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ORIGINAL RESEARCH

Testing for Consumer Risk-Pooling in the Open Economy – further Results

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Abstract

In this supplement to Minford et al. Int J Financ Econ 26(2):19932021 (2021), we revisit the 'puzzle' in open economy studies that evidence of international risk-sharing is hardly seen despite active cross-country financial markets. We reassess both risk-pooling via state-contingent bonds, and uncovered interest parity – both were believed to be different, and spuriously rejected, in previous work – in the context of a full DSGE model of the New Keynesian type. We prove that the two models are identical, both analytically and numerically. When tested as part of such a full DSGE model by indirect inference which circumvents the bias of single-equation tests, we find universal evidence of international risk-sharing.

Keywords Consumer risk-pooling · UIP · Two-country DSGE model · Indirect inference test

JEL Classification C12 · E12 · F41

1 Introduction

Given the depth and wide activity in international asset markets, it has seemed paradoxical that consumer risk-pooling via these markets and uncovered interest parity (UIP) have been difficult to find empirically – some recent examples

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include Hess and Shin (2000), Delcoure et al. (2003), Isard (2006) and Burnside (2019). The empirical testing in this work has been via single-equation regressions, where among others one of the main difficulties in assessing this evidence has been that all the variables in these regressions are endogenous. A notable recent example is Burnside (2019) who rejects UIP for a dozen pairs of industrialised economies on single-equation tests. The paper joins an 'empirical consensus' – now barely questioned – that UIP fails to fit, which is a 'puzzle' many including Burnside attempt to solve with a variety of model features.

However, the difficulties with the single-equation tests used by Burnside were circumvented by Minford et al. (2021, 2022) (MOZ1 and MOZ2, respectively, hereafter) where we embedded the risk-pooling hypothesis and its UIP variant in a full model and tested the model as a whole. The model takes the familiar IS curve, Phillips curve and Taylor rule New Keynesian set-up of Clarida et al. (1999) extended to embrace the US, Europe and the rest of the world, essentially a two-country model for the US and EU. We used the method of Indirect Inference to estimate and test the two model versions for the US and the EU pair of economies. What we found was that neither hypothesis is rejected on the test, with risk-pooling being more probable. MOZ1 accounts for the discrepancy between these findings and the rejection of both hypotheses in conventional single-equation tests by showing, in Monte Carlo experiments on that two-country model, when either hypothesis was true, that the widely-used single-equation tests would be heavily biased towards the hypothesis' rejection. We update these experiments below, in the light of our new model of risk-pooling.

In this supplement to our two previous papers, we re-test the risk-pooling hypothesis within this full DSGE model of the standard New Keynesian (NK) type where the consumption Euler equations are explicitly included, instead of being substituted out for the forward-looking IS curves. We discover in this new work that whereas when we used IS curves as in those two papers we found a distinction between risk-pooling through state-contingent assets, and UIP, in this full NK model there is no distinction between the two model versions; UIP, which relies on arbitrage between non-contingent bonds, provides the same scope for consumers to smooth their consumption over time and across borders, in a way we will demonstrate below. Our previous findings that the two hypotheses differ somewhat in their test performance comes about because the errors used in each hypothesis differed in their detailed application using the reduced form IS curves; when the full structural model version including the Euler equations is used, such a difference in errors disappears.

Our two-fold contribution in this note, which resolves a long-standing 'puzzle' in open economy research on international risk-sharing and exchange rate behaviour, is therefore: first, we prove that full risk-pooling is always obtainable in an NK-style open economy, whether state-contingent bonds are available or not; such a structural DSGE model will behave in the same manner whether the exchange rate is assumed to reflect the consumption gap between two economies as a result of international risk-sharing via state-contingent bonds, or to adjust to clear the interest rate gap between them as a result of international arbitrage. Not all open economy models are of this type and there is a literature, reviewed below, examining differential behaviour as asset market structures vary; however, we show that for the widely-used NK open economy structural DSGE model, the two asset setups deliver identical results. Second, we correct the spurious 'empirical consensus' that international risk-sharing is not supported by the data; we show that, once the correct assessment method is used on a full standard NK model, the data suggests that it exists universally.

