi}{2}\left[\frac{I_t}{K_t} + \delta\right] - U'_{ct} Q_t + \beta E_t U'_{ct+1}\left[E_t r_{t+1} + E_t Q_{t+1}(1-\delta)\right] = 0 \quad (6)$$

$$1 + \varpi\left(\frac{I_t}{K_t} - \delta\right) = Q_t \quad (7)$$

where U'_{ct} (U'_{Nt}) represents the marginal utility of consumption (labor) and Q_t represents the price of capital. Equation (3) is the first order condition with respect to labor and defines real wages as the result of agents' arbitrage between consumption and leisure. Equation (4) is the optimality condition with respect to domestic bonds and is thus a standard Euler equation. Equation (5) is the one with respect to foreign bonds; agents' intertemporal investment (consumption) decisions are thus also affected by their expectation on the real exchange rate path. Equation (7) (Equation 6) defines the optimal condition for investment (physical capital) and also accounts for capital adjustment costs.

[8] Alternatively, we can introduce domestically-denominated bonds. As in this case the real exchange rate appears in the budget constraint of the foreign country, this alternative choice would not modify the optimality conditions.

As it is well known (see Schmitt-Grohe & Uribe (2003) among many others), the incomplete-markets open-economy standard model is structurally featured by unit roots so that transient shocks have permanent effects on the equilibrium. Therefore, the equilibrium possesses a random walk component. This implies that the unconditional variance of endogenous variables such as consumption and foreign assets tends to infinity. It is thus not generally possible to solve the model using methods based on local approximation. To the purpose of stationarizing open-economy models, there are several possibilities.[9] We follow Schmitt-Grohe & Uribe (2003), and introduce a spread between interest rates, that is a function of the (real) value of the country's net foreign asset position:

$$R_t^F = R_t^* + \zeta \left(e^{-b_t^* + \bar{b}} - 1 \right) \tag{8}$$

with $\zeta > 0$. We assume that the law of one price (LOP) holds for single goods both at a producer and consumer level so that $P_{Ht} = e_t P_{Ht}^*$, where P_{Ht} is the price of the domestically produced good in domestic units, P_{Ht}^* is the price of the domestically produced good in Foreign units. This assumption is not neutral as it implies a perfect pass-through of exchange rate fluctuations into prices without any nominal frictions.[10] However, because of home bias[11], the Purchasing Power Parity (PPP) does not hold. Terms of trade are defined as: $tot_t \equiv \frac{P_{Ht}}{P_{Ft}}$.[12]

Foreign workers face an allocation of expenditure and wealth similar to the one of the households in the H region except for the fact that they do not pay an additional spread for investing in the Foreign bond, which is denominated in their currency. By combining Euler

[9] The literature has highlighted several stationarity-inducing methods such as specific calibrations of the utility function (see Cole & Obstfeld (1991)); introducing an overlapping-generations structure (see Cavallo & Ghironi (2002)); debt limits with discount heterogeneity (see Faia & Iliopulos (2011)), together with the methods proposed by Schmitt-Grohe & Uribe (2003): i) endogenous discount factors, ii) portfolio adjustment costs and iii) debt-elastic interest rates. Schmitt-Grohe & Uribe (2003) show that regardless on how they introduce stationarity, the model predictions on second moments are in practice the same.

[10] It also excludes other types of wedges breaking the direct link between consumer prices and exchange rates. We will discuss these wedges in Appendix C.

[11] Agents' preferences are such that domestically-produced goods have a greater weight in the consumption basket, consistently with the empirical evidence.

[12] Notice also that $\frac{P_{Ht}}{P_{Ft}} = \frac{f_t}{e_t^r f_t^*}$,where $f_t \equiv \frac{P_{Ht}}{P_t^c}$ denotes the ratio of the price of the domestically produced good with respect to the consumer price in the domestic country and $f_t^* \equiv \frac{P_{Ft}^*}{P_t^{*c}}$ denotes the ratio of the Foreign price of the Foreign produced good with respect to the consumer price in country F. Notice also that the real exchange rate can be rewritten as $e_t^r = \frac{1}{tot_t} \frac{f_t}{f_t^*} = \frac{1}{tot_t} \frac{\left[(1-\gamma)+\gamma\left(\frac{1}{tot_t}\right)^{1-\eta}\right]^{\frac{-1}{1-\eta}}}{\left[(1-\gamma)+\gamma tot_t^{1-\eta}\right]^{\frac{-1}{1-\eta}}}$.

equations with respect to international bonds for both H and F households, we obtain:

$$U'_{ct} = \beta E_t \left\{ \left[\frac{U^{*\prime}_{ct}}{\beta U^{*\prime}_{ct+1}} + \zeta \left(e^{-b^*_t + \bar{b}} - 1 \right) \right] U'_{ct+1} \frac{e^r_{t+1}}{e^r_t} \right\} \tag{9}$$

so that, in expectation, marginal utilities across countries are equalized up to a spread for the country risk.

3.1.2 Wholesale firms

The home-currency wholesale price is P^w. Thus, we define the mark-up Z so that $\frac{P^w}{P_H} = \frac{1}{Z}$. Moreover, as $P^c = \frac{P_H}{f}$, $\frac{P^w}{P_c} = \frac{f}{Z}$. The representative wholesale producer in country H operates in a perfect competition setting and maximizes thus the profits $f_t \frac{A_t, F(K_{t-1}, N_t)}{Z_t} - \frac{W_t}{P^c_t} N_t - R_t K_{t-1}$ where the technology, $F(A_t, K_{t-1}, N_t)$, is defined by a Cobb-Douglas function, so that output is

$$Y_t = A_t K^{\alpha}_{t-1} N^{1-\alpha}_t \tag{10}$$

where $0 < \alpha < 1$. A refers to the Home exogenous technological shock, such that

$$logA_t = \rho_A A_{t-1} + \varepsilon^A_t + \psi \varepsilon^{A*}_t \tag{11}$$

Notice that parameter ψ regulates the exogenous technological spillover across countries.[13] The optimality condition for capital demand is:

$$\alpha f_t \frac{Y_t}{K_{t-1} Z_t} = R_t \tag{12}$$

and that for labor demand is:

$$f_t \frac{(1-\alpha) Y_t}{N_t Z_t} = \frac{W_t}{P^c_t} \tag{13}$$

so that, in equilibrium, the rental rate of capital equals its marginal productivity (see equation (12)) and the marginal productivity of labor pins down real wages (see equation (13)). The problem of wholesalers in country F is symmetric.

[13] There are of course common shocks hitting all countries, such as changes in energy prices or pandemics. With common shocks, any model can in principle reproduce the large output international correlation found in the data; having said that, these shocks do also entail a large co-movement in consumption across countries, which is counterfactual. We thus take the stand of not exploring the impact of common shocks in this chapter.

3.1.3 Production and pricing of retailed goods

Retailers in the Home (Foreign) region operate in a monopolistic competition setting[14]. Because of the open-economy dimension, they have to be interpreted also as exporters. Retailing firms are owned by domestic (foreign) households and maximize nominal profits. We account for the stochastic discount factor, $\Lambda_{t,t+1} \equiv \frac{\beta E_t\left[U'_{ct+1}\right]}{U'_{ct}}$, so as to make firms' and households' optimisation problems consistent. Notice that since the demand addressed to H (F) retailers is also the one of the Foreign (Home) country, one has to account for world demand as well. As mentioned above, we assume a perfect pass-through of the exchange rate so that there are no frictions associated to the retailing activity.

Total final consumption and investment goods are aggregated à la Dixit-Stiglitz into the following basket of individual retail goods, $X_{Ht} \equiv \left(\int_0^1 X_{ht}(i)^{\frac{\upsilon-1}{\upsilon}} di\right)^{\frac{\upsilon}{\upsilon-1}}$ where $\upsilon > 1$ is the elasticity of substitution among varieties. The corresponding price index is $P_{Ht} = \left(\int_0^1 P_{ht}(i)^{1-\upsilon} di\right)^{\frac{1}{1-\upsilon}}$ and the demand curve facing each retailer is thus $X_{ht}(i) = \left[\frac{P_{ht}(i)}{P_{Ht}}\right]^{-\upsilon} X_{Ht}$. Retailers at Home maximize the flow of profits, $E_0\left\{\sum_{t=0}^{\infty} \Lambda_{t,t+1}\Pi_t(i)\right\}$ where $\Pi_t(i) = [Y_t(i)\left(P_{ht}(i) - P_t^w\right)]$ denote profits of retailer i, and $P_{ht}(i)$ is the price of the variety produced by i. The optimality conditions pin down the mark up, that is here constant (no nominal rigidities), ie: $Z_t = \frac{\upsilon}{\upsilon-1}$. The problem of the Foreign retailer is symmetric.

3.1.4 Demand aggregation

The final good X_t^c is obtained by assembling domestic, X_{Ht}, and imported intermediate goods, X_{Ft}, via an aggregate CES production function. It reflects agents' preferences: $X_t^c = \left[(1-\gamma)^{\frac{1}{\eta}} X_{Ht}^{\frac{\eta-1}{\eta}} + \gamma^{\frac{1}{\eta}} X_{Ft}^{\frac{\eta-1}{\eta}}\right]^{\frac{\eta}{\eta-1}}$. It follows that optimal demands are:

$$X_{Ht} = (1-\gamma)\left[\frac{P_{Ht}}{P_t^c}\right]^{-\eta} X_t^c; \quad X_{Ft} = \gamma\left[\frac{P_{Ft}}{P_t^c}\right]^{-\eta} X_t^c \tag{14}$$

so that $\frac{X_{Ht}}{X_{Ft}} = \frac{(1-\gamma)}{\gamma}\left[tot_t\right]^{-\eta}$. Analogous conditions apply for country F.

3.1.5 Market clearing

The world net supply of international bonds is zero. The aggregate supply of domestic bonds in each country is also zero. Market clearing for domestic variety i must satisfies

[14] Introducing retailers will allow us also to incorporate nominal rigidities in the following sections.

