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# International capital markets structure, preferences and puzzles: A "US–China World"☆

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ABSTRACT

The US–China data suggest that (i) the real exchange rate (RER) volatility puzzle (high RER volatility relative to consumption volatility), (ii) the Backus–Smith anomaly (negative correlation between the RER and consumption differentials), (iii) the consumption correlation puzzle (relatively low cross-country consumption correlation) became more severe in the aftermath of China's stock market liberalization. This indicates that international macro-anomalies do not show up exclusively among pairs of advanced economies. In an international endowment economy context, we show that the combination of recursive preferences and long-run risk allows for the simultaneous resolution of these anomalies. In contrast to standard macro models, this holds even in the presence of full financial integration, segmented goods markets and non-negligible changes in several parameter values.



## 1. Introduction

The international business cycle (IBC) literature of the last 20 years points out that the risk-sharing predictions of standard models with international complete markets do not match cross-country movements in consumption. Early studies show that a standard IBC model with complete markets encounters difficulties in matching international consumption and asset pricing data (Backus et al., 1994, 1995). In particular, it produces (i) smoothed asset prices; and (ii) an unrealistically high level of international risk-sharing. As discussed in Backus and Smith (1993), among others, this excess amount of risk-sharing gives rise to a perfect positive co-movement between RER and consumption differentials as well as between cross-country consumption growth rates. In a seminal contribution, Lewis (1996) suggests that high degrees of international risk-sharing might be generated by the non-separability of tradable and non-tradable goods in the utility function employed in the model as well as by the presence of complete markets. She concludes that capital market restrictions and non-separability are both required to explain the lack of international risk-sharing observed in the data.

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Overall, the international risk-sharing mechanism embodied in standard IBC models gives rise to three highly discussed international macroeconomic puzzles: (i) the high volatility of the RER relative to the volatility of consumption (RER volatility puzzle); (ii) the negative correlation between the RER and consumption differentials (Backus–Smith anomaly); (iii) the low correlation of consumption growth across countries (consumption correlation puzzle).[1] Further, traditional models with standard preferences do not address two well known domestic asset pricing puzzles: (i) the equity premium puzzle, EPP, (Mehra and Prescott, 1985; Mehra, 2003); (ii) the risk-free rate puzzle (Weil, 1989).

Financial integration and its implications for the resolution of both macroeconomic and asset pricing anomalies have received considerable attention in the most recent literature, much of it addressing individual anomalies (Benigno and Thoenissen, 2008; Corsetti et al., 2008; Kollmann, 2012; Hamano, 2013, among others). Relatively little research, however, has focused on the joint resolution of some of these puzzles (Bodenstein, 2008; Colacito and Croce, 2013). Benigno and Thoenissen (2008) develop a standard IBC model with non-traded goods and incomplete markets. They show that under strong complementary between domestic and foreign tradables the model reproduces the Backus–Smith correlation. Similarly, Corsetti et al. (2008) argue that international financial markets are not developed enough to generate full risk-sharing and show that standard macro models with incomplete markets may account for the Backus–Smith correlation. In particular, if there is a high level of complementary between exported and imported goods, then the model produces substantial movements in the RER as well as a negative correlation between the RER and relative consumption, and reduces the correlation between domestic and foreign consumption. However, these results are not robust to the introduction of a second trade asset (see Benigno and Kücük-Tuger, 2012).[2] Kollmann (2012) shows that the Backus–Smith anomaly can be explained by a simple model where only a fraction of households can trade assets freely in complete financial markets. Following Corsetti et al. (2008), Thoenissen (2011) shows that a standard IBC model with incomplete markets is able to solve the RER volatility puzzle, the RER persistence puzzle and the Backus–Smith anomaly. However, the success of the model heavily depends on the choice of the elasticity of substitution between domestic and foreign produced goods. In particular, the range of elasticity values that allows the model to address the macro-puzzles is very narrow, suggesting that the model's performance is not sufficiently robust. Bodenstein (2008) develops an international endowment economy with complete asset markets and limited enforcement for international financial contracts where the ability to share risk depends on the degree of patience of the agents. He shows that, if agents are sufficiently impatient (i.e. markets are incomplete), the model jointly solves the RER volatility puzzle, the Backus–Smith anomaly and the consumption correlation puzzle. In line with these studies, Hamano (2013) shows that market incompleteness (i.e. an inefficient international risk-sharing environment) is crucial for the resolution of the consumption-real exchange rate anomaly.

However, the debate on whether or not a "financial autarky" or a "single-bond economy" regimes may represent a realistic financial environment is still open. On the one hand, numerous international finance studies show that both developed and emerging (in particular Brazil, China and India) capital markets have become increasingly integrated over the last two decades (Cheung et al., 2006; Lane and Schmukler, 2007; Donadelli, 2013; Ma and McCauley, 2013; among others). For example, Fitzgerald (2012) finds that financial risk-sharing among developed countries is nearly optimal. Jappelli and Pistaferri (2011), show that the increasing degree of financial integration across international financial markets has largely improved households consumption smoothing (i.e. risk-sharing). This suggests that either a "financial autarky" or a "single-bond economy" regimes cannot be employed to model the current international capital markets structure. On the other hand, some theoretical studies directly argue that these two regimes do not represent realistic financial environments. Crucini (1999) and Santos Monteiro (2008) point out that standard incomplete markets models are problematic because they are characterized by limited consumption risk-sharing at both the domestic and international level. Kollmann (2012) argues that international capital markets allow for an almost frictionless trading activity in a large variety of securities (e.g. equities, futures, options, CDS, bonds). Heathcote and Perri (2002) stress that an efficient international trading activity is important for the cross-country business cycles.

The aim of the present paper is to compare the macroeconomic quantities and prices produced by two different international endowment economies: (i) one in which agents can trade assets for consumption smoothing purposes only domestically (i.e. financial autarky); and (ii) one where all agents are allowed to efficiently share their consumption risk by trading in complete financial markets. In other words, we ask the question whether a limited amount of international risk sharing is necessary to simultaneously solve the above mentioned international macroeconomic anomalies as well as two well known asset pricing puzzles. In addition, we examine whether these puzzles exist in the case of the US and China, an issue not previously investigated.

Our analysis is carried out by using the international endowment economy developed by Colacito and Croce (2010, 2013). In this economy, (i) home and foreign agents display recursive preferences; (ii) endowment processes embody a long-run risk component a là Bansal and Yaron (2004) and are co-integrated (see also Tretvoll, 2013). In this setup, capital markets are complete both domestically and internationally, and agents have preference for domestic goods (i.e. home bias in consumption). The choice of this model is motivated by several factors: (i) it reflects a period of increasing financial integration by assuming complete markets; (ii) it can capture both the first and second moments of asset pricing;

[1] For additional details, see Bodenstein (2008).

[2] Specifically, they say "... the performance of these models worsens considerably when we move away from a single-bond economy..." (Benigno and Kücük-Tuger, 2012, p. 562).

(iii) it accounts for consumption home bias (as suggested by international trade data); (iv) it embodies a novel risk-sharing mechanism which does not rely on any financial market imperfections.

Our paper contributes to the existing literature in several dimensions. First, it focuses on US–China data over two different periods: (i) the "financial autarky regime era" which runs from 1972 to 1990 (before China's stock market liberalization), and (ii) the "international complete markets era" which runs from 1991 to 2009 (after China's stock market liberalization). We observe that the RER volatility–consumption volatility ratio, the Backus–Smith correlation and the cross-country consumption correlation changed in the aftermath of China's equity market liberalization. In particular, the RER-volatility puzzle and the Backus–Smith anomaly became more apparent in the mid-90s. Therefore, international macro puzzles may arise also among developed and emerging countries. Second, as in Bodenstein (2008), it is aimed at addressing the RER volatility puzzle, the Backus–Smith puzzle and the low consumption correlation puzzle simultaneously. We show that the employed two country/two-good model with recursive preferences, long-run risk and complete markets can address the puzzles simultaneously, even if there are no financial market imperfections.[3] By contrast, a moderate amount of home bias in consumption is required. Third, it examines the robustness of the model and shows that the results hold for a relatively large range of parameter values. In particular, realistic changes in the RRA, IES, consumption home bias parameter and cross-country long-run shocks correlation only weakly affect the RER-consumption volatility ratio, the Backus–Smith correlation and the cross-country consumption growth correlation.

The rest of the paper is organized as follows. Section 2 presents some stylized facts for China and the US. Section 4 outlines the model. Section 4 discusses the results. Section 5 concludes.