In the next section of this note we demonstrate the formal equivalence of risk-pooling and UIP in a structural New Keynesian model where the Euler equation is present; in Section 3 we set out our full DSGE NK model in its two versions, of risk-pooling and UIP, and side by side with it we verify their numerical equivalence; in Section 4 we show how Monte Carlo experiments with our new model confirm the serious biases in the various single-equation tests used in the previous literature; in Section 5 we report our indirect inference test results, using our full structural NK DSGE model, for UIP/risk-pooling for the 10 pairs of economies previously assessed in MOZ1 and MOZ2 (which also explain in detail the indirect inference testing procedure); we review our findings and conclude in Section 6.

2 The Equivalence of Risk-Pooling and UIP

These two models of consumer behaviour in the open economy, risk-pooling via state-contingent assets and plain UIP, can be derived following Chari et al. (2002), as follows:

Case A: Full Risk-Pooling via State-Contingent Nominal Bonds

Let the price at time $t = 0$ (when the state was s_0) of a home nominal state-contingent bond paying 1 unit of home currency in state s_t be:

$$n(s_t \mid s_0) = \beta f(s_t \mid s_0) \frac{U_c(s_t \mid s_0)}{P(s_t \mid s_0)} / \frac{U_c(s_0)}{P(s_0)} \tag{1}$$

where β is time discount factor, $f(s_t \mid s_0)$ is the probability of s_t occurring given s_0 has occurred, U_c is the marginal utility of consumption, P is the general price level. Now note that foreign consumers can also buy this bond freely via the foreign exchange market and its value as set by them will be:

$$n(s_t \mid s_0) = \beta^* f(s_t \mid s_0) \frac{U_c^*(s_t \mid s_0)}{P^*(s_t \mid s_0) Q(s_t \mid s_0)} / \frac{U_c^*(s_0)}{P^*(s_0) Q(s_0)} \tag{2}$$

where '∗' denotes foreign variables, Q is the nominal exchange rate. Here they are equating the expected marginal utility of acquiring this bond with foreign currency, with the marginal utility of a unit of foreign currency at time 0. Plainly the price paid by foreign consumers must be equal by arbitrage to the price paid by home consumers. Equating these two equations yields:

$$\beta \frac{U_c(s_t \mid s_0)}{P(s_t \mid s_0)} / \frac{U_c(s_0)}{P(s_0)} = \beta^* \frac{U_c^*(s_t \mid s_0)}{P^*(s_t \mid s_0) Q(s_t \mid s_0)} / \frac{U_c^*(s_0)}{P^*(s_0) Q(s_0)} \tag{3}$$

Now we note that the terms for the period $t = 0$ are the same for all s_t so that for all t from $t = 0$ onwards:

$$\frac{U_c(s_t \mid s_0)}{U_c^*(s_t \mid s_0)} = \Theta \frac{P(s_t \mid s_0)}{P^*(s_t \mid s_0)Q(s_t \mid s_0)} \tag{4}$$

where $\Theta = \frac{U_c(s_0)}{P(s_0)} / \frac{U_c^*(s_0)\beta}{P^*(s_0)Q(s_0)\beta^*}$ is a constant.

Let the utility function be $U = C_t^{(1-\sigma)}\varepsilon_{j,t}/(1-\sigma)$ where σ is the inverse of the consumption elasticity and $\varepsilon_{j,t}$ is the time-preference shock, and $\hat{q}_t = -\hat{P}_t + \hat{P}_t^* + \hat{Q}_t$ is the real exchange rate (with '$\hat{x}_t$' denoting a variable x_t in percentage deviation from its steady-state value). Equation (4) implies:

$$\sigma(\hat{c}_t - \hat{c}_t^*) = \hat{q}_t - v_t \tag{5}$$

ignoring the constant, which is the risk-pooling condition; v_t is the difference between the logs of the two countries' time-preference shocks.[1]