$Y_t(i) = X_{ht}(i) + X^*_{ht}(i)$. By combining this equation with (14), and recalling that the law of one price holds, the resource constraint is

$$Y_t = (1-\gamma)\,[f_t]^{-\eta}\,X^c_t + [tot_t f^*_t]^{-\eta}\,\gamma^* X^{c*}_t \tag{15}$$

Market clearing in the final-good sector for country H implies:

$$X^c_t = C_t + I_t + \frac{\varpi}{2}\left(\frac{I_t}{K_t} - \delta\right)^2 K_t \tag{16}$$

As net supply of domestic bonds is zero and substituting for profits, $\Pi_t = [Y_t\,(P_{H,t} - P^w_t)]$, into agents' budget constraint we obtain the current account equation[15]:

$$\left(b^*_t - R^F_{t-1} b^*_{t-1}\right) e^r_t = Y_t f_t - X^c_t \tag{17}$$

where the right-hand side of equation (17) defines the trade balance, i.e., the difference between domestic production and domestic absorption:

$$tb_t \equiv Y_t f_t - X^c_t \tag{18}$$

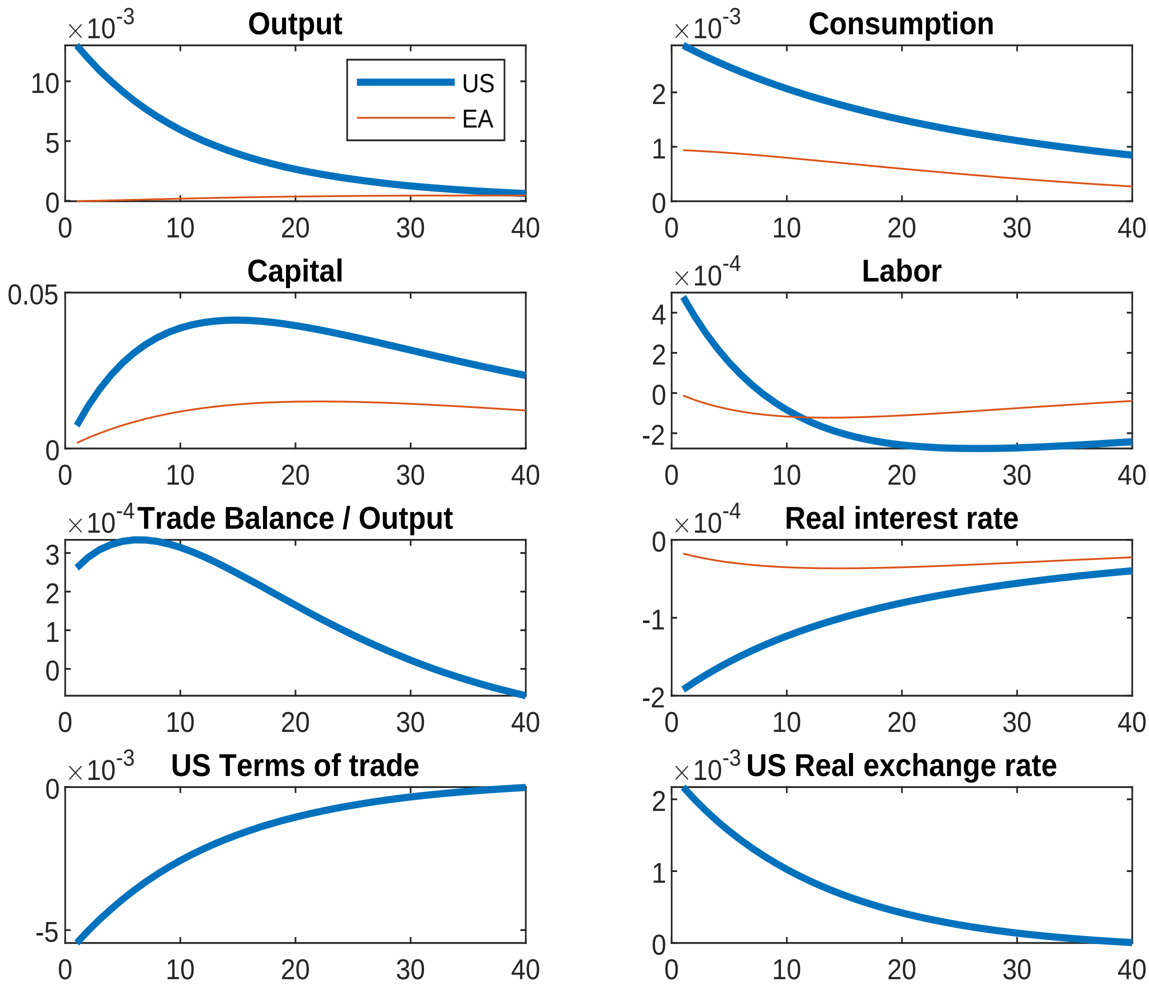
The calibration of the model is standard and it is the one used by Iliopulos et al. (2021) (see Appendix B).

3.2 The response of the model to technological shocks

In this section, we analyze the mechanisms underlying the response of the model to a productivity shock. To the purpose of confronting the response of the model with data, we will now refer to the Home (Foreign) country as the Euro Area (US). Figure 1 presents the Impulse Response Functions (IRF) following a temporary increase in technology of 1-unit standard deviation in the US. In order to isolate the mechanisms inherent to the model, we consider a shock that only hits the Foreign country ($\psi = 0$ in equation (11)). Variables are expressed in absolute deviations from steady state.

[15]Profits can be rewritten as $\frac{\Pi_t}{P^c_t} = \left[Y_t\left(f_t - \frac{f_t}{Z_t}\right)\right]$, where $f_t \frac{Y_t}{Z_t} = \frac{W_t}{P_t} N_t + r_t K_{t-1}$. By using the above definition of X^c_t, the budget constraint becomes thus the current account equation, (17), $e^r_t b^*_t + X^c_t = R^F_{t-1} b^*_{t-1} e^r_t + [Y_t f_t]$

Figure 1: US positive technological shock



3.2.1 Local propagation of local shocks

In response to a positive local technology shock in US, the US economy expands. The economic mechanisms are well known: the marginal productivity of labor and that of capital spike, triggering an increase in capital and labor demand (see equations (13) and (12)). As capital is a predetermined variable, labor adjusts first. Since the shock is persistent, investment is boosted and the capital stock k^* builds up. On the supply side, the increase in real wages prompts households to supply more labor (see eq. (3)) because the leisure-labor substitution effect is greater than the positive wealth effect. Analogous considerations apply for capital. Capital adjustment costs slow the process of capital accumulation while the price of capital increases (see eq. (7)).

The positive technology shock generates a fall in the production price of US goods and a decrease in $tot*$ (export prices fall with respect to import prices). This triggers a switching effect in favor of US goods that, together with the expansionary effects of the shock itself, boosts US consumption (c^*). The increase in US investment plus the switching effects in favor of US production trigger a trade-balance surplus and further raise output (y^*). Not surprisingly, in contrast to the data, the model delivers a pro-cyclical trade balance (see Table 2, line "BKK", column (4)). We will discuss this point in what follows.

3.2.2 International spillover of shocks

The shock hitting the US is transmitted endogenously to the EA. On the one hand, because of the expansionary effects of the shock, US agents' behavior has an impact also on the EA (entailing feedback effects). On the other hand, the terms of trade dynamics following the shock trigger both wealth and expenditure switching effects in both countries. We now describe the economic mechanisms behind the transmission across countries.

High consumption correlation Figure 1 shows that consumption increases in both countries. The implied international correlation of consumption is thus very large, which is counterfactual (0.76 in the model versus 0.38 in the data, see Table 2, line "BKK", column (2)). Indeed, because of the improvement of terms of trade, EA consumers enjoy a positive wealth effect. In addition, by substituting EA with US consumption, they can afford more consumption. This is not surprising as equation (9) links international consumption levels with the real exchange rate. The adjustment of relative demands in response to exchange rate movements is called "expenditure switching effects". The magnitude of this effect is regulated by the elasticity of substitution between Foreign and Home produced goods.

In addition, consumption behaviors are accommodated by investment decisions. To grasp intuition behind the high co-movement of international consumption levels, let us first consider a simple framework with complete markets, log utility and PPP (so that $e_t^r = 1$ at all times). Equation (9) becomes the risk sharing condition

$$\frac{C_t}{C_{t+1}} = \frac{C_t^*}{C_{t+1}^*} \tag{19}$$

Indeed, through international assets trade, consumption growth is equalized across countries.[16] In response to a local positive productivity shock, the household in the booming

[16] With generic specification of the utility function, the path of marginal utilities of consumption is equalized among countries in all periods. When calibration is symmetrical, with equal initial share of world wealth at the steady state, equation (19) even leads to $C_t = C_t^*$, i.e. the international consumption co-movement equals 1.

economy transfers wealth to the other household. Each period, thanks to international assets, the world production is shared among the households of both countries who are then insured against local shocks each period. As a result, consumption increases in both countries following a country-specific shock. By combining equation (4) and (12), we obtain

$$\frac{1}{C_t} = \beta E_t \left\{ \frac{1}{C_{t+1}} \alpha f_{t+1} \frac{Y_{t+1}}{K_t Z_{t+1}} \right\} \tag{20}$$

Further combining (20) and (19) we see that the marginal product of capital is equalized across countries. As in Backus et al. (1992), in response to a positive technological shock in one country, all resources are attracted to the most productive country. This is because, in presence of complete markets, the world production is shared among households in both countries. With perfect consumption risk sharing, the efficient shift of resources implies that capital shall go to the most productive location, which maximizes world production. As stressed by Heathcote & Perri (2014), production efficiency interacts with consumption efficiency.

Table 2: International business cycles: Stylized facts

		Cross-country correlations			net exports	UIP	BS
		y,y*	c,c*	i,i*	TB*/y*,y*	β^{UIP}	c-c*,e^r
		(1)	(2)	(3)	(4)	(5)	(6)
Data		0.53	0.38	0.38	-0.56	-0.006	-0.19
BKK		0.28	0.76	0.70	0.08	0.99	0.99
NK		0.65	0.79	0.75	0.13	0.95	0.96
FF	FIRE	0.56	0.82	0.95	0.18	0.97	0.97
	HIB	0.43	0.39	0.47	-0.58	0.70	0.77

"Data": AWM data, 1973Q1–2014Q4 for the Euro Area; US FRED for the US. See Appendix B. "UIP" presents the coefficient of the estimation in equation (1). "Cross-country correlations" presents the international correlation of investment i, output y, consumption c and the cyclicality of the trade balance over GDP, tb^*/y^*. "BS": Backus & Smith (1993*a*) correlation between relative consumption across countries and real exchange rate e^r. "BKK" is the two-country Walrasian model with incomplete markets (without financial frictions and without nominal rigidities). "NK" stands for the New Keynesian model (with nominal rigidities but without financial frictions). "FF" refers to Financial Frictions. "HIB": Predictions from model with Home Information Bias and adaptive learning. "FIRE": Predictions from model with full information and rational expectations. Simulation results are provided after technology shocks (1000 simulations of the model of 100 periods' length).