## 2. The background of the US–China relationship

### 2.1. Why US–China?

Most international finance, RBC and IBC studies have focused exclusively on developed economies (or Western, Educated, Industrialized, Rich, and Democratic, WEIRD, societies). As suggested by Heinrich et al. (2010), these papers implicitly assume that there is no variation across countries (i.e. human populations). However, low–middle income societies account for more than 80% of the World population. In particular, (i) China accounts for 20% of the World population; (ii) the sum of US and China GDPs is almost one third of the World's GDP.[4] At present, the literature on macroeconomic anomalies in emerging economies is rather thin. With this study, we also aim to fill this gap at least to some extent.[5]

The Chinese stock market was closed for nearly half a century and reopened less than 25 years ago. In the late 1980s, China transformed many state-owned-enterprises into stock companies. The first stock market in the history of the People's Republic of China, the Shanghai Stock Exchange, opened on November 26, 1990. Shenzhen Stock Exchange opened on April 11, 1991, and initially only one class of shares (public A shares) were allowed to trade on Qualified Foreign Institutional Investor (QFII). This allows us to analyze two different international capital market regimes, a financial autarky one (i.e. before 1991) and a complete markets one (i.e. after 1991). Specifically, we estimate the RER volatility–consumption volatility ratio, correlation between RER and consumption differentials, and cross-country consumption correlation over two different sub-samples: (i) pre-liberalization era (i.e. 1972–1990); (ii) post-liberalization era (i.e. 1991–2009). Consequently, international macroeconomic quantities and prices are computed by imposing these two different regimes.

### 2.2. US–China stylized facts

Fig. 1 suggests that these two countries have substantially increased their degree of openness toward international markets after 1990, and that fluctuations of their currencies have significantly increased after capital market liberalizations. This is clear from the dynamics of the ratios of the sum of US and China trade to world trade and the sum of US-owned assets abroad and foreign-owned assets in the US to the sum of US and China's GDPs. Both measures are increasing over time (Fig. 1, top-left panel). We argue that the increasing degree of integration across both equity and goods markets has also largely influenced the RER volatility–consumption volatility ratio and the Backus–Smith correlation.[6] The former has increased sharply (Fig. 1, top-right panel), whereas the latter has significantly decreased (Fig. 1, bottom-left panel).[7] The ratio between the RER and consumption volatility is constantly above one. Over the post-liberalization period the average is 5.2, a much higher value than the one usually produced by standard macro models. The correlation between RER and real consumption growth differentials declined sharply immediately after 1990 and started to become negative in the mid-90's

[3] This is in stark contrast to Bodenstein (2008), whose model requires an inefficient international risk-sharing environment to address macroeconomic anomalies.

[4] *Source*: World Development Indicators (World Bank).

[5] In this respect, our work is most closely related to Jahan-Parvar et al. (2013).

[6] Donadelli and Paradiso (2014) show that full risk-sharing (i.e. the presence of perfectly integrated markets) tends to produce a relatively high RER volatility.

[7] Two facts are noteworthy for the dynamics of the RER volatility–consumption volatility ratio and Backus–Smith correlation: (i) the Renminbi (RMB) has appreciated by almost 38% since 1994 even if China adopted a fixed exchange rate regime; (ii) a managed floating exchange rate system in China started on July 21st 2005.

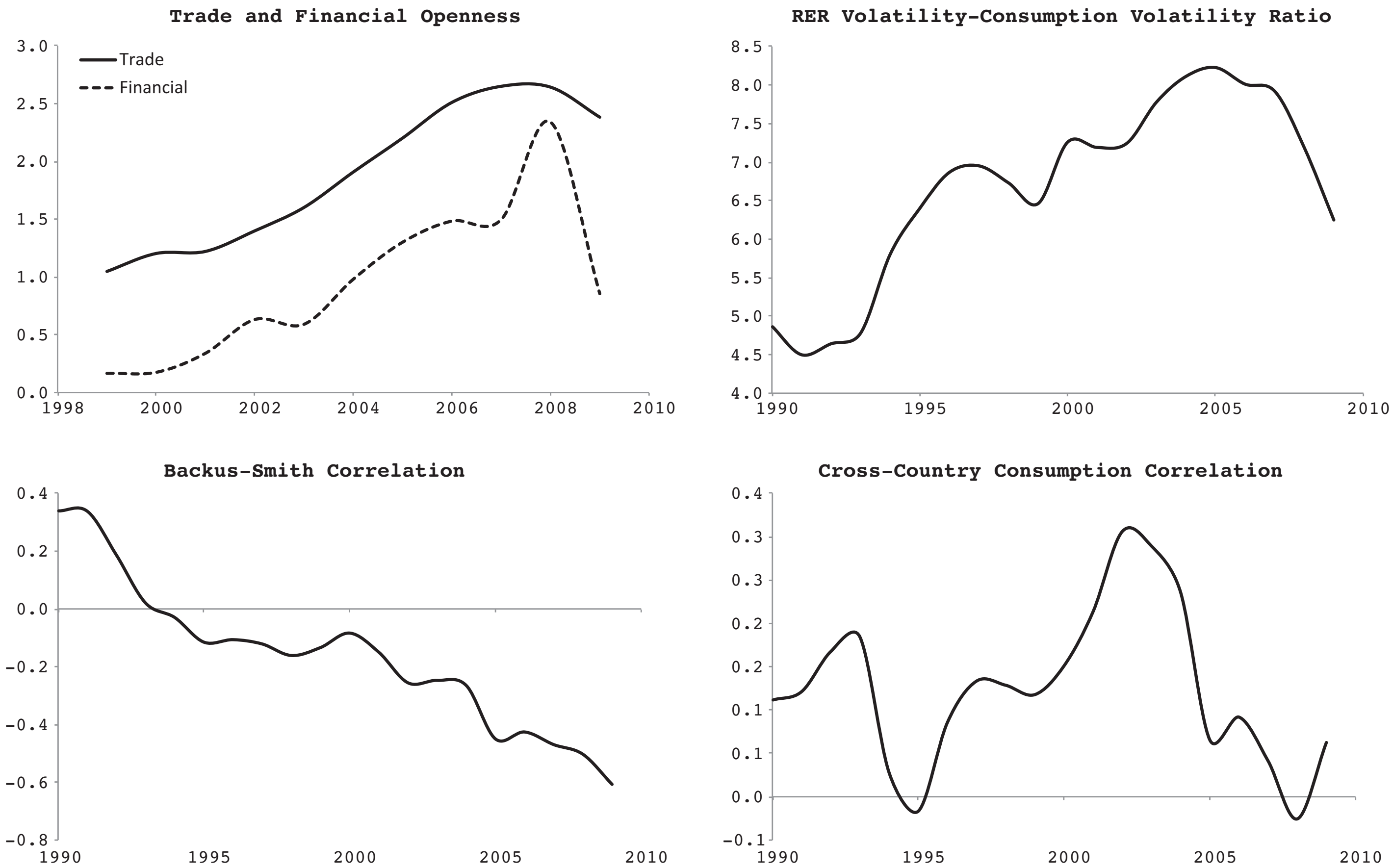


**Fig. 1.** Financial and trade openness vs. puzzles. *Notes*: trade openness (TO) is defined as follows: TO=EI/GDP, where EI represents the sum of exports and imports of the US and China, and GDP is the sum US and China GDPs. Financial openness is defined as follows: FO=(USOA+FOA)/GDP where USOA denote US-owned assets abroad (i.e. in China), FOA are China-owned assets in the United States. The ratio between the RER volatility and consumption growth volatility, the correlation between the RER and consumption differentials and the cross-country consumption correlation are computed using a rolling window of 20 years. Details on data sources are given in Appendix A.

(Fig. 1, bottom-left panel). In particular, it is positive under financial autarky (0.34 over the period 1972–1990), and negative after the equity market liberalization (−0.56 over the period 1991–2009). At odds with the results of a standard IBC model with complete markets, the correlation between the US and China real consumption growth rates is well below one (Fig. 1, bottom-right panel). However, we observe a sharp increase over the period 1995–2003 (i.e. after liberalization), which appears to be due to a rapid expansion of financial and trade linkages across the US and China (Fig. 1, top-left panel). Still, the consumption correlation puzzle seems to be more severe if emerging and developed economies are jointly considered.

## 3. The model

This section describes an international endowment economy along the lines of Colacito and Croce (2010, 2013). Many elements of the model are standard in the long-run risk literature (see for example Bansal and Yaron, 2004; Bansal et al., 2012; and Beeler and Campbell, 2012) as well as in the IBC literature (see for example Tretvoll, 2013 and Grüning, 2014). What is new is that prices and quantities are computed under several scenarios, which, among others, include different degrees of economic and financial integration, and cross-country long-run shocks comovement. This allows us to test the robustness of the model in addressing macroeconomic anomalies.