To see that this implies the UIP relationship, use the Euler equations for consumption (e.g. for home consumers $\hat{C}_t = -\frac{1}{\sigma}\left(\frac{r_t}{1-B^{-1}} - \hat{\varepsilon}_{j,t}\right)$ where B^{-1} is the forward operator keeping the date of expectations constant). Substituting for consumption into (5) gives us UIP:

$$E_t\hat{q}_{t+1} - \hat{q}_t = r_t - r_t^* \tag{6}$$

Case B: when there are only non-contingent bonds

In this case arbitrage and rational expectations forces the UIP equation; this comes about via arbitrage on the covered real interest differential, while rational expectations force the real forward rate to equality with the expected future real exchange rate – due to risk aversion and random shocks to the real exchange rate there is also a risk premium which is a function of household risk aversion, the variance of the real exchange rate and its covariance with consumption, all of which are constant in the model, implying a constant premium which is dropped from the model together with all other constants, since the model solves for the effects of shocks. When (6) is substituted back into the Euler equations, it yields:

$$(1 - B^{-1})\sigma\left(\hat{C}_t - \hat{C}_t^*\right) = (1 - B^{-1})(\hat{q}_t - v_t) \tag{7}$$

[1] An implicit simplifying assumption here is that home and foreign consumers share the same consumption elasticity, such that σ is the same for both economies. Allowing σ to take different values for the two economies does not change the implication, as we show in the appendix.

Thus the risk-pooling condition occurs in expected form from where it currently is. But it can be shown to yield the same risk-pooling outcome period by period – exactly as (5) – most easily by dividing through the equation[2] by $\left(1 - B^{-1}\right)$.

What these two cases have illustrated is that, whether there are state-contingent bonds or simple borrowing with non-contingent bonds, relative consumption is exactly correlated with the real exchange rate and time-preference shocks. Thus, even without explicit insurance contracts, consumers can insure themselves by borrowing from foreigners, smoothing out consumption across good and bad times; we do not need explicit future contingent contracts to supplement the workings of free markets. Indeed, these futures can be thought of as copying the market solution in advance, much like Arrow-Debreu contracts map out the future of the economy as it will respond freely to shocks. It follows that an open economy model with optimising consumers will behave the same under risk-pooling via state-contingent contracts as under UIP; so the two models are identical.

Note however that if there is no explicit Euler equation in the model and instead there is a forward-looking IS curve reflecting a variety of demand shocks (as in MOZ1 and MOZ2), the IS curve implies: $\widehat{y}_t - \widehat{y}_t^* = -\frac{1}{\sigma}\frac{c}{y}\frac{r_t - r_t^*}{1-B^{-1}} + err_t$ (where $\frac{c}{y}$ is the steady-state consumption-to-output ratio and err_t includes the effect of v_t). If we impose UIP now we will get a relationship between relative outputs and the real exchange rate under UIP as: $\widehat{y}_t - \widehat{y}_t^* = \frac{1}{\sigma}\frac{c}{y}\widehat{q}_t + err_t$. If instead of imposing UIP we impose risk-pooling, then $\widehat{q}$ will be solved from the risk-pooling Eq. (5) conditional on output and market-clearing consumption. This generally will not deliver the same real exchange rate as under UIP, because the consumption derived from the market-clearing condition will not generally be the one implied by the IS curve used.[3]

This explains why our previous work—which compared risk-pooling and UIP using an IS curve to abstract the demand side—found a differential ability of the two models to fit the facts of different country pairs' behaviour. In effect, the model with UIP there only will not produce risk-pooling for consumers because there is not a tight relationship between relative output minus the shock vector err, and relative consumption. Yet empirically the results for full risk-pooling and UIP were fairly close, as one would expect. However, if we set out a full DSGE model with explicit Euler equations, then whether we include fully state-contingent bonds or UIP will give us full risk-pooling, as risk-pooling relating consumption differences to the real exchange rate implies the UIP