More generally, when the Purchasing Power Parity (PPP) does not hold, and the calibration is symmetrical with equal initial share of world wealth at the steady state, equation (19) generalizes to the standard complete-markets risk sharing equation:

$$\frac{U'^{*}_{ct}}{U'_{ct}} = e^r_t \tag{21}$$

that is at the roots of the above discussed expenditure switching effects linking international consumption with the real exchange rate. This condition simply says that consumption should be temporarily higher where its cost is lower. However, as first emphasized by Backus & Smith (1993*b*) and Kollmann (1995), this does not hold in the data (see Table 2, line "data", column (6)). The correlation between cross-country consumption and real exchange rate actually appears negative in the data, while the theory predicts a high a positive correlation between relative consumption and the real exchange rate (equation (21)). The Backus & Smith (1993*b*) puzzle relates to the inability of the model to capture large departures from perfect risk sharing.

Financial imperfections such as incomplete markets can introduce a wedge into this mechanism (see Kehoe & Perri (2002)). Indeed, by rewriting equation (9), we obtain:

$$E_t\left\{\frac{U'_{ct}}{\beta U'_{ct+1}}\right\} = E_t\left\{\left[\frac{U^{*\prime}_{ct}}{\beta U^{*\prime}_{ct+1}} + \zeta\left(e^{-b^*_t+\bar{b}} - 1\right)\right]\frac{e^r_{t+1}}{e^r_t}\right\} \tag{22}$$

Equation (22) shows that in a bond economy, the intertemporal *path* of consumption is equalized among countries, in expectations, once we take into account for the *path* of real exchange rate changes, $\frac{e^r_{t+1}}{e^r_t}$ (and here additional wedges such as the risk premium on external debt). Although the expected marginal rates of intertemporal consumption substitution tends to be equated, ex post, fast-growing countries will enjoy faster consumption growth than slow-growing countries. However, Figure 1 suggests that unexpected changes in real exchange rate are not large enough to introduce any significant disconnect between US and EA consumption. Indeed, consumption co-movement across countries remains large in the model, which is counterfactual (see Table 2, line "BKK", column (2)).[17]

[17] Specific calibrations can improve the performance of the model. By introducing non-stationary technology shocks and no productivity spillovers among countries into a one-good model, Baxter & Crucini (1995*b*) can match a correlation of international consumption levels that is lower than the one of output, but obtain a counterfactual negative correlation of investment across countries. Indeed, when shocks are permanent, households benefiting from the shock increase both consumption and investment together with their demand for international borrowing so that the interest rate rises. As risks are not shared, residents of the Foreign country do not benefit from the shock. However, in order to meet the international demand for funds, they supply more labor and save more in international bonds (but less in physical capital).

Low output co-movement We recall that, in each country, output is defined by a Cobb-Douglass production function of capital and labor inputs together with exogenous Total Factor Productivity (equation (10)). TFP shocks are country-specific and in this exercise they only hit the US. In what follows, we discuss how, because of *asymmetric dynamics of capital and labor*, output co-movement in response to TFP shocks is low, as in Figure 1. This is at the roots of a too low international correlation of output with respect to the empirical evidence. Moreover, contrarily to the data (see Table 2, line "BKK", column (1)[18]), the international correlation of output is significantly smaller than the one of consumption, confirming the existence of the "quantity anomaly" emphasized by Backus & Kydland (1995) in their complete-markets environment.

Asymmetric capital movements In the above analysis, we have discussed how "production efficiency" implies capital to flow towards the most productive country. This has the potential to introduce very asymmetric evolutions of capital stocks among countries, thereby driving asymmetric output co-movement. In the benchmark model, capital flight is mitigated by imperfect risk sharing and capital adjustment costs. As emphasized by Ambler et al. (2002), introducing capital adjustment costs instead of time-to-build *à la* Backus & Kydland (1995) makes capital adjustments very sluggish, which helps the model reduce the international flight of capital towards the most productive country. This pushes in favor of a positive international correlation of investment (which is too high compared with the data, see Table 2, line "BKK", column (3)).

Asymmetric labor movements In response to a US positive technological shock, EA labor supply falls. Indeed, EA households benefit from strong and positive wealth effects associated to the improvement of their terms of trade. We have discussed the impact of these wealth effects on consumption. In order to understand the economic intuition of labor dynamics, let us now assume common preferences across countries, separable log utility function (such as $logC_t + \gamma_H log(1 - N_t)$), and complete markets. Equations (3), (13) and (19) thus write:

$$(1 - N_t^*) \frac{f_t^*}{Z^*} A_t^* (K_{t-1}^*)^{\alpha} (N_t^*)^{-\alpha} = (1 - N_t) \frac{f_t}{Z} A_t K_{t-1}^{\alpha} (N_t)^{-\alpha} \tag{23}$$

[18]The IRF on Figure 1 suggest that the model's predicted international output correlation should be zero. However, the model's simulated GDP co-movement (Table 2, line "BKK", column (1)) is 0.28. This is due to the exogenous technological spillover ψ in equation (11) that is set to 0 in Figure 1 to illustrate the economic mechanisms, as above mentioned. Notice however that ψ is set to 0.30 in the simulations (see Appendix B). As the model predicts a GDP co-movement of 0.28 (i.e., approximately the calibrated exogenous spillover of shocks), this illustrates the failure of the model to generate endogenous transmission of shocks.

On impact, as capital is predetermined, only labor supply reacts to the shock in each country. In the US, the positive technological shock A^* is the dominant force pushing up the left-hand side of equation (23). This implies that the right-hand side of equation (23) shall increase as well. This is made possible by a combination of a decrease in EA labor supply, N_t with an improvement in terms of trade (pushing up $\frac{f_t}{Z}$). This positive wealth effect pushing up EA consumption also leads to lower labor supply in the EA and thus to asymmetric labor dynamics among countries. This underlines the importance of studying output and consumption correlations jointly.[19]

Trade balance counter-cyclicality Figure 1 shows that, in response to the local increase in productivity, the US trade balance improves. This implies in turn that the trade balance is pro-cyclical, in contrast to the data (see Table 2, line "BKK", column (4)). It happens because, in response to the shock, current income is higher than permanent income and is expected to return quickly to long-run level. Therefore, both the trade balance and the current account absorb the shock: households save(borrow) with positive(negative) shocks.[20] We rewrite equation (18) for the US economy as follows:

$$tb_t^* = Y_t^* \frac{P_{Ft}^*}{P_t^{*c}} - C_t^* - I_t^* - \frac{\varpi}{2} \left(\frac{I_t^*}{K_t^*} - \delta \right)^2 K_t^* \tag{24}$$

It is straightforward to see in equation (24) the interplay of effects in response to the shock. On the one hand the technology shock pushes up local output, Y_t^*. On the other hand, it dampens the relative price of the US produced good, $\frac{P_{Ft}^*}{P_t^{*c}}$, while pushing up US absorption.

The size of parameter ρ_A, the persistence of technological shocks, is key in determining the resulting change in the trade balance. To ensure a decrease in the trade balance, we need an increase in output today that creates expectations of even higher output in the future through the accumulation of capital. When ρ_A is large, agents expect the increase in productivity to last during several periods and decide to exploit it by increasing investment significantly. Analogously, because of consumption smoothing, they increase also consumption. The size of adjustment costs also plays a role. The greater they are, the smaller the jumps in investment (and the resulting increase in expected output) and the more likely to obtain a pro-cyclical trade balance. Finally, the response of relative prices to the shock also plays a role, which is

[19] As asymmetric labor changes translate into more asymmetric consumption changes, non-separability between consumption and leisure as in by Devereux et al. (1992) can also generate low consumption correlation. In the same vein, Stockman & Tesar (1995) introduce asymmetric taste shocks in consumption decisions to the aim of dampening international consumption risk-sharing.

[20] The less persistent the shock, the more volatile the current account.

magnified in presence of price rigidities (see Section 5).

Exchange rate dynamics and the UIP The productivity shock makes US production cheaper and thus triggers a terms of trade deterioration and a depreciation of the US real exchange rate. This entails a negative correlation between terms of trade and the real exchange rate (see also Figure 1), that contrasts with Atkeson & Burstein (2008)'s empirical results. In fact, they find that the terms-of-trade deterioration and the real exchange-rate depreciation are only weakly positively correlated, and terms of trade exhibit a lower volatility. Generally, as first emphasized by Obstfeld & Rogoff (2001), exchange rate dynamics in the data seem to be disconnected from the fundamentals of the economy. This is especially true if we focus on its correlation with respect to other macroeconomic variables. A broader view of the "exchange rate disconnect" includes additional patterns that are structural for international macro models and at odds with the empirical evidence (Itskhoki & Mukhin (2021)).[21] These open questions include the linkage among international returns of bonds. Indeed, in general equilibrium, interest rates should be equalized internationally once accounting for exchange-rate expected dynamics (the UIP). However, while standard open-economy DSGE models are built on UIP, departures from this condition have been extensively documented in the data (Engel (2016)). We will discuss UIP deviations in what follows, once our model will be enriched with nominal features and thus nominal interest rates (see sections 5 and 6).

4 Bringing models closer to the data: Trade in intermediate inputs and production chains

In this section, we review some of the solutions proposed by the literature to help the standard two-country benchmark RBC model matching the data. We will focus in particular on the production side. This branch of the literature investigates how introducing imperfections on firms' use of inputs or a multi-sectoral structure modifies the performance of the benchmark model. This strand of the literature aims in particular at increasing the international output co-movement implied by the models, thereby bringing it closer to the data. There is however not much improvement on the counterfactual high consumption synchronization that features our benchmark model.

[21] According to Itskhoki & Mukhin (2021), the above discussed Backus-Smith puzzle is part of the exchange rate disconnect phenomenon.

4.1 Constraints on production inputs

These works have explored several types of frictions featuring the production side. The intuition lies in the idea that output is driven by 3 elements (see equation (10)): country-specific TFP shocks (which are asymmetric across countries), capital (which is a state variable, but mobile across countries), and labor (which is immobile across countries). Because of the optimizing nature of agents, a positive productivity shock inevitably induces a shift of resources in favor of the most productive country. This implies in turn a negative (or too low) international correlation of inputs and output. By hindering input flows, frictions have the potential of dampening this mechanism.