### *3.1. Consumption structure*

The economy comprises two countries, home (H) and foreign (F), and two goods $G_h$ and $G_f$. The home (foreign) country is endowed with good $G_H$ ($G_F$). In our world, the home country is the US. The agents' preferences are defined over a consumption aggregate of both home and foreign goods. Formally,

$$C_{h,t} = (g^h_{h,t})^{\alpha}(g^h_{f,t})^{1-\alpha} \tag{1a}$$

$$C_{f,t} = (g^f_{h,t})^{1-\alpha}(g^f_{f,t})^{\alpha} \tag{1b}$$

where $C_{h,t}$ ($C_{f,t}$) is the consumption aggregate in the home (foreign) country, $g^h_{h,t}$ ($g^f_{h,t}$) and $g^h_{f,t}$ ($g^f_{f,t}$) denote the consumption of good $G_h$ and good $G_f$ in the home (foreign) country at time $t$, and $\alpha \in (0, 1)$ represents the home bias parameter.

### *3.2. Preferences*

#### *3.2.1. Standard preferences*

First, as in canonical studies, we assume standard preferences:

$$U_{h,t} = \frac{C^{1-\gamma}_{h,t} - 1}{1-\gamma} \tag{2a}$$

$$U_{f,t} = \frac{C^{1-\gamma}_{f,t} - 1}{1-\gamma} \tag{2b}$$

where $\gamma$ captures relative risk aversion (RRA).

#### *3.2.2. Recursive preferences*

In the second part of our analysis we turn our attention to a scenario where households are equipped with recursive preferences:

$$U_{h,t} = [(1-\delta)(C_{h,t})^{1-\gamma/\theta} + \delta E_t[(U_{h,t+1})^{(1-\gamma)}]^{1/\theta}]^{\theta/1-\gamma} \tag{3a}$$

$$U_{f,t} = [(1-\delta)(C_{f,t})^{1-\gamma/\theta} + \delta E_t[(U_{f,t+1})^{(1-\gamma)}]^{1/\theta}]^{\theta/1-\gamma} \tag{3b}$$

where $0 < \delta < 1$ is the subjective discount factor and $\delta^{-1} - 1$ the rate of time preference, $\theta = 1 - \gamma/1 - 1/\psi$, and $\psi$ is the intertemporal elasticity of substitution. In this setup, if $\gamma - 1/\psi > 0$, households care about future uncertainty.[8]

[8] This preference specification is consistent with recent experimental studies. Specifically, the recent experimental work of Brown and Kim (2014) reveals that most subjects display relative risk aversion greater than the reciprocal of the elasticity of intertemporal substitution, confirming that they exhibit preferences for early resolution of uncertainty.

### 3.3. Endowments

As in Tretvoll (2013), endowments are cointegrated processes. In addition, they embody a long-run risk component. Formally,

$$\begin{aligned}\Delta \log G_{\mathrm{h},t} &= \mu + \omega_{\mathrm{h},t-1} + \tau(\log G_{\mathrm{f},t-1} - \log G_{\mathrm{h},t-1}) + \epsilon^{\mathrm{SR}}_{\mathrm{h},t}\\ \Delta \log G_{\mathrm{f},t} &= \mu + \omega_{\mathrm{f},t-1} + \tau(\log G_{\mathrm{h},t-1} - \log G_{\mathrm{f},t-1}) + \epsilon^{\mathrm{SR}}_{\mathrm{f},t}\\ \omega_{\mathrm{h},t} &= \rho_{\mathrm{h}}\omega_{\mathrm{h},t-1} + \epsilon^{\mathrm{LR}}_{\mathrm{h},t}\\ \omega_{\mathrm{f},t} &= \rho_{\mathrm{f}}\omega_{\mathrm{f},t-1} + \epsilon^{\mathrm{LR}}_{\mathrm{f},t}.\end{aligned} \tag{4}$$

where $\mu$ is the long-run endowment growth rate, $\tau \in (0, 1)$ denotes the co-integration parameter, $\omega_{\mathrm{h},t}$ and $\omega_{\mathrm{f},t}$ are highly persistent AR(1) processes, $\epsilon^{\mathrm{SR}}_{\mathrm{h},t}$ and $\epsilon^{\mathrm{SR}}_{\mathrm{f},t}$ are short-run shocks, and $\epsilon^{\mathrm{LR}}_{\mathrm{h},t}$ and $\epsilon^{\mathrm{LR}}_{\mathrm{f},t}$ are long-run shocks. Shocks are distributed as follows

$$\underbrace{\begin{pmatrix}\epsilon^{\mathrm{SR}}_{\mathrm{h},t}\\ \epsilon^{\mathrm{SR}}_{\mathrm{f},t}\\ \epsilon^{\mathrm{LR}}_{\mathrm{h},t}\\ \epsilon^{\mathrm{LR}}_{\mathrm{f},t}\end{pmatrix}}_{\Xi} \sim i.i.d.N\left(\underbrace{\begin{pmatrix}0\\0\\0\\0\end{pmatrix}}_{\mathbf{0}}, \underbrace{\begin{pmatrix}\sigma^2_{\epsilon^{\mathrm{SR}}_{\mathrm{h}}} & \sigma_{\epsilon^{\mathrm{SR}}_{\mathrm{h}},\epsilon^{\mathrm{SR}}_{\mathrm{f}}} & 0 & 0\\ \sigma_{\epsilon^{\mathrm{SR}}_{\mathrm{f}},\epsilon^{\mathrm{SR}}_{\mathrm{h}}} & \sigma^2_{\epsilon^{\mathrm{SR}}_{\mathrm{f}}} & 0 & 0\\ 0 & 0 & \sigma^2_{\epsilon^{\mathrm{LR}}_{\mathrm{h}}} & \sigma_{\epsilon^{\mathrm{LR}}_{\mathrm{h}},\epsilon^{\mathrm{LR}}_{\mathrm{f}}}\\ 0 & 0 & \sigma_{\epsilon^{\mathrm{LR}}_{\mathrm{f}},\epsilon^{\mathrm{LR}}_{\mathrm{h}}} & \sigma^2_{\epsilon^{\mathrm{LR}}_{\mathrm{f}}}\end{pmatrix}}_{\Omega}\right)$$

where $\Xi$ is vector of shocks and $\Omega$ represents the variance–covariance matrix of the cross-country short- and long-run shocks.

### 3.4. Capital market structure and optimal allocations

#### 3.4.1. Financial autarky

As suggested by Cole and Obstfeld (1991), in a financial autarky regime trade in the goods market takes place and it must be balanced in every period. Formally, the budget constraint for the home and foreign country:

$$g^{\mathrm{h}}_{\mathrm{h},t} + p_t g^{\mathrm{h}}_{\mathrm{f},t} = G_{\mathrm{h},t} \tag{5a}$$

$$g^{\mathrm{f}}_{\mathrm{h},t} + p_t g^{\mathrm{f}}_{\mathrm{f},t} = p_t G_{y,t} \tag{5b}$$

where $p_t$ is the price of good $G_{\mathrm{f},t}$ in terms of good $G_{\mathrm{h},t}$. Under financial autarky agents cannot trade securities internationally. In practice, markets are complete only domestically. Therefore, there is no room for international consumption smoothing. This capital market structure gives rise to the following optimal allocation

$$g^{\mathrm{h}}_{\mathrm{h},t} = \alpha G_{\mathrm{h},t}, g^{\mathrm{f}}_{\mathrm{h},t} = (1-\alpha)G_{\mathrm{h},t} \tag{6a}$$

$$g^{\mathrm{h}}_{\mathrm{f},t} = (1-\alpha)G_{\mathrm{f},t}, g^{\mathrm{f}}_{\mathrm{f},t} = \alpha G_{\mathrm{f},t} \tag{6b}$$

In this setup, the real exchange rate is simply represented by the home-bias adjusted current relative supply of the home and foreign goods. Formally,

$$\Delta e_t = (2\alpha - 1)(\Delta g_{\mathrm{h},t} - \Delta g_{\mathrm{f},t}) \equiv \Delta c_{\mathrm{h}} - \Delta c_{\mathrm{f}} \tag{7}$$

#### 3.4.2. Complete markets

In order to emphasize that the resolution of the puzzles does not rely on any financial market imperfections, we also account for complete and frictionless markets (i.e. full risk-sharing). Complete markets are almost invariably assumed in international finance and IBC studies (Colacito and Croce, 2010; Ready et al., 2013, among others). Such environment is supported by recent studies showing that risk-sharing via financial markets is nearly optimal, and that trade frictions in goods markets are not negligible (Fitzgerald, 2012). However, the debate on whether emerging and developed financial markets are fully integrated is still open. One may argue that the US–China capital market are still incomplete and embody frictions. Anyhow, similar to other works (see Bacchetta and van Wincoop, 2013; Ready et al., 2013; Tretvoll, 2013), the model accounts for partial risk-sharing by means of good markets frictions.