[2] An alternative way to show this equivalence is to first write UIP as $\widehat{q}_t = -(\widehat{r}_t - \widehat{r}_t^*)/(1 - B^{-1})$, where in effect the real exchange rate mirrors the whole expected future path of the real interest rate; then using directly the Euler equations, in which also current consumption reflects the same whole expected path of real rates, which yields: $\widehat{q}_t = \sigma\left(\widehat{c}_t - \widehat{c}_t^*\right) + v_t$, so $\sigma\left(\widehat{c}_t - \widehat{c}_t^*\right) = \widehat{q}_t - v_t$.

[3] Under risk-pooling, $\widehat{q}_t = \sigma\left(\widehat{c}_t - \widehat{c}_t^*\right) + v_t$, where the consumption is calculated from market-clearing output. Since the Euler equation was only loosely imposed in the model in deriving the IS curve, the consumption derived from the market-clearing condition will not be strictly the same as that implied by the IS curve. Thus we will have $\widehat{q}_t = \sigma\left(\widehat{c}_t - \widehat{c}_t^*\right) + v_t = \sigma\frac{y}{c}\left[\left(\widehat{y}_t - \widehat{y}_t^*\right) - \widehat{x}_t\right] + v_t$, where $\widehat{x}_t$ is given by the difference between outputs and consumptions. This solution will only be the same as UIP if $\sigma\frac{y}{c}\left(-\widehat{x}_t\right) + v_t = -\left(\frac{1}{\sigma}\frac{c}{y}\right)^{-1} err_t$, i.e., when $err_t = \widehat{x}_t - \sigma\frac{y}{c}v_t$ holds, which it will not do in general since err_t includes elements in demand that are not explicitly in the model – such as investment and government spending on this occasion.

condition via the Euler equations while the UIP condition in turn implies the risk-pooling condition via these Euler equations. We can test such a model by indirect inference and this model will test in a tight way for risk-pooling; our previous papers explain the workings of this testing process. We carry out this ’tight test’ in this note as a supplement to our earlier work. Since risk-pooling and UIP imply each other, it is also a tight test for UIP in contrast to Burnside (2019).

3 A Full, Two-Country DSGE Model

We start by constructing a two-country model without state-contingent bonds which is ‘standard’ in the open economy set-up. UIP in this benchmark setting is enforced by international arbitrage as households in both home and foreign economies are allowed to buy bonds issued by any country. We then construct the risk-pooling (RP) model equivalent where, as illustrated above, the allowance for state-contingent bonds implies an RP equation for real exchange rate determination, which replaces the UIP equation. To save space we only present the home economy equations; the foreign economy is symmetrical, and connected with the home economy via international capital movements and trades. Variables/parameters of the home economy are unmarked; those of the foreign economy are asterisked. Variables without a time subscript denote the steady-state value of them. ‘$\hat{x}_t$’ continues to denote the percentage deviation of a variable x_t from its steady-state value. We outline the model structure in the main text. The linearised model equations are listed in the appendix.

3.1 The Standard UIP Version

3.1.1 Households

There is a continuum of measure one of representative households who work, consume and save; and have life-time utility:

$$U_0 = E_0 \sum_{t=0}^{\infty} \beta^t \varepsilon_{j,t} \left(\ln c_t - \psi \frac{n_t^{1+\eta}}{1+\eta} \right) \tag{8}$$

where c_t is consumption, n_t is labour hour, ψ is the preference of leisure, η is the inverse of wage elasticity, β is the time discount factor, and $\varepsilon_{j,t}$ is the time preference shock. The composite consumption index is defined by:

$$c_t \equiv \left[(1-\alpha)^{\frac{1}{v}} c_{h,t}^{\frac{v-1}{v}} + \alpha^{\frac{1}{v}} im_t^{\frac{v-1}{v}} \right]^{\frac{v}{v-1}} \tag{9}$$

where $c_{h.t}$ is the consumption on domestic goods, im_t is imports, $v(>0)$ is the substitutability between $c_{h.t}$ and im_t, α is the degree of openness.