4.1.1 Frictions on capital adjustment

Capital adjustment costs Following a positive technological shock in the Foreign country (US), all capital flies to the US, where marginal productivity of capital is the highest. These capital flows are important sources of negative co-movements of output and also labor (as higher capital stock raises labor productivity). As mentioned above, Ambler et al. (2002) stress that higher convex capital adjustment costs can dampen the size of asymmetric international capital flows in response to a technology shock in one country, thereby leading to increased output co-movement. Notice however that the predicted investment co-movement is too large compared to the data (see Table 2, line "BKK", column (3))[22]

Firms entry and aggregate investment in capital. Ghironi & Melitz (2005) develop a seminal 2-country DSGE model with endogenous firms entry and exit into domestic and foreign markets, respectively. Expenditures on firm creation are a tangible form of investment that contributes to the accumulation of the economy's capital stock. In the class of models *à la* Ghironi & Melitz (2005), firm creations embody households' investment while the stock of firms represents the resulting capital stock of the economy. Sunk costs and time to build as in Ghironi & Melitz (2005) or convex costs as in Fattal Jaef & Ignacio Lopez (2014) can slow the entry of firms. This hinders in turn the flow of capital towards the country hit by country-specific technological shocks. However, the model does not completely escape from the asymmetric flow of resources to the most productive location, which keeps international co-movement of firm dynamics, investment and output low. Fattal Jaef & Ignacio Lopez

[22]More generally, the specific calibration of parameters concerning the capital stock affects output co-movement. For instance, Ambler et al. (2002) point out that, with high capital depreciation, lower investment translates directly into a lower capital stock. This raises drastically its marginal productivity, thereby dampening the international productivity differentials that drive asymmetric capital movements.

(2014) find that entry and exporting decisions yield minimal departures from the standard two-country model with a representative firm. The quantity puzzle thus carries over to the class of models *à la* Ghironi & Melitz (2005).[23]

4.1.2 Frictions on labor changes

Another way to dampen the asymmetric response of output in response to country-specific technological shocks is to introduce labor frictions. Hairault (2002) incorporates search frictions into an otherwise standard two-country RBC model. As finding new workers takes time and effort, firms view their existing workforce as a capital asset. Therefore, employment cannot react abruptly to a shock, as it happens in the standard model. Given the exogenous international diffusion of local disturbances, a local technology shock hitting one country gives incentives for firms of the other country to post more vacancies. Employment rises slowly in the two countries, displaying a typical hump-shaped response, because of the time-consuming nature of the search process. Higher employment can also dampen the capital outflow from the foreign country because of higher capital productivity.

On the top of hindering asymmetric labor flows, search models have the advantage of exhibiting non-separability between consumption and labor supply. This cancels out the international positive wealth effects that are generally responsible for the asymmetric response of labor. Hairault (2002)'s findings imply that labor market frictions matter for business cycle synchronization. This suggests that labor market institutions and, more generally, institutional settings, should be taken into account when analyzing cross-country fluctuations – whether in terms of exchange rate arrangements (Sopraseuth (2003)), labor market institutions (Fonseca et al. (2010)) or financial institutions (Faia (2007*b*)).

4.2 Multi-sectoral models: production interactions

Empirical evidence suggest that international trade is a driving force behind output international co-movement. Intermediate inputs represent approximately 56% of total goods trade (Miroudot et al. (2009)). Trade flows are thus dominated by products that are not consumed but further used in the production of other goods. This suggests that trade linkages can play a major role in driving the international co-movement of output. This is confirmed by Frankel & Rose (1998), Clark & VanWincoop (2001), Baxter &

[23] The inability to solve the quantity puzzle must not lead the reader to neglect these models. Indeed, these models shed light on the margin of trade and the persistence of business cycles (Liao & Santacreu (2015)) as well as net export dynamics (Alessandria & Choi (2007)).

Kouparitsas (2005), and Kose & Yi (2006) who use macroeconomic data to gauge the impact of bilateral trade intensity on business cycle co-movement. They find that an increase in a country-pair's trade intensity is indeed associated with higher GDP correlation.

The evidence in macroeconomic data is confirmed by studies on micro-data. di Giovanni et al. (2018) examine the properties of international co-movement at the firm level and its aggregate implications. They use data covering the universe of French firm-level value-added, destination-specific imports and exports, and cross-border ownership over the period 1993-2007. There is substantial evidence of transmission of shocks through trade and multinational linkages (cross-border ownership). di Giovanni et al. (2018) stress that the aggregate correlation between French GDP with that of another country is simply a weighted sum of the correlations of firm-level total value added with that country's GDP. They then decompose aggregate co-movement of French aggregate growth (in value added) with country C's GDP growth into two components: one due to the directly connected firms[24], and one to due the rest of firms. They find that directly-connected firms account for 67% of the aggregate business-cycle correlation observed in the data. Trade linkages matter, downstream input linkages in particular.

Trade in intermediate inputs: the 2-sector 2-country model is not good enough. This literature has explored the role of intermediate inputs by extending the seminal work by Long & Plosser (1983) to an open-economy framework. This model incorporates a positive transmission of inter-sectoral fluctuations. In each sector, the production process uses inputs coming from other sectors. Therefore, a positive sectoral shock results in the expansion of the demand for goods from other sectors of the economy. Uncorrelated sectoral shocks in a dynamic closed-economy model can thus lead to positive spillover effects in other sectors via changes in the demand for intermediate inputs. The degree of substitutability of goods in the production function controls the magnitude of this phenomenon.

Extensions of Long & Plosser (1983)'s mechanisms to an open-economy context aim to explain the interdependence in production among the main industrialized countries. The hypothesis is that sectoral shocks in one country would lead to increased demand for imported intermediate inputs, which generates a positive international transmission of the cycle. Ambler et al. (2002) introduce multiple sectors and trade in intermediate goods. At a first look, their framework seems to be satisfying, as data on international GDP correlations are matched. However, their 2-sector 2-country model delivers disappointing results. In fact,

[24] An internationally-connected firm to a given country C is one that: i) exports to the foreign country C, ii) imports from C, iii) is a French affiliate of a multinational based in C or iv) is part of a French multinational that has affiliates in C.

the improvement in output co-movement implied by Ambler et al. (2002)'s model is not due to trade linkages. When all the weights on intermediate goods are set to zero in the production function (in both sectors and in both countries), the model still predicts a sizable cross-country correlation of output. Ambler et al. (2002) explain this result by pointing out to the significant role of sector disaggregation *itself* in driving the international transmission. The intuition is simple. Consider 2 countries, A and B. Each country has two sectors (1 and 2). A positive technological shocks in sector 1 of country A (i.e., sector A_1) draws resources from the other sector in the same economy (sector A_2) and from abroad (sectors B_1 and B_2). This generates a co-movement between all three sectors not being hit by the shock (A_2, B_1 and B_2), and thus increases the international output co-movement.

Trade in intermediate inputs: more elaborate models might allow for a better match with the data One might argue that the small significance of trade in intermediates to drive international output co-movements is a by-product of the model's simplicity. Zimmermann (1997) enriches thus the standard framework by accounting for a "third-country" effect.[25] To prevent symmetry constraints on output co-movement between couples of countries, Zimmermann (1997) builds a three-country model. Consider for instance France, Germany and Italy. If Germany enjoys a hike in productivity, French and Italian capital will move to Germany. Both France and Italy experience a decrease in domestic investment, implying a positive investment correlation between France and Italy. However, even the multi-country setting cannot solve the quantity anomaly. Indeed, in our example, the 3-country model is still characterized by the capital flight to the most productive country, which gives rise to lower output co-movement between Germany and its European partners. In addition, Zimmermann (1997) finds that the business cycle is transmitted mostly through exogenous innovation spillovers (ψ in equation (11)) rather than through trade.

The literature also explored the trade-co-movement nexus by investigating the *structure* of trade linkages. diGiovanni & Levchenko (2010)'s empirical investigation provides an interesting avenue for future research. Using a large cross-country, industry-level panel dataset of manufacturing production and trade, diGiovanni & Levchenko (2010) decompose changes in output co-movement into changes in input trade (vertical linkages) and other changes. They find that trade of intermediate inputs is an important driver of business cycle synchronization. They lay stress on the sizable role of cross-sector co-movement in output international correlation. As an example, let us consider the textile sector in the United States and the textile sector in the United Kingdom. The correlation of textiles production in the US with

[25]In the same spirit, his work is followed by Kose & Yi (2006), Juvenal & Santos Monteiro (2017) and Ishise (2014).

textiles production in the UK is relatively low, and the share of the textile industry in each economy is small. Therefore, *within*-sector trade does not significantly affect aggregate output co-movement. In contrast, the correlation of textiles output in the US with apparel (or machinery) output in UK is large. This infers that *cross*-sector trade and cross-sector co-movement have a sizable effect on aggregate output co-movement, through vertical linkages. diGiovanni & Levchenko (2010)'s results suggest that an open-economy RBC model with many sectors and a realistic input-output structure could help understanding the trade-co-movement conundrum. To our knowledge, such a model has not been developed yet.[26]

Networks Production linkages find an echo in the recent literature on networks and the macroeconomy. These models build input-output tables and geographic networks to track the downstream propagation of supply-side shocks. Interestingly, the amplification associated to the network-based structure can be greater than the one due to the direct effects of shocks. A shock to a single firm (or sector) can have a much greater impact on the macroeconomy because, in these models, it affects output of this firm (or sector) and of the firms that are connected to it through a network of input-output linkages. The transmission of different types of shocks through networks and industry inter-linkages have first-order implications for the macroeconomy. Not surprisingly, sectoral connections are now extensively explored as a framework to investigate macroeconomic issues, well beyond the field of international macroeconomics.[27]

Finally, it would be misleading to argue that, if shocks hitting firms (or disaggregated sectors) are idiosyncratic, they wash out when we aggregate across these units (and look at macroeconomic fluctuations) because of the law of large numbers. In fact, evidence by Gabaix (2011) shows that firm-size distribution has very fat tails so that shocks hitting the larger firms cannot be balanced out by those affecting smaller firms. Thus, the law of large numbers does not apply.[28] This opens in turn the way to sizable macroeconomic fluctuations from idiosyncratic firm-level shocks. The study of firm heterogeneity in a framework with international connections based on input-output matrices could bring interesting insights

[26]Interestingly, diGiovanni & Levchenko (2010) also use a rich set of sector and country fixed-effects to control for common aggregate shocks, similarity in sectoral structure, common currency, policy coordination, and other factors. They show that, after controlling for these factors, transmission of sectoral shocks still matters for the understanding of output co-movement. diGiovanni & Levchenko (2010)'s results then suggest that the focus in the literature on the understanding of *spillovers* is supported by empirical evidence.

[27]Bouakez et al. (2022) explore the implications of production networks on public-spending multipliers in the US.

[28]Analogously, Farhi & Baqaee (2018) show how input-output linkages can also neutralize the force of the law of large numbers because shocks hitting some sectors (that are particularly important as suppliers to other sectors) will not wash out and can translate into aggregate fluctuations.

into the output co-movement conundrum.

5 Bringing models closer to the data: Nominal rigidities and variable markups

The benchmark RBC model rules out price rigidities and assumes a perfect pass through of exchange rate changes (ERPT) into consumer prices. This contradicts Mussa (1986)'s findings showing that the real exchange rate mimics the behavior of the nominal exchange rate.[29] This fact suggests that real prices do depend on nominal ones and that nominal rigidities should play a role. In what follows, we will enrich our benchmark model so as to account for nominal rigidities and introduce the New Keynesian open-economy paradigm.[30] We will then discuss whether the introduction of nominal rigidities allows our framework to better match the evidence in Section 2.