Under market completeness the following home and foreign budget constraints hold:

$$g^{\mathrm{h}}_{\mathrm{h},t} + p_t g^{h}_{\mathrm{f},t} + \sum_{s_{t+1}} P_{t+1}(s^{t+1})A_{\mathrm{h},t+1}(s^{t+1}) \le G_{\mathrm{h},t} + A_{\mathrm{h},t} \tag{8a}$$

$$g^{\mathrm{f}}_{\mathrm{h},t} + p_t g^{f}_{\mathrm{f},t} + \sum_{s_{t+1}} P_{t+1}(s^{t+1}) A_{\mathrm{f},t+1}(s^{t+1}) \le p_t G_{\mathrm{f},t} + A_{\mathrm{f},t} \tag{8b}$$

where $A_{\mathrm{h},t}(s^t)$ ($A_{\mathrm{f},t}(s^t)$) denotes the claim of country home (foreign) to time $t$ consumption of good $G_{\mathrm{h},t}$, and $P_{t+1}$ is the state-contingent price (i.e. the price of one unit of $t+1$ consumption contingent on the realization of $s^{t+1}$ at time $t+1$). In equilibrium, the following holds:

$$A_{\mathrm{h},t} + A_{\mathrm{f},t} = 0 \quad \forall t.$$

The efficient allocation is the solution of a planner's problem choosing a sequence of allocations $\{g^{\mathrm{h}}_{\mathrm{h},t}, g^{\mathrm{f}}_{\mathrm{h},t}, g^{\mathrm{h}}_{\mathrm{f},t}, g^{\mathrm{f}}_{\mathrm{f},t}\}_{t=0}^{+\infty}$ to maximize

$$Q = W_{\mathrm{h}} U_{\mathrm{h},0} + W_{\mathrm{f}} U_{\mathrm{f},0}$$

subject to the following feasibility constraints:

$$g^{\mathrm{h}}_{\mathrm{h},t} + g^{\mathrm{f}}_{\mathrm{h},t} = G_{\mathrm{h},t}; \quad g^{\mathrm{h}}_{\mathrm{f},t} + g^{\mathrm{f}}_{\mathrm{f},t} = G_{\mathrm{f},t} \quad \forall t \ge 0$$

where $W_{\mathrm{h}}$ and $W_{\mathrm{f}}$ are the date $t=0$ non-negative Pareto weights attached to the consumer by the planner. By assuming $S_t = W_{\mathrm{h},t}/W_{\mathrm{f},t}$, the first order conditions of the social planning problem give rise to the following optimal allocation[9]

$$g^{\mathrm{h}}_{\mathrm{h},t} = \alpha G_{\mathrm{h},t}\left[1 + \frac{(1-\alpha)(S_t-1)}{1-\alpha+\alpha S_t}\right], \quad g^{\mathrm{f}}_{\mathrm{h},t} = (1-\alpha) G_{\mathrm{h},t}\left[1 + \frac{\alpha(S_t-1)}{1-\alpha+\alpha S_t}\right] \tag{9a}$$

$$g^{\mathrm{h}}_{\mathrm{f},t} = (1-\alpha) G_{\mathrm{f},t}\left[1 + \frac{\alpha(S_t-1)}{\alpha+(1-\alpha) S_t}\right], \quad g^{\mathrm{f}}_{\mathrm{f},t} = \alpha G_{\mathrm{f},t}\left[1 + \frac{(1-\alpha)(S_t-1)}{\alpha+(1-\alpha) S_t}\right] \tag{9b}$$

where

$$S_t = S_{t-1}\frac{M_{\mathrm{h},t}}{M_{\mathrm{f},t}}\left(\frac{e^{\Delta c_{\mathrm{h},t}}}{e^{\Delta c_{\mathrm{f},t}}}\right)$$

and $M_{\mathrm{h},t}$ ($M_{\mathrm{f},t}$) is the home (foreign) stochastic discount factor. In the presence of full financial integration, the RER growth is equal to the difference between the log of the foreign and domestic stochastic discount factors.

$$\Delta e = \log M_{\mathrm{f},t} - \log M_{\mathrm{h},t} \tag{10}$$

### 3.5. The stochastic discount factor

#### 3.5.1. Standard preferences

CRRA preferences imply the following stochastic discount factor

$$M_{\mathrm{h},t+1} = \delta\left(\frac{C_{\mathrm{h},t+1}}{C_{\mathrm{h},t}}\right)^{-\gamma} \tag{11a}$$

$$M_{\mathrm{f},t+1} = \delta\left(\frac{C_{\mathrm{f},t+1}}{C_{\mathrm{f},t}}\right)^{-\gamma} \tag{11b}$$

for the home and foreign country, respectively.

#### 3.5.2. Recursive preferences

As shown in Epstein and Zin (1989), the stochastic discount factor in the home and foreign country takes the following form

$$M_{\mathrm{h},t+1} = \delta\left(\frac{C_{\mathrm{h},t+1}}{C_{\mathrm{h},t}}\right)^{-(1/\psi)}\left(\frac{U^{1-\gamma}_{\mathrm{h},t+1}}{E_t[U^{1-\gamma}_{\mathrm{h},t+1}]}\right)^{(1/\psi-\gamma)/(1-\gamma)} \tag{12a}$$

$$M_{\mathrm{f},t+1} = \delta\left(\frac{C_{\mathrm{f},t+1}}{C_{\mathrm{f},t}}\right)^{-(1/\psi)}\left(\frac{U^{1-\gamma}_{\mathrm{f},t+1}}{E_t[U^{1-\gamma}_{\mathrm{f},t+1}]}\right)^{(1/\psi-\gamma)/(1-\gamma)} \tag{12b}$$

[9] The detailed solution of the Pareto problem associated with this economy can be found in Colacito and Croce (2013). For a similar problem, see also Tretvoll (2013) and Grüning (2014).

**Table 1**
Benchmark calibration.

| Parameter | | Value | Parameter | | Value |
|---|---|---|---|---|---|
| $\mu$ | Endowment long-run growth rate | 2.00% | $\alpha$ | Consumption home-bias | 0.97 |
| $\sigma_{\epsilon}^{SR}$ | Short-run shock volatility | 1.87% | $\tau$ | Co-integration parameter | 0.055% |
| $\sigma_{\epsilon}^{LR}$ | Long-run shock volatility | $4.4\%\sigma_{\epsilon}^{SR}$ | $\delta$ | Subjective discount factor | 0.9825 |
| $\rho_h, \rho_f$ | Long-run component persistence | 0.985 | $\gamma$ | RRA | 8 |
| $\rho_{\epsilon_h^{LR}\epsilon_f^{LR}}$ | Long-run shocks correlation | 0.90 | $\psi$ | IES | 1.5 |
| $\rho_{\epsilon_h^{SR}\epsilon_f^{SR}}$ | Short-run shocks correlation | 0.05 | | | |

## 4. Calibration and results

Recent IBC studies argue that international consumption and financial risk sharing is incomplete (Heathcote and Perri, 2002; Bodenstein, 2008; Corsetti et al., 2008; Devereux and Yetman, 2010; Kollmann, 2012, among others). For this reason, canonical macro models with complete markets do not address classic international macroeconomic puzzles. In addition, by assuming standard preferences, frictionless and complete markets, this class of models inherits all domestic asset pricing puzzles. In this section, we demonstrate that, if agents have recursive preferences and there is a relatively high positive cross-country long-run shocks correlation and home bias in consumption, market incompleteness and financial frictions are not necessary to address the aforementioned macroeconomic puzzles. In this setup, we also solve domestic asset pricing puzzles. However, if agent's preferences are represented by power utility, the presence of complete markets only allows for the resolution of the RER volatility puzzle.

### *4.1. Benchmark calibration*

We calibrate the parameters of the long-run risk components, $\omega_{h,t}$ and $\omega_{f,t}$, in line with the long-run risk literature. In particular, we fix the persistence of $\omega_{h,t}$ and $\omega_{f,t}$ to be $\rho_h = \rho_f = 0.985$ as in Colacito and Croce (2010), and $\sigma_{\epsilon}^{LR}$ to be a small percentage of the standard deviation of endowment (i.e. $\sigma_{\epsilon}^{LR} = 0.044\sigma_{\epsilon}^{SR}$). Cross-country short- and long-run news are correlated as in Colacito and Croce (2010). As in Tretvoll (2013) and Colacito and Croce (2013), the cointegration parameter is assumed to be very small. We set $\tau = 0.055\%$. The consumption home bias parameter, $\alpha$, is equal to 0.97, suggesting that agents in the domestic country consume only 3% of foreign goods (i.e. 3% of total consumption is represented by imported goods).[10] Given the observed growth in international trade since the 80s this value may appear unrealistic. However, the average ratio between US imports from China and US total consumption is around 2% over the period 1999–2009 (source: bea.gov). It turns out that the choice of $\alpha = 0.97$ fits our US–China world, and is line with the benchmark calibration of Colacito and Croce (2013).[11] This parameter choice is also in line with Erceg et al. (2008) who show that foreign consumption goods account for only 3–5% of the US consumption. All the other parameters (i.e. $\mu$, $\delta$, $\gamma$, $\psi$) are calibrated following standard long-run risk studies (Bansal and Yaron, 2004; Bansal et al., 2012; Pancrazi, 2014) (Table 1).