The household budget constraint is:

$$c_{h,t} + q_t im_t + b_t + q_t bf_t + t_t = w_t n_t + \left(1 + r_{t-1}\right) b_{t-1} + \left(1 + r^*_{t-1}\right) q_t bf_{t-1} + \Pi_t \tag{10}$$

where q_t is the real exchange rate (defined as the units of domestic goods per unit of foreign goods), b_t and bf_t are holdings of home and foreign bonds, respectively, r_{t-1} and r^*_{t-1} are the home and foreign real interest rates, w_t is the real wage rate, t_t and Π_t are lump-sum tax payment and profit received, respectively.

The household problem is to maximise (8) by choosing $c_{h,t}$, im_t, n_t, b_t and bf_t, subject to (10). The first order conditions imply the demand for domestic and foreign goods, the labour supply, and the UIP condition:

$$E_t \hat{q}_{t+1} - \hat{q}_t = r_t - r^*_t \tag{11}$$

which suggests that home currency must depreciate/appreciate to eliminate any arbitrage opportunity should there be a positive/negative margin between the home and foreign interest rates.

3.1.2 Firms

There is a continuum of measure one of representative firms which produce differentiated goods using the same technology; for simplicity we assume a labour-only production function:

$$y_t = \varepsilon_{z,t} n_t \tag{12}$$

where y_t is the aggregate output, $\varepsilon_{z,t}$ is productivity.

Under Calvo (1983) pricing, which assumes that in each period only a fraction $(1 - \omega)$ of the firms are able to reset prices, the standard profit maximisation problem under the assumptions of a zero-inflation steady state and no past-inflation indexation implies the Phillips curve for domestic price inflation:

$$\pi_{h,t} = \beta E_t \pi_{h,t+1} + \kappa \widehat{mc}_t + \hat{\varepsilon}_{\pi,t} \tag{13}$$

where $\kappa = \frac{(1-\omega)(1-\beta\omega)}{\omega}$, $mc_t \left(= w_t / \varepsilon_{z,t}\right)$ is the real marginal cost of production, $\hat{\varepsilon}_{\pi,t}$ is price mark-up shock. Given the definition of CPI:

$$P_t = \left[(1 - \alpha) P^{1-v}_{h,t} + \alpha \left(Q_t P^*_{h,t} \right)^{1-v} \right]^{\frac{1}{1-v}} \tag{14}$$

where $P_{h,t}$ and $P^*_{h,t}$ are the price levels of domestic and imported goods, respectively, and Q_t is the nominal exchange rate (defined as the units of home currency per unit of foreign currency), CPI inflation may be shown as:

$$\pi_t = (1 - \alpha)\pi_{h,t} + \alpha \pi^*_{h,t} + \alpha \Delta \hat{Q}_t \tag{15}$$

which is the weighted average of the domestic and foreign inflation, adjusted by the nominal exchange rate movement.[4]

The firm profit in each period $\left(\Pi_t = y_t - w_t n_t\right)$ is transferred to households, who are assumed to own these firms, as a lump-sum.

3.1.3 Monetary and fiscal policies

The central bank adjusts the nominal interest rate following a Taylor rule:

$$1 + R_t = \left(1 + R_{t-1}\right)^{\rho_R}\left(1 + \pi_t\right)^{(1-\rho_R)\phi_\pi}\left(\frac{y_t}{y_{t-1}}\right)^{(1-\rho_R)\phi_y}(1 + r)^{(1-\rho_R)}\varepsilon_{R,t} \tag{16}$$

where the rate responds to both inflation $\left(\phi_\pi\right)$ and growth $\left(\phi_y\right)$, subject to inertia $\left(\rho_R\right)$ and a monetary policy shock $\left(\varepsilon_{R,t}\right)$.