A second point implicitly raised by Mussa (1986) when underlying the large fluctuations of the real exchange rate concerns the extent of the deviations from the Purchasing Power Parity assumption (PPP). Indeed, as emphasized by Burstein & Gopinath (2014), the PPP does not hold in the data both in relative terms (i.e., changes in prices of goods are not the same across countries once converted in the same currency), nor at a product-level.[31] As PPP deviations affect expenditure switching effects, we will provide a focus on the most common explanations provided by the literature in Appendix C.

5.1 The New-Keynesian open-economy paradigm

Following the lead of Kollmann (2001) and Chari & McGrattan (2002), a rich literature has incorporated staggering prices into RBC open-economy models.[32] We now introduce the standard New-Keynesian open economy model à la Gali & Monacelli (2005), that has become the workhorse model accounting for nominal rigidities in an open economy context. Differently from them, instead of using Calvo-type staggered price-setting, we use Rotemberg-type

[29] The analysis of Burstein & Gopinath (2014) based on recent data confirms the evidence that real exchange rates for consumer prices co-move closely with nominal exchange rates in the short and medium term. See also Itskhoki (2021).

[30] An early analysis of the Mussa's puzzle by using the standard New-Keynesian model is Monacelli (2004).

[31] Note that in our benchmark model we have assumed that the Law of One Price (LOP) holds at a good level, but the PPP does not hold at an aggregate level because of home bias. In absence of home bias the PPP holds.

[32] Among other seminal contributions see also McCcallum & Nelson (2000), Corsetti & Pesenti (2001), Clarida & Gertler (2001) and Benigno & Benigno (2003).

nominal adjustment costs because of simplicity.[33]

Our benchmark model needs thus to account for nominal costs into firm's profits in each country, , i.e., $\Pi_t(i) = Y_t(i)\left[P_{ht}(i) - P_t^w\right] - \frac{\omega_P}{2}\left(\frac{P_{ht}(i)}{P_{ht-1}(i)} - 1\right)^2 P_{ht}(i)$, where $\frac{\omega_P}{2}\left(\frac{P_{ht}(i)}{P_{ht-1}(i)} - 1\right)^2 P_{ht}(i)$ are price adjustment costs. It also requires to close the model by the mean of an interest rate rule. Contrarily to our RBC benchmark, the mark-up is no more fixed at $Z = \frac{\upsilon}{\upsilon-1}$ but is determined by the resulting Kew-Keynesian Phillips curve:

$$(\pi_{Ht} - 1)\,\pi_{Ht} = Y_t \frac{\upsilon}{\omega_P}\left[\frac{1}{Z_t} - \frac{(\upsilon - 1)}{\upsilon}\right] + \beta E_t \frac{U'_{ct+1}}{U'_{ct}}\left(\pi_{Ht+1} - 1\right)\frac{f_{t+1}}{f_t}\pi_{Ht+1} \tag{25}$$

where π_{Ht} denotes domestic-goods inflation and aggregate output, Y_t, needs to account for price adjustment costs. Notice also that agent's Euler equation is modified so that the term $\beta E_t \frac{U'_{ct+1}}{U'_{ct}}$ into (25) is as well affected by aggregate inflation, i.e., $\beta E_t\left[R_t \frac{U'_{ct+1}}{U'_{ct}\pi_{t+1}}\right] = 1$. By combining agents' Euler equations we obtain the UIP condition $R_t = E_t\left\{R_t^F \frac{e_{t+1}}{e_t}\right\}$, that can be rewritten as:

$$E_t\left[\frac{U'_{ct}}{U'_{ct+1}}\frac{e_t}{e_{t+1}}\pi_{t+1}\right] = \beta\left\{E_t\left[\frac{U^{*\prime}_{ct}}{\beta U^{*\prime}_{ct+1}}\pi^*_{t+1}\right] + \zeta\left(e^{-b_t^* + \bar{b}} - 1\right)\right\} \tag{26}$$

so as to track both aggregate inflation rates in each country, π and π^*, and the evolution of the nominal exchange rate.

The structure of nominal rigidities and their interaction with other frictions has important implications for the optimal design of monetary policies. Corsetti et al. (2010) among others provide an overview of the very rich literature studying monetary policies in an open-economy, that is beyond the scope of this article. What is important here is that by affecting prices, nominal rigidities also modify the international transmission of *non-monetary* disturbances such as productivity shocks. Indeed, by entering into Euler equations, output determination and markups, they have the potential to modify agents' responses to shocks. Notice that all these terms interact via the above Phillips curve. In response to a Foreign (US) technological shock, Foreign prices decrease slowly, implying a smaller (and hump-shaped) terms-of-trade deterioration and thus a smaller expenditure switching effect in favor of Foreign goods.[34] The decrease in Foreign inflation is then exported abroad (i.e., to the EA). On the financial side, interest rates are tightly related to inflation through interest-rate rules and are linked internationally via the UIP.

[33] We have followed Monacelli (2009) and calibrated the Rotemberg adjustment-cost parameter so as to imply an average frequency of price adjustment of one quarter as with Calvo-type adjustment costs.

[34] In contrast, asymmetric price rigidities have the potential of changing the nature of expenditure switching effects.

However, while providing an useful framework for policy analysis, NK price rigidities *alone* are not enough to solve the above mentioned empirical puzzles (see also Itskhoki & Mukhin (2022) and Itskhoki (2021)). Table 2 (line "NK", column (1)) shows that nominal rigidities entail a greater international correlation of output (0.65) with respect to the standard RBC model (0.28). This is because in response to a positive Foreign productivity shock, prices decrease less, entailing a smaller expenditure switching effect. Thus, the Foreign country benefits from a smaller increase in output even if the international correlation of capital investment increases. This explains why even if the domestic-country (i.e., EA) wealth effect associated to an improvement in terms of trade is smaller, consumption is too highly correlated, as for the RBC model (Table 2, line "NK", column (2)). This also explains why the trade balance reacts pro-cyclically, in contrast to the data (Table 2, line "NK", column (4)). There are no significant deviations from the UIP nor an improvement in the match of risk sharing (see 2, line "NK", columns (5) and (6)). In sections 6.1 and 6.2, we will discuss possible directions to improve the match with data.

6 Bringing models closer to the data: Financial frictions at the frontier

6.1 Financial frictions

Following the seminal works of Bernanke et al. (1999) and Kiyotaki & Moore (1997) a rich literature has introduced financial imperfections into dynamic general equilibrium macroeconomic models. In open economy, because of the financial accelerator mechanism, financial frictions can amplify and transmit disturbances towards the real economy via the exchange rate. Moreover, as emphasized by Maggiori (2022), the exchange rate assumes the potential of becoming a source of shocks hitting the real economy, rather than a shock absorber only (see also Pavlova & Rigobon (2008) and Itskhoki & Mukhin (2021) among others).

Driving on Baxter & Crucini (1995*a*) and Heathcote & Perri (2002)'s result that restrictions on financial assets' trade can entail a greater international correlation of output, Iacoviello & Minetti (2006) introduce collateral constraints into a two-country model.[35] Their model is able to reproduce the international correlation of output. However, the international

[35] Among others, other examples of models with financial frictions à la Kiyotaki & Moore (1997) in an open-economy framework are Faia & Iliopulos (2011) and Guerrieri et al. (2013). The literature stemming from overborrowing considerations as in Mendoza (2002), Mendoza (2010), Uribe (2006), Jeanne & Korinek (2010), Bianchi (2011), Benigno et al. (2013) among others is beyond the scope of this work.

correlation of consumption remains too large with respect to the data. In the same spirit, Faia (2007*a*) introduces financial frictions à la Bernanke et al. (1999) to solve the output correlation puzzle.[36]

We now modify our benchmark NK model so as to account for financial frictions as Faia (2007*a*). Domestic (foreign) entrepreneurs have access to loans from domestic (foreign) banks to finance their production activity. Because of a costly state verification problem, entrepreneurs' credit conditions are the result of an optimal loan contract established by the bank, subject to a financial friction. Indeed, entrepreneurs finance the purchase of new capital partly with external funding and pay a positive external finance premium to have access to it. There is indeed a positive spread between entrepreneurs' rate and the safe interest rate, $E_t \frac{R_{t+1}^k}{R_t}$, that captures the existence of monitoring costs.

As Faia (2007*a*), the new benchmark model is featured by a positive *financial spillover* that is transmitted internationally. Table 2 (line "FF FIRE", column (3)) shows how financial frictions push up the international correlation of investment in physical capital. Indeed, in response to a positive productivity shock in the Foreign country (i.e., the US), the associated decrease in inflation in the Foreign country is exported to the domestic country (the EA), as in the standard NK model. As lower inflation entails lower interest rates and, thus, lower credit costs, it also triggers an investment boom in the domestic country (EA). The investment co-movement is however too large (0.95) compared to the data (0.38). While output correlation is in line with the data, the international correlation of consumption remains too high (Table 2, line "FF FIRE", columns (1) and (2)). As the UIP condition equation (26) is not modified, the international financial opportunities for risk sharing are still to large. Indeed, beyond the wedge associated to closing incomplete markets model (already present in our RBC benchmark model), changes in international consumption are still tightly liked to changes in the real exchange rate, which is the Backus & Smith (1993*a*) puzzle. Not surprisingly, contrarily to the data, the trade balance is pro-cyclical (Table 2, line "FF FIRE", column (4)).

6.2 The open-economy macro frontier with finance

The exchange rate is a key variable for the *international transmission* of shocks in open economies because it is at the heart of the above-discussed expenditure switching effects and international risk sharing. Moreover, it plays a dual role as it represents the relative price of

[36]Other examples of open-economy models with Bernanke et al. (1999)' frictions include Faia (2007*b*), Kolasa & Lombardo (2014), Christiano et al. (2010) and Christiano et al. (2011).

international production and international assets. It acts thus also as a linkage between the real economy and financial markets.

A closer look at international risk-sharing. The macroeconomic open-economy literature has extensively studied ways to overcome the inability of the above macroeconomic models to track the lack of international risk-sharing (Backus-Smith puzzle) and, more in general, the fact that the real exchange rate tightly mimics the nominal exchange rate and seems disconnected from macroeconomic fundamentals (the exchange rate disconnect). An important contribution in this literature is Corsetti et al. (2008) who show that, with a combination of a very low trade-elasticity parameter and large distribution costs (driving further down the global trade elasticity), it is possible to increase the volatility of the real exchange rate implied by their model, but only up to 75% of the empirical one. This modeling device also allows them to introduce large wealth effects in response to positive technological shocks helping to modify international risk sharing and solve the Backus-Smith puzzle. With low trade elasticity, a domestic increase in tradable production cannot be absorbed by an increase in world demand at low prices, as with standard expenditure switching effects. The domestic terms of trade (and the real exchange rate) need thus to appreciate so as to absorb the increase of domestic production. Alternatively, Benigno & Thoenissen (2008) solve the Backus-Smith puzzle with strong Balassa-Samuelson effects that drive up domestic consumption and appreciate the real exchange rate. The mechanisms however contradict the evidence in Engel (1999).