### *4.2. Results: financial autarky vs. market completeness*

To examine the role of the novel risk-sharing mechanism embodied in the model, we compare the results obtained in an international complete markets regime (i.e. post-liberalization) with those obtained under financial autarky (i.e. pre-liberalization). First, we present the results of the model with standard preferences and both long-run risk and no long-run risk. Second, we turn our attention to the model with recursive preferences.[12]

#### *4.2.1. Standard preferences*

Under financial autarky, the ratio of domestic and foreign consumption determines the RER rate between two countries (see Eq. (7)). It turns out that the correlation between consumption differentials and the RER equals unity. Because of standard preferences, this holds even if there are complete markets. Of course, full risk-sharing tends to produce a high degree of comovement between domestic and foreign consumption growth rates. It is also well known that traditional macro models with power utility do not address domestic asset pricing puzzles. We review most of these findings in Table 2, which reports international macroeconomic quantities and prices estimated over the pre- and post-liberalization periods along with the results for the benchmark calibration for two different capital market structures (i.e. financial autarky and complete markets), both in the presence and absence of long-run risk.

[10] A moderate amount of consumption home bias can be found also in Thoenissen (2011) and Corsetti et al. (2008), who introduce preferences towards domestic goods in a standard IBC model with incomplete markets.

[11] For a detailed discussion on the role of home-bias in consumption and equity in a IBC context, see Tretvoll (2008).

[12] The system of equations is solved by employing the perturbation methods. We compute our policy functions using the dynare++4.3.3 package.

**Table 2**
Model vs. data: macroeconomic quantities and prices. *Notes*: this table reports the average equity premium, ERP, risk-free rate, $E(R^f)$, real exchange rate volatility–consumption growth volatility puzzle, $\sigma(\Delta e)/\sigma(\Delta c)$, the cross-country consumption growth correlation, $Corr(\Delta c_h, \Delta c_f)$, and the Backus–Smith correlation, $Corr(\Delta c_h - \Delta c_f, \Delta e)$, simulated under different international capital market structures. The risk premium is not levered. All parameters are calibrated to the values reported in Table 1. With no-LRR the long-run shock volatility and the cross-country long-run shock correlations are re-calibrated, $\sigma_\epsilon^{LR} = 0$ and $\rho_{\epsilon_h^{SR}\epsilon_f^{SR}} = 0.35$. Moments are obtained from repetitions of small-sample simulations. The ERP and $E(R^f)$ are annualized and expressed in percentage points. The pre-liberalization period runs from 1972 to 1990. The post-liberalization period runs from 1991 to 2009. Details on data sources are given in Appendix A.

| Model CRRA | Data US–China (*Pre-Lib*) | (1) Financial autarky (no LRR) | (2) Financial autarky (with LRR) | Data US–China (*Post-Lib*) | (3) Complete markets (no LRR) | (4) Complete markets (with LRR) |
|---|---|---|---|---|---|---|
| Macro quantities | | | | | | |
| $\sigma(\Delta e)/\sigma(\Delta c)$ | 4.869 | 1.115 | 1.128 | 5.259 | 5.276 | 5.094 |
| $\text{Corr}(\Delta c_h, \Delta c_f)$ | 0.112 | 0.404 | 0.392 | 0.016 | 0.784 | 0.799 |
| $\text{Corr}(\Delta c_h - \Delta c_f, \Delta e)$ | 0.338 | 1.000 | 1.000 | −0.557 | 1.000 | 1.000 |
| Asset prices | | | | | | |
| ERP | 4.357 | 0.248 | −0.207 | 7.542 | 0.190 | −0.281 |
| $E(R^f)$ | 1.458 | 16.686 | 15.921 | 0.999 | 16.850 | 16.078 |

In line with the dynamics reported in Fig. 1, we observe that (i) the RER volatility in the post-liberalization era is higher than in the pre-liberalization era (i.e. 5.259 vs. 4.869); (ii) the correlation between the RER and consumption growth differentials is positive over the period 1972–1990 (i.e. 0.338) and negative over the period 1991–2009 (i.e. −0.557).

As expected, if both domestic and foreign agents are not allowed to efficiently share their consumption risk by trading in complete financial markets, the model does not produce a realistic RER volatility. Specifically, under financial autarky, the RER volatility–consumption volatility ratio produced by the model is just above one (i.e. 1.115 and 1.128 in the model with no long-run risk and with long-run risk, respectively). Of course, financial autarky gives rise also to a relatively low cross-country consumption correlation. In other words, specifications (1) and (2) in Table 2 can only account for the relatively low cross-country consumption growth correlation in the data.

Differently, if all agents can efficiently share their consumption risk by trading in complete financial markets, the model produces a much higher RER volatility. The latter is five time higher than consumption volatility, allowing the model to address the RER volatility puzzle (see specifications (3) and (4) in Table 2). The result is in stark contrast to the findings of Heathcote and Perri (2002) and Bodenstein (2008). Under complete markets the international production economy of Heathcote and Perri (2002) generates extremely low RER volatility.[13] Similarly, the endowment economy of Bodenstein (2008) with complete markets produces a close to unity RER volatility–consumption volatility ratio.[14] However, the presence of full risk-sharing tends to generate a stronger positive cross-country consumption comovement (i.e. 0.784 and 0.799 in the model with no long-run risk and with long-run risk, respectively). This suggests that the model cannot account for the low cross-country consumption correlation in the US–China macroeconomic data.[15] Because of standard preferences, the model does not address the Backus–Smith anomaly and domestic asset pricing puzzles. In other words, for all specifications, it produces (i) a perfect positive correlation between RER and consumption differentials; (ii) an unrealistically high risk-free rate; (iii) an almost zero ERP.[16]

### 4.2.2. Recursive preferences

Table 3 reports data on the US and China for the pre- and post-liberalization periods along with the macro quantities and prices produced by the model with recursive preferences for the benchmark calibration for two different capital market structures (i.e. financial autarky and complete markets), both with and without long-run risk.

On the one hand, similarly to the economy with standard preferences, under financial autarky, the RER volatility–consumption volatility ratio is close to one (i.e. 1.115 and 1.128 in the economy with no long-run risk and long-run risk, respectively) whereas in the data it is close to five (i.e. 4.869).[17] In addition, the correlation between the RER and consumption differential equals unity both in the model with and without long-run risk. In this regime resources do not flow

[13] They obtain a RER volatility–consumption volatility ratio equal to 0.86, three times lower than the value suggested by their empirical moments (i.e. 2.76). We stress that they do not match the RER volatility puzzle even if there is an inefficient international risk-sharing environment (i.e. financial autarky regime or single-bond economy). They obtain a RER volatility–consumption volatility ratio equal to 1.97 and 0.94, respectively. Both values are still lower than the 2.76 they observed in the data.

[14] When markets are complete (i.e. agents are patient ⇒ subjective discount factor approaches one) the international endowment economy of Bodenstein (2008) produces a ratio equal to 1.2. However, the international macro-data suggest a value around 5.

[15] We stress that in both capital markets regimes the results produced by the model with and without long-run risk, respectively, are very similar. Loosely speaking, long-run risk plays a key role only if agents have preferences for early resolution of uncertainty.

[16] Notice that the pre- and post-liberalization US ERP is equal to 4.36% and 7.54%, respectively. This gap reflects both the great moderation and the dot-com bubble years, and confirms that the US ERP embodies a strong time-varying component.

[17] Kollmann (2015) shows that this result holds even if a single bond is traded internationally. He argues that the combination of long-run productivity shocks and recursive preferences gives rise to a realistic RER volatility, only if there is a sufficient amount of international risk-sharing. Therefore, a model with long-run risk and recursive-preferences, where only a fraction of households trades in complete markets, can generate a relatively high RER volatility.