Segmented currency markets and financial wedges. Flirting with the frontier between international macroeconomics and international finance, Maggiori (2022) introduces financial frictions entailing segmented currency markets. This assumption modifies the structure of the UIP so as to allow his model to explain the exchange rate disconnect and carry trade. Indeed, because of limited risk-bearing capacity of global financiers, their demand for assets is modified and currency markets are segmented: the lower risk-bearing capacity, the more segmented the assets market. This entails an endogenous wedge so that the UIP condition does not hold. In the same vein, Itskhoki & Mukhin (2021) introduce an asymmetric financial wedge, ψ_t (i.e., an exogenous spread between the effective returns on foreign bonds for home versus foreign households) into a standard NK model to explain several puzzles associated to the exchange rate disconnect. The financial wedge structurally breaks the UIP, equation (26), so that the RHS of the equation minus its LHS are equal to ψ_t. When properly calibrated, the financial wedge allows the model to reproduce salient features of exchange rates but co-movements in macroeconomic aggregates are not analyzed.

Portfolio theories. A rich literature in international finance has studied exchange-rate dynamics because of their role in globalized financial markets. As remarked by Maggiori (2022), on a theoretical front, there is a revived interest into portfolio theories trying to explain the witnessed dramatic breakdown of the Covered Interest Parity (CIP) condition starting from 2007, a central condition for the absence of arbitrage. The impact of expectation errors on interest rate differentials and the UIP has been examined in several papers (Gourinchas & Tornell (2004), 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 & Evans (2008) use a simplified exchange-rate model with adaptive learning to explain the forward premium puzzle. Evans & 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.

Information matters. Iliopulos et al. (2021) build a bridge between the open-economy macroeconomic literature and international finance. They introduce home information bias (HIB) in agents' expectations into an otherwise standard NK open-economy model with financial frictions à la Bernanke et al. (1999). The HIB assumption is supported by empirical evidence surveyed in their work according to which both households and investors follow national and local news more closely than international ones. Moreover, investors who know more about local economic conditions exploit the informational advantage so as to specialize in collecting domestic information and obtain greater excess returns. Iliopulos et al. (2021) take HIB as given, and explore the impact of information asymmetries in a 2-country model. Because of imperfect information, domestic agents focus only on local information and observe their terms of trade improvement after a positive technology shock abroad. They do not observe foreign variables and interpret the response to the shock 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 full information case and seek to invest abroad. In practice, HIB is incorporated into the model through adaptive learning. It is a powerful mechanism affecting expectations' formation in the UIP equation (26) and thus, agents' risk sharing.

To see it more clearly, consider a simple two-periods framework with perfect foresight. HIB enters the model as a 'cognitive' parameter $0 < M < 1$, as in Gabaix (2020). M is a proxy for HIB as it captures the extent of agents' inattention to foreign variables. M brings agents to perceive the foreign interest factor as MR^F. When $M = 1$, domestic households are fully informed about the Foreign interest rate. When $M = 0$, domestic households are not informed about the Foreign interest rate. This entails the following modified UIP condition:

$$R_1 = M \frac{e_2}{e_1} R_1^F$$

When $0 < M < 1$, the foreign interest rate R^F is not perfectly known by domestic investors and the UIP does not hold.

HIB allows the model to generate endogenous departure from UIP. Under HIB, Iliopulos et al. (2021) obtain a UIP coefficient of 0.70 (Table 2, line "FF HIB", column (6)). Given that the estimated coefficient hovers around zero in the data (Table 2, line "Data", column (6)) and around 1 under full information (Table 2, line "FF FIRE", column (6)), the model can explain approximately 30% of departure from UIP, which is significant and robust to different specification of nominal or financial frictions.

Table 2 shows how, consistently with the economic mechanisms explained here above, HIB allows the model to solve for the quantity puzzle: output international correlation matches the data and it is significantly greater than the one of consumption. This is because the positive effects of a local technology shock are not tracked by the foreign country so that the response of foreign agents' consumption is dampened, even if their terms of trade improve. Moreover, 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. In Iliopulos et al. (2021), 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. Consistently with the reduced consumption correlation, the model also predicts lower investment correlation, which makes the model's predictions closer to the data (Table 2, line "FF HIB", column (3), investment co-movement is 0.47 versus 0.95 under full-information, and 0.38 in the data). This mechanism goes in the same direction but is of different nature with respect to the one in Corsetti et al. (2008). In their work, 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.

Finally, by introducing an endogenous wedge into the UIP, the HIB mechanism helps to explain the Backus-Smith puzzle by lowering the correlation between relative consumption and the real exchange rate. Iliopulos et al. (2021) do not investigate the potential of their framework to explain other puzzles related to the exchange rate disconnect.

We conclude this section by highlighting promising avenues in the literature. While they have been explored by a very large literature, several above-mentioned puzzles are still open questions for future research. Answering to them will eventually require an unified framework being able to reconcile exchange rate dynamics with developments on both the financial and production sides of open economies. The above recent works are promising examples accounting for the impact of information asymmetries and financial frictions on international risk sharing.

7 Conclusion

In this chapter we have introduced the standard RBC open-economy framework for economic analysis. We have analyzed its building blocks, the implied economic mechanisms and confronted it to the data. We have then enriched the model so as to account for the main developments proposed by the literature in order to overcome its limits in matching data. We have first analyzed the production side of the model to understand what mechanisms are key in reproducing stylized facts. We have then considered possible frictions affecting agents decisions, such as standard price rigidities and financial frictions.

We conclude the analysis by emphasizing the key role of the exchange rate in driving international spillovers, both by absorbing international shocks and being at the roots of amplifications (Maggiori (2022)). We have thus analyzed promising recent contributions closing the gap between standard macro models of open economy and international finance. These works account for factors having the potential to modify the structure of international risk sharing, such as information asymmetries and financial frictions. As Itskhoki (2021), we believe that a full understanding of open-economy cycles requires an unified framework properly reconciling exchange rate dynamics with developments on both the financial and production sides of open economies. We leave this promising challenge open for future research.

References

Alessandria, G. & Choi, H. (2007), 'Do sunk costs of exporting matter for net export dynamics?', *Quarterly Journal of Economics* **122**, 289–336.

Ambler, S., Cardia, E. & Zimmermann, C. (2002), 'International transmission of the business cycle in a multi-sector model', *European Economic Review* **46**, 273–300.

Atkeson, A. & Burstein, T. (2008), 'Trade costs, pricing-to-market, and international relative prices', *American Economic Review* **98**(5), 1998–2031.

Backus, D., Kehoe, P. & Kydland, F. (1992), 'International real business cycles', *Journal of Political Economy* **100**(4), 745–775.

Backus, D., Kehoe, P. & Kydland, F. (1994), 'Dynamics of the trade balance and the terms of trade: the j-curve?', *The American Economic Review* **84**(1), 84–103.

Backus, D. Kehoe, P. & Kydland, F. (1995), International real business cycles: Theory versus evidence, *in* T. Cooley, ed., 'Frontiers of Business Cycle Research', Princeton University Press, pp. 213–231.

Backus, D. & Smith, G. (1993*a*), 'Consumption and real exchange rates in dynamic economies with non-traded goods', *Journal of International Economics* **35**(3).

Backus, D. & Smith, G. (1993*b*), 'Consumption and real exchange rates in dynamic economies with non-traded goods', *Journal of International Economics* **35**, 297–316.

Baxter, M. & Crucini, M. (1995*a*), 'Business cycles and the asset structure of foreign trade', *International Economic Review* **36**(4), 821–854.

Baxter, M. & Crucini, M. J. (1995*b*), 'Business cycles and the assets structure of foreign trade', *International Economic Review* **36**(4), 821–854.

Baxter, M. & Kouparitsas, M. (2005), 'Determinants of business cycle comovement: a robust analysis', *Journal of Monetary Economics* **52**(1), 113–157.

Benigno, G. & Benigno, P. (2003), 'Price stability in open economies', *Review of Economic Studies* **70**(4), 743–764.

Benigno, G., Chen, H., Otrok, C., Rebucc, A. & Young, E., R. (2013), 'Financial crises and macro-prudential policies.', *Journal of International Economics* **89**(2), 453–470.

Benigno, G. & Thoenissen, C. (2008), 'Consumption and real exchange rates in dynamic economies with non-traded goods', *Journal of International Money and Finance* **27**(6), 926–948.

Bernanke, B., Gertler, M. & Gilchrist, S. (1999), The financial accelerator in a quantitative business cycle framework, *in* J. B. Taylor & M. Woodford, eds, 'Handbook of Macroeconomics', Vol. 1, Elsevier, pp. 1341–1393.

Bianchi, J. (2011), 'Overborrowing and systemic externalities in the business cycle.', *American Economic Review* **101**, 3400–3426.

Bouakez, H., Rachedi, O. & Santoro, E. (2022), 'The government spending multiplier in a multi-sector economy', *American Economic Journal: Macroeconomics* (forthcoming).

Burstein, A. & Gopinath, G. (2014), International prices and exchange rates, *in* G. Gopinath, E. Helpman & K. Rogoff, eds, 'Handbook of International Economics', Vol. 4, Elsevier, pp. 250–289.

Caballero, J. (2010), 'Macroeconomics after the crisis : Time to deal with the pretense-of-knowledge syndrome', *Journal of Economic Perspectives* **24**(4), 85–102.

Cavallo, M. & Ghironi, F. (2002), 'Net foreign assets and the exchange rate: Redux revived', *Journal of Monetary Economics* **49**(5), 1057–1097.

Chakraborty, A. & Evans, G. (2008), 'Can perpetual learning explain the forward-premium puzzle?', *Journal of Monetary Economics* **55**, 477–490.

Chari, V. V., K. P. & McGrattan, E. (2002), 'Can sticky price models generate volatile and persistent exchange rates?', *Review of Economic Studies* **69**(3), 533–563.

Christiano, L., Rostagno, M. & Motto, R. (2010), Financial factors in economic fluctuations, Working Paper Series 1192, European Central Bank.

Christiano, L., Trabandt, M. & Walentin, K. (2011), 'Introducing financial frictions and unemployment into a small open economy model', *Journal of Economic Dynamics and Control* **35**, 1999–2041.

Clarida, R., G. J. & Gertler, M. (2001), 'Optimal monetary policy in open vs. closed economies: An integrated approach', *American Economic Review* **91**(2), 248.

Clark, T. & VanWincoop, E. (2001), 'Borders and business cycles', *Journal of International Economics* **55**(1), 59.

Cole, H. & Obstfeld, M. (1991), 'Commodity trade and international risk sharing: How much do financial markets matter?', *Journal of Monetary Economics* **28**, 3–24.

Corsetti, G., Dedola, L. & Leduc, S. (2008), 'International risk sharing and the transmission of productivity shocks', *The Review of Economic Studies* **75**(2), 443–473.

Corsetti, G., Dedola, L. & Leduc, S. (2010), Optimal monetary policies in open economies, *in* F. B. M., ed., 'Handbook of Monetary Economics', North-Holland, pp. 722–783.

Corsetti, G. & Pesenti, P. (2001), 'Welfare and macroeconomic interdependence', *Quarterly Journal of Economics* (2), 421–446.

Devereux, M., Gregory, A. & Smith, G. (1992), 'Realistic cross-country consumption correlations in a two-country equilibrium business cycle model', *Journal of International Money and Finance* **11**, 3–16.

di Giovanni, J., Levchenko, A. & Mejean, A. (2018), 'The micro origins of international business-cycle comovement', *American Economic Review* **108**(1), 82–108.

diGiovanni, J. & Levchenko, A. (2010), 'Putting the parts together: Trade, vertical linkages, and business cycle comovement', *American Economic Journal: Macroeconomics* **2**(2), 95–124.

Engel, C. (1999), 'Accounting for u.s. real exchange rate changes.', *Journal of Political Economy* **107**(3), 507–538.

Engel, C. (2014), Exchange rates and interest parity, *in* G. Gopinath, E. Helpman & K. Rogoff, eds, 'Handbook of International Economics', Vol. 4, Elsevier, pp. 453–522.

Engel, C. (2016), 'Exchange rates, interest rates, and the risk premium', *American Economic Review* **106**(2), 436–474.

Evans, D. & Lyons, R. (2002), 'Order flow and exchange rate dynamics', *Journal of Political Economy* **110**(11), 170–180.

Faia, E. (2007*a*), 'Finance and international business cycles', *Journal of Monetary Economics* **54**, 1018–1034.

Faia, E. (2007*b*), 'Financial differences and business cycle co-movements in a currency area', *Journal of Money, Credit and Banking* **39**(1), 151–185.

Faia, E. & Iliopulos, E. (2011), 'Financial openness, financial frictions and optimal monetary policy', *Journal of Economic Dynamics and Control* **35**(11), 1976–1996.

Farhi, E. & Baqaee, D. (2018), Macroeconomics with heterogeneous agents and input-output networks, NBER Working Paper 24684.

Fattal Jaef, R. & Ignacio Lopez, J. (2014), 'Entry, trade costs, and international business cycles', *Journal of International Economics* **94**, 224–238.

Fonseca, R., Patureau, L. & Sopraseuth, T. (2010), 'Business cycle comovement and labor market institutions: An empirical investigation', *Review of International Economics* **18**(5), 865–881.

Frankel, J. & Rose, A. (1998), 'The endogenity of the optimum currency area criteria', *Economic Journal* **108**(449), 1009–1025.

Gabaix, X. (2011), 'The granular origins of aggregate fluctuations', *Econometrica* **79**(3), 733–772.

Gabaix, X. (2020), 'A behavioral new keynesian model', *American Economic Review* **110**(8), 2271–2327.

Gali, J. & Monacelli, T. (2005), 'Monetary policy and exchange rate volatility in a small open economy', *Review of Economic Studies* **72**, 707–734.

Ghironi, F. & Melitz, M. (2005), 'International trade and macroeconomic dynamics with heterogeneous firms', *Quarterly Journal of Economics* **120**(3), 865–915.

Gourinchas, P. & Tornell, A. (2004), 'Exchange rate puzzles and distorted beliefs', *Journal of International Economics* **64**(2), 303–333.

Guerrieri, L., Iacoviello, M. & Minetti, R. (2013), Banks, sovereign debt and the international transmission of business cycles, Vol. 9, University of Chicago Press, pp. 339–412.

Hairault, J. (2002), 'Labor-market search and international business cycles', *Review of Economic Dynamics* **5**, 535–558.

Heathcote, J. & Perri, F. (2002), 'Financial autarky and international business cycles', *Journal of Monetary Economics* **49**(3), 601–627.

Heathcote, J. & Perri, F. (2014), Assessing international efficiency, *in* G. Gopinath, E. Helpman & K. Rogoff, eds, 'Handbook of International Economics', Vol. 4, Elsevier, pp. 523–584.

Iacoviello, M. & Minetti, R. (2006), 'International business cycles with domestic and foreign lenders', *Journal of Monetary Economics* **53**(8), 2267–2282.

Iliopulos, E., Perego, E. & Sopraseuth, T. (2021), 'International business cycles: Information matters.', *Journal of Monetary Economics* **123**, 19–34.

Ilut, C. (2012), 'Ambiguity aversion: Implications for the uncovered interest rate parity puzzle', *American Economic Journal: Macroeconomics* **4**(3), 33–65.

Ishise, H. (2014), The world has more than two countries: Implications of multi-country international real business cycle models, Manuscript.

Itskhoki, O. (2021), 'The story of the real exchange rate', *Annual Review of Economics* **13**, 423–455.

Itskhoki, O. & Mukhin, D. (2021), 'Exchange rate disconnect in general equilibrium', *Journal of Political Economy* **129**(8), 2183–2232.

Itskhoki, O. & Mukhin, D. (2022), Mussa puzzle redux., Nber working paper no. 28950.

Jeanne, O. & Korinek, A. (2010), 'Excessive volatility in capital flows: A pigouvian taxation approach', *American Economic Review* **100**(2), 403–407.

Juvenal, L. & Santos Monteiro, P. (2017), 'Trade and synchronization in a multi-country economy', *European Economic Review* **92**, 385–415.

Kehoe, P. & Perri, F. (2002), 'International business cycle models with endogenous incomplete markets', *Econometrica* **70**, 907–928.

Kiyotaki, N. & Moore, J. (1997), 'Financial frictions and optimal monetary policy in an open economy', *The Journal of Political Economy* **105**(2), 211–248.

Kolasa, M. & Lombardo, G. (2014), 'Financial frictions and optimal monetary policy in an open economy', *International Journal of Central Banking* **10**(1), 43–94.

Kollmann, R. (1995), 'Consumption, real exchange rates and the structure of international asset markets', *Journal of International Money and Finance* **14**(2), 191–211.

Kollmann, R. (2001), 'The exchange rate in a dynamic-optimizing business cycle model with nominal rigidities : a quantitative investigation', *Journal of International Economics* **55**, 243–262.

Kose, A. & Yi, M. (2006), 'Can the standard international business cycle model explain the relation between trade and comovement?', *Journal of International Economics* **68**, 267–295.

Liao, W. & Santacreu, A. (2015), 'The trade comovement puzzle and the margins of international trade', *Journal of International Economics* **96**, 266–288.

Long, J. & Plosser, C. (1983), 'Real business cycles', *Journal of Political Economy* **91**, 39–69.

Maggiori, M. (2022), International macroeconomics with imperfect financial markets, *in* G. Gopinath, E. Helpman & K. Rogoff, eds, 'Handbook of International Economics', Vol. 6, elsevier, pp. 199–236.

McCcallum, B. & Nelson, E. (2000), 'Monetary policy for an open economy: An alternative framework with optimizing agents and sticky prices', *Oxford Review of Economic Policy* **16**, 74–91.

Mendoza, E., G. (2002), Credit, prices, and crashes: Business cycles with a sudden stop., *in* S. Edward & J. A. Frankel, eds, 'Preventing Currency Crises in Emerging Markets. NBER Conference Report series', University of Chicago Press, pp. 335–383.

Mendoza, E., G. (2010), 'Sudden stops, financial crises, and leverage.', *American Economic Review* **100**(5), 1941–1966.

Miroudot, S., Lanz, R. & Ragoussis, A. (2009), Trade in intermediate goods and services, OECD Trade Policy Paper 93.

Monacelli, T. (2004), 'Into the mussa puzzle: Monetary policy regimes and the real exchange rate in a small open economy', *Journal of International Economics* **62**, 191–217.

Monacelli, T. (2009), 'New keynesian models, durable goods, and collateral constraints', *Journal of Monetary Economics* **56**(2), 242–254.

Mussa, M. (1986), Nominal exchange regimes and the behavior of real exchange rates: evidence and implications., Carnegie-rochester conference series on public policy.

Obstfeld, M. & Rogoff, K. (2001), The six major puzzles in international macroeconomics: Is there a common cause?, *in* B. Bernanke & K. Rogoff, eds, 'NBER Macroeconomics Annual 2000', Vol. 15, MIT Press, pp. 339–412.

Pavlova, A. & Rigobon, R. (2008), 'The role of portfolio constraints in the international propagation of shocks', *The Review of Economic Studies* **75**(4), 1215–1256.

Schmitt-Grohe, S. & Uribe, M. (2003), 'Closing small open economy models', *Journal of International Economics* **61**(1), 163–185.

Sopraseuth, T. (2003), 'Exchange rate regimes and international business cycles: Theory and evidence', *Review of Economic Dynamics* **6**, 338–361.

Stockman, A. & Tesar, L. (1995), 'Tastes and technology in a two-country model of the business cycle: Explaining international comovements', *The American Economic Review* **85**(1), 168–185.

Uribe, M. (2006), 'On overborrowing.', *American Economic Review* **96**(2), 417–421.

Uribe, M. & Schmitt-Grohe, S. (2017), *Open Economy Macroeconomics*, Princeton University Press.

Zimmermann, C. (1997), 'International real business cycles among heterogeneous countries', *European Economic Review* **41**(2), 319–356.

Appendix

A Data

A.1 US

Quarterly US data is downloaded from FRED Economic data, from the Federal Reserve bank of Saint Louis.

GDP is Real Gross Domestic Product, Billions of Chained 2012 Dollars, Quarterly, Seasonally Adjusted Annual Rate.

Consumption is Real Personal Consumption Expenditures, Billions of Chained 2012 Dollars, Quarterly, Seasonally Adjusted Annual Rate.

Nominal interest rate is 3-Month Treasury Bill: Secondary Market Rate, Percent, Quarterly, Not Seasonally Adjusted.

GDP deflator is the Gross Domestic Product, Implicit Price Deflator, Index 2012=100, Quarterly, Seasonally Adjusted

Labor productivity is Real Output Per Hour of All Persons, Nonfarm Business Sector, Index 2012=100, Quarterly,Seasonally Adjusted

Trade balance is net exports, NIPA's, Billions of Dollars, Quarterly, Seasonally Adjusted.