**Table 3**
Model vs. data: macroeconomic quantities and prices. *Notes*: this table reports the average equity premium, ERP, risk-free rate, $R^f$, real exchange rate volatility–consumption growth volatility puzzle, $\sigma(\Delta e)/\sigma(\Delta c)$, the cross-country consumption growth correlation, Corr($\Delta c_h$, $\Delta c_f$), and the Backus–Smith correlation, Corr($\Delta c_h - \Delta c_f$, $\Delta e$), simulated under different international capital market structures. The risk premium is not levered. All parameters are calibrated to the values reported in Table 1. With no-LRR the long-run shock volatility and the cross-country long-run shock correlations are re-calibrated, $\sigma_\epsilon^{LR} = 0$ and $\rho_{\epsilon_h^{SR}\epsilon_f^{SR}} = 0.35$. Moments are obtained from repetitions of small-sample simulations. The ERP and $E(R^f)$ are annualized and expressed in percentage points. The pre-liberalization period runs from 1972 to 1990. The post-liberalization period runs from 1991 to 2009. Details on data sources are given in Appendix A.

| Model EZ | Data US–China (*Pre-Lib*) | (1) Financial autarky (no LRR) | (2) Financial autarky (with LRR) | Data US–China (*Post-Lib*) | (3) Complete markets (no LRR) | (4) Complete markets (with LRR) |
|---|---|---|---|---|---|---|
| Macro quantities | | | | | | |
| $\sigma(\Delta e)/\sigma(\Delta c)$ | 4.869 | 1.115 | 1.128 | 5.259 | 5.112 | 7.595 |
| Corr($\Delta c_h$, $\Delta c_f$) | 0.112 | 0.404 | 0.392 | 0.016 | 0.768 | 0.578 |
| *Corr*($\Delta c_h - \Delta c_f$, $\Delta e$) | 0.338 | 1.000 | 1.000 | −0.557 | 1.000 | −0.145 |
| Asset prices | | | | | | |
| ERP | 4.357 | 0.237 | 2.610 | 7.542 | 0.189 | 2.470 |
| $E(R^f)$ | 1.458 | 2.892 | 1.646 | 0.999 | 2.926 | 1.747 |

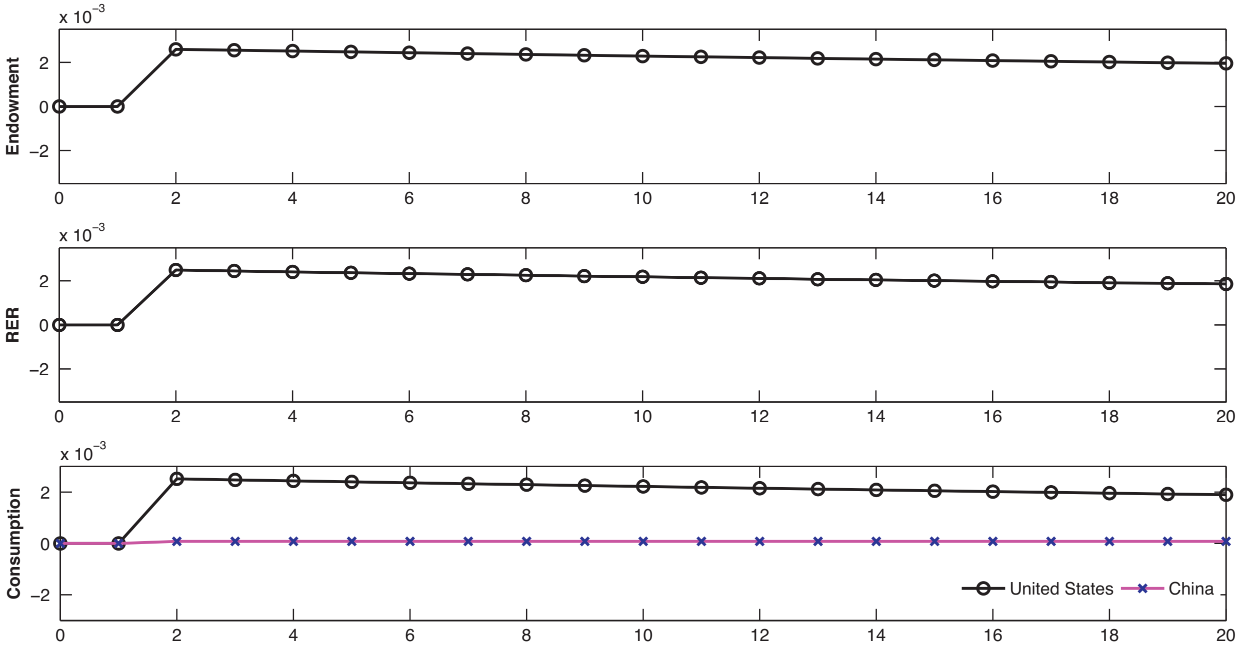


**Fig. 2.** Impulse response functions: financial autarky. *Notes*: this figure shows the impulse response functions of endowment, exchange rate and domestic (black line) and foreign (pink line) consumption to a long-run positive news to the supply of the US good. (For interpretation of the references to color in this text, the reader is referred to the web version of the article.)

from the low-marginal utility country to the high-marginal utility one for consumption smoothing purposes. In practice, following positive long-run news regarding the supply of the domestic goods, agents in the home country have no access to international financial markets in order to buy insurance assets, and, therefore, give up part of their resources. This implies that, under financial autarky, foreign consumption does not move from $t+1$ onward and domestic consumption moves symmetrically with the RER (see middle and bottom panels of Fig. 2).

As is well known, recursive preferences allow to separate the RRA parameter from the IES. Such separability is a necessary condition to match asset pricing data (Bansal and Yaron, 2004; Bansal et al., 2012; Beeler and Campbell, 2012; Pancrazi, 2014). Therefore, in contrast to the economy with standard preferences, specification (2) in Table 3 produces a sizable ERP and a relatively low risk-free rate (consistent with asset pricing data).[18]

The presence of full risk-sharing in the model without long-run risk only affects the RER volatility which is more than five times the consumption volatility (consistent with US–China post-liberalization data). Therefore, specification (3) in Table 3 addresses only the RER volatility puzzle. This because the novel risk sharing mechanism embodied in the

[18] Note that this result is in line with the single endowment economy of Bansal and Yaron (2004).

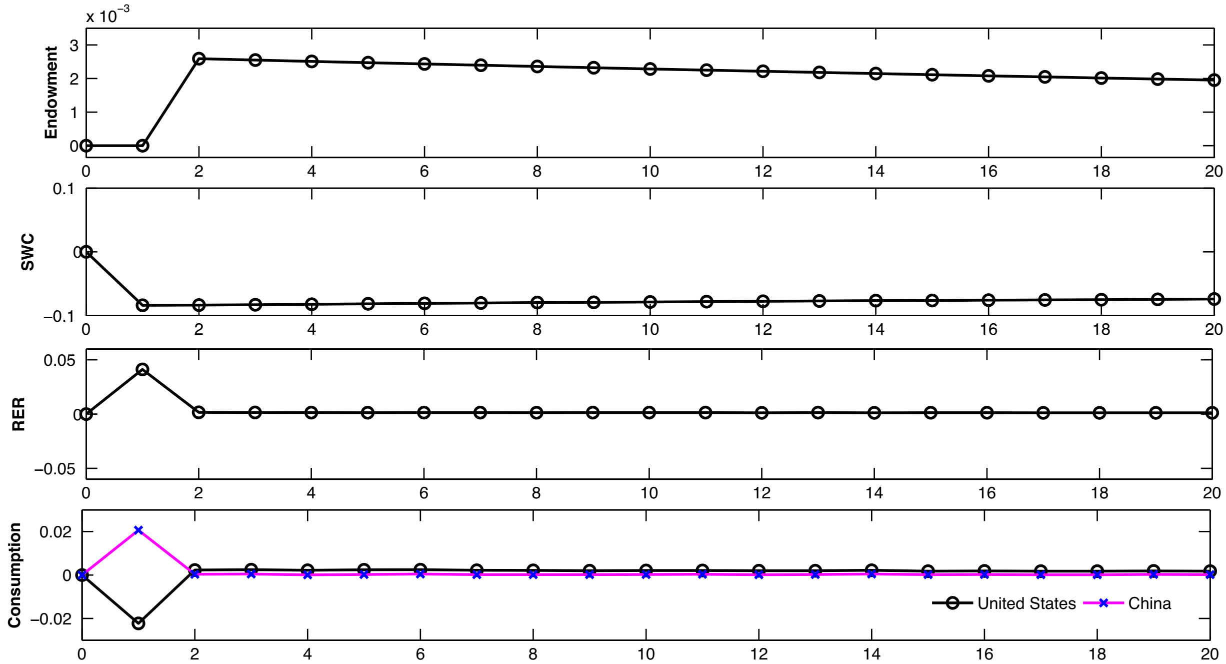


**Fig. 3.** Impulse response functions: complete markets. *Notes*: this figure shows the impulse response functions of endowment, share of world consumption, exchange rate and domestic (black line) and foreign (pink line) consumption to a long-run positive news to the supply of the US good. (For interpretation of the references to color in this text, the reader is referred to the web version of the article.)

two-country/two-good model with recursive preferences and complete markets produces endogenous time variation in the distribution of consumption and currency risk across countries. It turns out that the combination of recursive preferences, complete and frictionless markets, and long-run risk can simultaneously address the three international macroeconomic anomalies as well as the domestic asset pricing puzzles (see specification (4) in Table 3). In this environment, risk-sharing takes place through imports and exports (i.e. endowments flow from the low-marginal utility country to the high-marginal utility one). For example, following positive long-run news on the supply of the domestic good, there is a long-lasting impact on the domestic marginal utility. This implies that domestic agents will steadily decrease their share of world consumption (via exports) from time $t+1$ onward (as long-run news does not affect current consumption). It turns out that domestic consumption decreases and foreign consumption increases. Because of the excess supply of the domestic good, the RER depreciates. The last two effects are key to replicate the Backus–Smith anomaly. This is clear from Fig. 3, which shows the impulse response functions of endowment, share of world consumption, RER and domestic and foreign consumption following long-run news on the supply of the home good. We stress that in this international endowment economy agents are averse to both consumption and utility risk. This means that they are willing to exchange part of their current resources in order to insure themselves against variations in future utility. Therefore, in the presence of long-run news, domestic agents will reduce their share of world consumption to buy insurance assets in the financial markets. This mechanism generates a substantial amount of pressure on the currency and significantly affects asset prices. Consequently, the model with recursive preferences, complete markets and long-run risk produces a much higher RER volatility (see also Donadelli and Paradiso, 2014).[19] In fact, the RER volatility–consumption volatility ratio jumps to a value of 7.595 (see specification (4) in Table 3).[20]

### *4.3. A sensitivity analysis*

Table 4 reports quantities and prices produced by the model for different values of the RRA (see specification (2)), $\gamma$, the IES (see specification (3)), $\psi$, consumption home bias (see specification (4)), $\alpha$, cross-country long-run shocks correlation (see specification (5)), $\rho_{\epsilon_h^{LR}\epsilon_f^{LR}}$, and the subjective discount factor (see specification (6)), $\delta$. The first column (i.e. specification (1)) reports the results for the benchmark calibration (as in the last column of Table 3). The last column of Table 4 reports the empirical moments for the post-liberalization period (consistent with an international complete markets regime). The

[19] This results is in line with Kollmann (2015) who shows that a long-run risk, recursive-preferences model can reproduce a realistic RER volatility even if only a fraction of households is allowed to trade in complete markets.

[20] Notice that the model produces also a non-close to unity cross-country equity market returns correlation (see Donadelli and Paradiso, 2014). This differs from Devereux and Yetman (2010) and Devereux and Sutherland (2011) who find a perfect positive comovement between cross-country returns.

**Table 4**
Model vs. data: a sensitivity analysis on macroeconomic quantities and prices. *Notes*: this table reports the equity premium, ERP, the risk-free rate, $E(R^f)$, real exchange rate volatility–consumption growth rate volatility puzzle, $\sigma(\Delta e)/\sigma(\Delta c)$, the cross-country consumption growth correlation, $\text{Corr}(\Delta c_h, \Delta c_f)$, and the Backus–Smith correlation, $\text{Corr}(\Delta c_h - \Delta c_f, \Delta e)$. The ERP and $E(R^f)$ are annualized and expressed in percentage points. The risk premium is not levered. CM ≡ Complete Markets. EZ ≡ Recursive Preferences. SV ≡ model with Stochastic Volatility. Moments are obtained from repetitions of small-sample simulations. Details on data sources are given in Appendix A.

| Model (LRR) CM (EZ) | (1) BM | (2) RRA ↑ $\gamma = 10$ | (3) IES ↑ $\psi = 2$ | (4) $\alpha$↓ $\alpha = 0.9$ | (5) CORR ↓ $\rho_{\epsilon_h^{LR}\epsilon_f^{LR}} = 0.75$ | (6) $\delta$↓ $\delta = 0.96$ | (7) $\tau$↓ $\tau = 0$ | (8) SV | Data (*Post-Lib*) |
|---|---|---|---|---|---|---|---|---|---|
| Macro quantities | | | | | | | | | |
| $\sigma(\Delta e)/\sigma(\Delta c)$ | 7.595 | 9.428 | 9.525 | 3.053 | 9.381 | 2.62 | 7.17 | 9.707 | 5.259 |
| $Corr(\Delta c_h, \Delta c_f)$ | 0.578 | 0.510 | 0.631 | 0.484 | −0.012 | 0.69 | 0.60 | 0.196 | 0.016 |
| $Corr(\Delta c_h - \Delta c_f, \Delta e)$ | −0.145 | −0.418 | −0.304 | −0.517 | −0.639 | −0.12 | −0.15 | −0.583 | −0.557 |
| Asset prices | | | | | | | | | |
| ERP | 2.470 | 3.153 | 4.760 | 2.434 | 2.305 | 0.76 | 2.47 | 3.099 | 7.542 |
| $E(R^f)$ | 1.747 | 1.408 | 0.700 | 1.773 | 1.843 | 4.91 | 1.75 | 0.081 | 0.999 |

RER volatility, the cross-country consumption growth correlation and the Backus–Smith anomaly are weakly affected by different RRA and IES values. The subjective discount factor, the coefficient of risk aversion and the intertemporal elasticity of substitution represent risk-sharing based parameters. In practice, they control agent's willingness to share risk. This implies that changes in these parameters tend to affect mainly the agents' utility function but leave the set of feasible allocations unchanged. In other words, different values of $\delta$, $\gamma$ and $\psi$ alter mainly the ERP and the risk-free rate. As is standard in the long-run risk literature (Bansal and Yaron, 2004; Pancrazi, 2014), a higher RRA or IES produces a higher ERP as well as a higher RER volatility–consumption volatility ratio. The explanation is straightforward. With higher RRA or IES values, agents become more risk averse to consumption and utility risk and their willingness to buy insurance assets in international capital markets (for consumption smoothing) increases. Therefore, asset prices change and the currency becomes much more volatile.

By assuming sufficiently impatient agents (i.e. $\delta = 0.96$), the model is still able to produce a high RER volatility, a negative correlation between RER and consumption differentials, and a relatively low cross-country consumption correlation. More myopic agents tend to place less weight on the distant future. Doing so, they care less about uncertainty on future utility. As a result, trading activity decreases (i.e. $\sigma(\Delta e)\downarrow$) and they ask for a lower equity premium (i.e. *ERP*↓). These results are in line with those of Bodenstein (2008). However, in this model there is full financial risk-sharing whereas in the Bodenstein (2008)'s endowment economy financial markets are complete but the enforcement of international financial contracts is limited (i.e. agents cannot share risk efficiently). By contrast, if contract enforcement is not limited and agents are not impatient, the model behaves as a standard IBC model with complete markets, that is, it produces a RER volatility–consumption volatility ratio close to one, a higher cross-country consumption correlation, and the correlation between RER and relative consumption is equal to one. As in Bodenstein (2008), we find that a higher degree of economic integration (i.e lower consumption home bias – $\alpha$ closer to 0.5), leads to a decrease in the RER volatility, and to a higher (negative) correlation between the RER and consumption differentials compared to the benchmark calibration.

Overall, the entries in Table 4 suggest that the parameter space of $\gamma$, $\psi$, $\alpha$, $\rho_{\epsilon_h^{LR}\epsilon_f^{LR}}$ and $\delta$ allowing the model to solve the three classic international macroeconomic puzzles is relatively large. Note also that the model's performance is preserved even if the endowment processes are not cointegrated (i.e. $\tau = 0$). The model fails if the correlation between domestic and foreign long-run innovations is significantly lower than in the benchmark calibration. In this case, it produces a negative correlation between consumption growth rates, but still addresses the RER volatility and the Backus–Smith puzzle as well as the domestic asset pricing puzzles. It is noteworthy that it produces a negative correlation rather than a correlation close to unity (as in standard macro models). Therefore, in our opinion, it "partially fails".[21] We stress that if the correlation between domestic and foreign long-run shocks ranges from 0.9 (benchmark calibration) to 0.76, the performance of the model is not affected, that is, it still solves the five puzzles simultaneously. This is clear from Fig. 4, which plots the RER volatility–consumption volatility ratio, $\sigma(\Delta e)/\sigma(\Delta c)$, the correlation between the RER and consumption differentials, $\text{Corr}(\Delta c_h - \Delta c_f, \Delta e)$, the cross-country consumption growth correlation, $\text{Corr}(\Delta c_h, \Delta c_f)$, for various values of the cross-country long-run shocks correlation (on the horizontal axes), $\rho_{\epsilon_h^{LR}\epsilon_f^{LR}}$, by assuming $\alpha = 0.97$ (Panel a) and $\alpha = 0.9$ (Panel b).[22]

Finally, specification (8) in Table 4 suggests that stochastic volatility does not affect much the model's performance.[23] Two results are noteworthy. First, and not surprisingly, the model with stochastic volatility produces a higher ERP as well as a higher RER volatility. Second, it allows for a much lower cross-country consumption correlation. The correlation is almost three times lower than the one produced in the benchmark model (i.e. 0.196 vs. 0.578). However, this is more consistent with

[21] This is in line with US–China consumption data over specific periods (see Fig. 1, bottom-right panel).
[22] Notice that the model produces a cross-country consumption correlation lower than an empirical cross-country GDP correlation (see dotted blue line in Fig. 4). This holds if the parameter space of $\rho_{\epsilon_h^{LR}\epsilon_f^{LR}}$ is quite narrow.
[23] Stochastic volatility is modeled as in Caldara et al. (2012).