A.2 Euro Area

EA data comes from AWM (Area Wide Model) dataset, available online from the Euro Area Business Cycle Network website.

We use the following quarterly time series: real GDP, Real private consumption, Nominal exchange rate (euro per USD), Nominal short-term interest rates. GDP Deflator, Index, Index base year 1995 ($1995 = 1$), defined as the ratio of nominal, and real gross domestic product (GDP).

Labor Productivity: Calculated as the ratio of real GDP, and total employment (Thousands of persons, Calendar and seasonally adjusted data.) (LPROD = YER / LNN).

B Calibration

Our calibration is the one in Iliopulos et al. (2021) that we report in what follows for clarity. 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 (2007), Christiano et al. (2010), Christiano et al. (2014), Kolasa & Lombardo (2014)). Parameter values lie thus within the range found in the literature. Table 3 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[37] and the share of foreign goods into the domestic basket, γ, is equal to 0.3 consistently with Faia (2007). The elasticity of substitution among varieties υ 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 α is set to 0.40 and the capital depreciation rate is 0.025 as in CMR among others. The capital adjustment costs parameter Φ is set to 5.2 in line with Kolasa & Lombardo (2014) and so as to ensure that the volatility of consumption is lower that the one of investment in both countries, as Faia (2007).

The monitoring cost parameter μ is set equal to 0.21, based on Christiano et al. (2014), which is in the range of the values chosen by Faia (2007) (between 0.07 and 0.3). The interest rate premium parameter, ζ, is 0.000742 as in Schmitt-Grohe & Uribe (2003). The share of surviving entrepreneurs lies between 0.97 in Faia (2007) and 0.985 in CMR. We set $\varsigma = 0.978$ as in Kolasa & 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 & Lombardo (2014), Christiano et al. (2014), Faia (2007).

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

[37] 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.

parameter is $\chi = 0.8$ in both countries, as in Faia (2007) 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 (2007).

Table 3: Calibration

Parameter		Value	Reference
β	discount factor	0.9887	CMR (2014)
σ	elasticity of intertemporal substitution	2	KL (2014)
Ψ	disutility of labor	2.6	Labor normalized at 1/3 at ss
γ	share of foreign goods in domestic basket	0.3	KL (2014)
η	elasticity of substitution home-foreign goods	1.5	Faia (2007)
υ	elasticity of substitution between varieties	6	CMR (2014)
α	production function	0.4	CMR (2014)
δ	capital depreciation	0.025	CMR (2014)
ϕ	capital adjustment costs	5.2	KL (2014)
ω_p	Rotemberg parameter	35.84	CMR (2014), Monacelli (2009)
μ	monitoring cost	0.21	CMR (2014)
σ_ω	sd idiosyncratic productivity	0.26	CMR (2014), KL (2014)
ζ	interest rate premium parameter	0.000742	SGU (2003)
b^*	steady state Net Foreign Asset	0	SGU (2003)
ς	share of surviving entrepreneurs	0.978	KL (2014)
χ	weight on lagged int. rate into Taylor Rule	0.8	Faia (2007)
b_π	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)
ρ_A	persistence technology shock	0.9	Faia (2007)
σ_A	standard deviation technology shock	0.008	Faia (2007)
$corr(\epsilon^a, \epsilon^{a_*})$	cross-correlation technology shocks	0.30	Faia (2007)

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

C PPP deviations

Our analysis of the benchmark RBC model has highlighted how international efficiency requires that changes in prices are the same across countries as long as costs of making goods available are the same (this is straightforward in equations (20) and (19)). At the same time, as emphasized by Burstein & Gopinath (2014), while deviations in relative PPP can be explained by the fact that firms charge different markups across locations, the way prices react to exchange-rate changes depends also on the exchange rate pass through (ERPT). Both do affect international expenditure switching effects in response to shocks.

When firms price goods in the domestic currency (producer currency pricing, PCP) as we have assumed until now, the ERPT is complete so that all changes in nominal exchange rates are transmitted to the foreign country. A domestic depreciation entails an expenditure switching in favor of domestic goods and a deterioration of domestic terms of trade. In contrast, if prices are set in the foreign currency (local currency pricing, LCP), the ERPT is not complete.[38] In practice, this require firms to account for foreign-currency prices into the definition of profits. When prices are sticky in the destination-currency market, there are short-term deviations from the LOP: there is no expenditure switching because a nominal depreciation does not make cheaper goods for the producer country nor foreign goods more expensive. In their article, Burstein & Gopinath (2014) provide conditions for individual firms to choose LCP vs PCP as a function of the desired path of dynamic pass-through. They also point out to the possibility of multiple equilibria in the currency pricing decision, depending on the currency choice of other firms. While both LCP and PCP paradigms have appealing features, recent evidence surveyed by Gopinath & Itskhoki (2022) stresses that there is significant asymmetry in the role of currencies in trade, which is inconsistent with both the LCP and the PCP paradigm. Most countries rely on vehicle currencies, that is a currency that is neither the currency of the exporter nor of the importer. Their work opens the door to a third pricing paradigm: dominant currency pricing, (DCP).

Alternatively, a rich literature on international pricing recently surveyed by Burstein & Gopinath (2014) has used models delivering variable markups and incomplete pass-through, beyond nominal rigidities. At a firm level[39], markups Z_i are a function of the elasticity of substitution among varieties, υ and additional non-constant factors, so as to obtain a negative relationship between markups and relative prices (price of the variety versus the aggregate price). The elasticity of the relative price $\frac{P_i}{P}$ with respect to the markup, is positive and increases i) for low relative-price firms[40] or for ii) higher market-share firms[41] or iii) firms with higher distribution shares[42]. It follows that the LOP does not hold.

In the same spirit, variable markups can be obtained by incorporating consumer search (see Burdett & Judd (1983) and Alessandria (2009)). As this limits consumer arbitrage, it is possible to observe different prices across locations for the same good. Alternatively,

[38]Seminal contributions of the LCP paradigm are Betts & Devereux (2000), Devereux & Engel (2003), Bacchetta & van Wincoop (2000) and Chari & McGrattan (2002). The PCP and LCP paradigms have been surveyed by Corsetti et al. (2010) and Burstein & Gopinath (2014) among others.

[39]When prices are adjusted infrequently, firm-level changes in markups can affect both aggregate-price and quantities movements.

[40]Kimball (1995) uses an homothetic aggregator over individual varieties instead of a CES.

[41]Atkeson & Burstein (2008) introduce strategic complementarities in pricing with CES demand.

[42]Corsetti & Dedola (2005) introduce fixed distribution costs for each good.

costs may not fully pass through to prices because of adjustment costs carried by the firms to expand sales in the foreign market (see Drozd & Nosal (2012)) or the accumulation of inventories when goods are storable, firms face shipping lags and fixed costs of importing (see Alessandria et al. (2010)).

References

Alessandria, G. (2009), 'Consumer search, price dispersion and international relative price volatility.', *International Economic Review* **50**, 803–829.

Alessandria, G., Kaboski, J. P. & Midrigan, V. (2010), 'Inventories, lumpy trade, and large devaluations.', *American Economic Review* **100**, 2304–2339.

Atkeson, A. & Burstein, A. (2008), 'Trade costs, pricing-to-market, and international relative prices.', *American Economic Review* **98**(5), 1998–2031.

Bacchetta, P. & van Wincoop, E. (2000), 'Does exchange-rate stability increase trade and welfare?', *American Economic Review* **90**(5), 1093–1109.

Backus, D., Kehoe, P. & Kydland, F. (1994), 'Dynamics of the trade balance and the terms of trade: the j-curve?', *The American Economic Review* **84**(1), 84–103.

Betts, C. & Devereux, M. (2000), 'Exchange rate dynamics in a model of pricing-to-market', *Journal of International Economics* **50**(1), 215–244.

Burdett, K. & Judd, K. (1983), 'Equilibrium price dispersion.', *Econometrica* **51**, 955–969.

Burstein, A. & Gopinath, G. (2014), International prices and exchange rates, *in* G. Gopinath, E. Helpman & K. Rogoff, eds, 'Handbook of International Economics', Vol. 4, Elsevier, pp. 250–289.

Chari, V. V., K. P. & McGrattan, E. (2002), 'Can sticky price models generate volatile and persistent exchange rates?', *Review of Economic Studies* **69**(3), 533–563.

Christiano, L., Motto, R. & Rostagno, M. (2014), 'Risk shocks', *American Economic Review* **104**(1), 27–65.

Christiano, L., Rostagno, M. & Motto, R. (2010), Financial factors in economic fluctuations, Working Paper Series 1192, European Central Bank.

Corsetti, G. & Dedola, L. (2005), 'A macroeconomic model of international price discrimination.', *Journal of International Economics* **67**(1), 129–155.

Corsetti, G., Dedola, L. & Leduc, S. (2008), 'International risk sharing and the transmission of productivity shocks', *The Review of Economic Studies* **75**(2), 443–473.

Corsetti, G., Dedola, L. & Leduc, S. (2010), Optimal monetary policies in open economies, *in* F. B. M., ed., 'Handbook of Monetary Economics', North-Holland, pp. 722–783.

Devereux, M. & Engel, C. (2003), 'Monetary policy in the open economy revisited: Price setting and exchange rate flexibility', *Review of Economic Studies* **70**, 765–784.

Drozd, L. & Nosal, J. (2012), 'Understanding international prices: Customers as capital.', *American Economic Review* **102**(1), 364–395.

Faia, E. (2007), 'Finance and international business cycles', *Journal of Monetary Economics* **54**, 1018–1034.

Gopinath, G. & Itskhoki, O. (2022), Dominant currency paradigm: a review, *in* G. Gopinath, E. Helpman & K. Rogoff, eds, 'Handbook of International Economics', Vol. 6, Elsevier, pp. 45–90.

Iliopulos, E., Perego, E. & Sopraseuth, T. (2021), 'International business cycles: Information matters.', *Journal of Monetary Economics* **123**, 19–34.

Kimball, M. (1995), 'The quantitative analytics of the basic neomonetarist model.', *Journal of Money, Credit and Banking,* **27**, 1241–1277.

Kolasa, M. & Lombardo, G. (2014), 'Financial frictions and optimal monetary policy in an open economy', *International Journal of Central Banking* **10**(1), 43–94.

Monacelli, T. (2009), 'New keynesian models, durable goods, and collateral constraints', *Journal of Monetary Economics* **56**(2), 242–254.

Schmitt-Grohe, S. & Uribe, M. (2003), 'Closing small open economy models', *Journal of International Economics* **61**(1), 163–185.