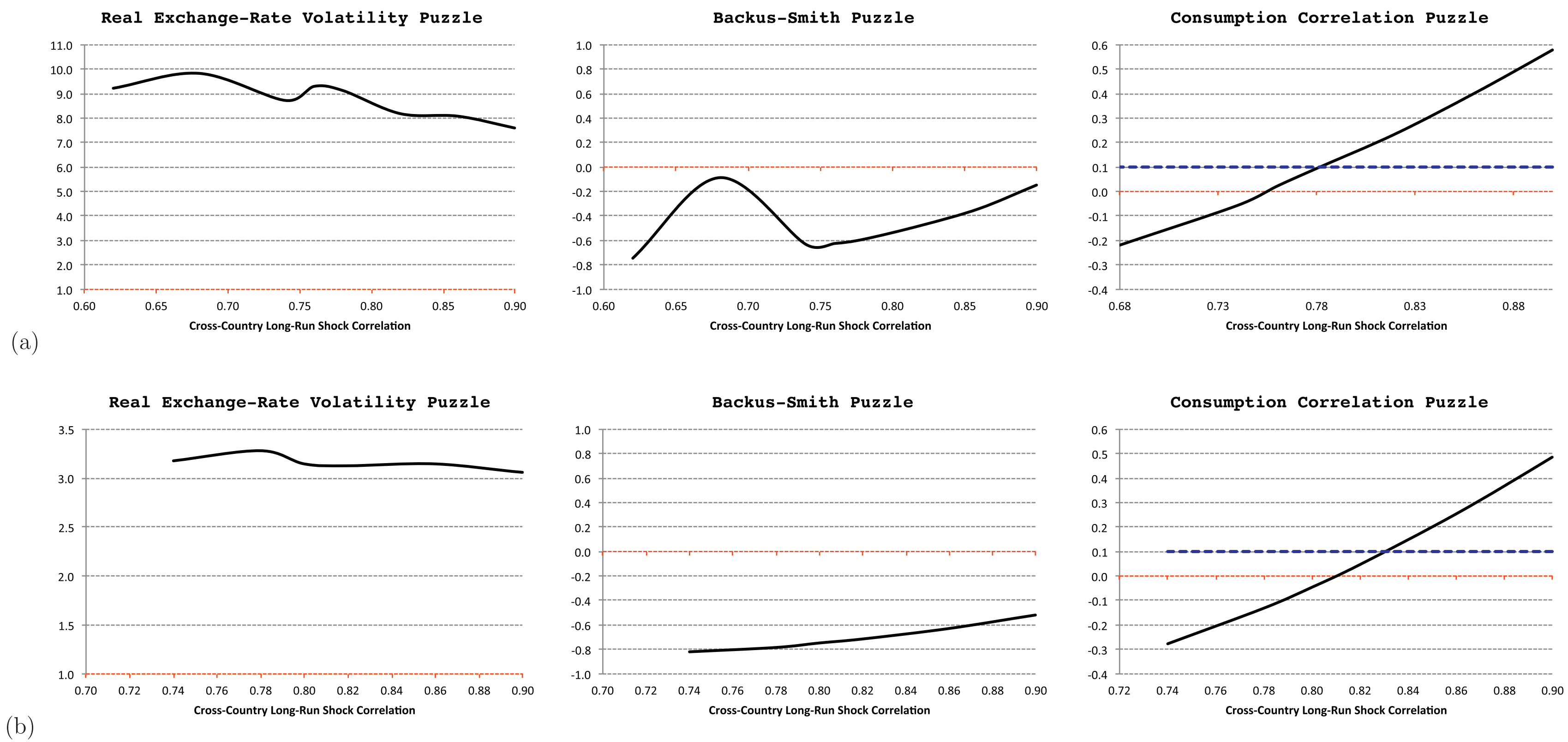


**Fig. 4.** *Puzzles vs. cross-country correlation in the long-run innovations*: alpha = 0.97 (Panel a) and alpha = 0.90 (Pane b). *Notes*: This figure reports the real exchange rate volatility–consumption volatility ratio, $\sigma(\Delta e)/\sigma(\Delta c)$, the correlation between the real exchange rate and consumption differentials, $\mathrm{Corr}(\Delta c_{\mathrm{h}} - \Delta c_{\mathrm{f}}, \Delta e)$, the cross-country consumption growth correlation, $\mathrm{Corr}(\Delta c_{\mathrm{h}}, \Delta c_{\mathrm{f}})$, for various values of the correlation between long-run endowment shocks, $\rho_{\epsilon_h^{LR}\epsilon_f^{LR}}$, from 0.62 to 0.9 (Panel a), and from 0.74 to 0.9 (Panel b). The dotted blue line represents the correlation between the US and China GDP growth rates (post-liberalization sample: 1991–2009). Moments are obtained from repetitions of small-sample simulations.

US–China post-liberalization data, which suggest a correlation of 0.016. Overall, stochastic volatility improves risk-sharing. As a results, it brings us closer to the correlation between the RER and consumption differentials observed in the US–China data over the period 1991–2009.

## 5. Concluding remarks

Early IBC studies show that a standard model with international complete markets does not account for the relatively high RER volatility, the negative correlation between RER and consumption differentials and the low cross-country consumption correlation in the data. They argue that such failure is due to the fact that market completeness produces an unrealistically high level of risk-sharing. Therefore, more recent IBC studies argue that a lower degree of international risk-sharing seems to be a necessary condition to solve international macroeconomic puzzles. They rely on international incomplete market regimes (e.g. "financial autarky" and "single-bond economy") or financial market imperfections (e.g. "borrowing contraints" and "limited enforcement").

This paper compares the international quantities and prices generated under financial autarky (with standard and recursive preferences) with those under international complete markets (with standard and recursive preferences). For this purpose it uses an international endowment economy with frictionless markets, highly correlated long-run innovations and preferences towards domestic goods, and relies on US–China macroeconomic data. The analysis suggests that the RER-volatility puzzle, the Backus–Smith anomaly and the consumption correlation puzzle can be more or less pronounced under different capital market regimes. In particular, we observe that (i) the RER-volatility puzzle and the Backus–Smith anomaly have become more apparent in the aftermath of China's stock market liberalization (i.e. after 1991); (ii) the consumption correlation puzzle (on average) is even stronger if a developed economy and an emerging one are considered. Therefore, international macroeconomic puzzles do not arise exclusively among pairs of developed countries (e.g. US vs. Canada, US vs. UK).

In contrast to recent IBC studies, we point out that an inefficient international risk-sharing environment does not represent a necessary condition to address international macroeconomic puzzles. Instead, a moderate amount of home bias in consumption is required. Specifically, we show that, in the presence of complete and frictionless markets, the combination of recursive preferences and correlated long-run innovations allows for the simultaneous resolution of three important international macroeconomic puzzles (i.e. RER volatility puzzle, Backus–Smith anomaly, consumption correlation puzzle) and two asset pricing puzzles (i.e. EPP and risk-free rate puzzle). This holds even if there are non-negligible changes in several parameter values, suggesting that the model's performance is robust.

## Appendix A. Data

We base our analysis on US–China data over the period 1972–2009. Real consumption data are from the Robert Barro's website (Barro-Ursua Macroeconomic Data, 2010, freely available at http://rbarro.com/data-sets/).The annual average China/US nominal exchange rate, and the US and China GDP deflator are collected from the St. Louis FED (FRED ECONOMIC DATA, freely available at http://research.stlouisfed.org/fred2/). The US annual average equity risk premium and risk-free rate are from Kenneth French Data Library (freely available at http://mba.tuck.dartmouth.edu/pages/faculty/ken.french/data_library.html). The Gross Domestic Product (GDP) of the US, China, UK, and Germany (at current US$ prices) are from the IMF World Economic Outlook Databases (WEO).

Data on international transactions are from Bureau of Economic Analysis (Table 12, U.S. International Transactions, by Area – China, freely available at http://www.bea.gov/international/index.htm). We collect the following series: Exports of goods and services and income receipts (line 1), imports of goods and services and income payments (line 18), U.S. – owned assets abroad, excluding financial derivatives (line 40), Foreign-owned assets in the United States, excluding financial derivatives (line 55). All series are available from 1999.

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