The fiscal authority adjusts government spending, which is assumed to be a stationary exogenous process around its steady-state level:

$$g_t = \varepsilon_{g,t} g \tag{17}$$

where $\varepsilon_{g,t}$ is the shock to the spending.

3.1.4 Identities and Shock Processes

Goods market clearing requires:

$$y_t = c_{h,t} + g_t + im_t^* \tag{18}$$

where im_t^* is imports by the foreign economy, hence exports of the home economy.

Balance of international payments requires:

$$q_t\left[bf_t + im_t - \left(1 + r_{t-1}^*\right)bf_{t-1}\right] = im_t^* \tag{19}$$

where in solving the model we impose the terminal condition that $\Delta bf = 0$ to find the equilibrium real exchange rate.

The real exchange rate is defined as:

$$q_t = \frac{Q_t P_{h,t}^*}{P_{h,t}} \tag{20}$$

The real interest rate is calculated by the Fisher equation:

$$r_t = R_t - E_t \pi_{t+1} \tag{21}$$

All shocks of the model, except for the productivity shock, are assumed to follow an AR(1) process in natural logarithm:

[4] In deriving this, it is assumed that full PPP holds in the long run, such that $\frac{P_h}{P} = \frac{P_h^*}{P} = 1$.

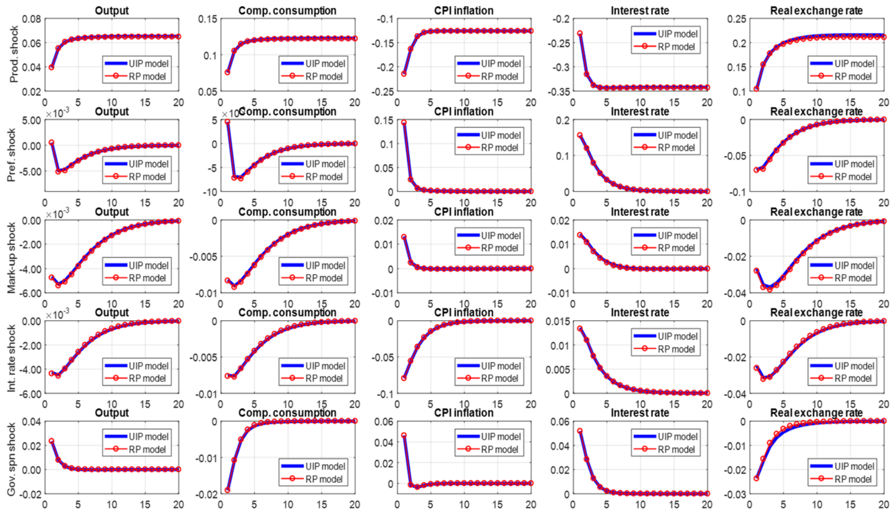

Fig. 1 Key IRFs of the UIP and RP models

$$\widehat{\varepsilon}_{i,t} = \rho_i \widehat{\varepsilon}_{i,t-1} + u_{i,t} \tag{22}$$

where $i = j, \pi, R, g$. The productivity shock, whose impact is assumed to be permanent, is let follow a simple ARIMA (1,1, 0) process:

$$\widehat{\varepsilon}_{z,t} - \widehat{\varepsilon}_{z,t-1} = \Gamma - \delta\left(\widehat{\varepsilon}_{z,t-1} - \widehat{\varepsilon}_{z,t-2}\right) + u_{z,t} \tag{23}$$

where Γ is a constant, δ is the mean-reversing parameter. All u's in the shock processes are *iid*.

3.2 The RP Model Equivalent

To construct the RP model equivalent, recall as reviewed earlier that arbitrage and the law of one price in a world with state-contingent nominal bonds implies $\frac{U_c(s_t,s_0)}{U_c^*(s_t,s_0)} = \Theta \frac{P(s_t,s_0)}{P^*(s_t,s_0)Q(s_t,s_0)}$ (Eq. (4) in the last section). Given that $U_t = \varepsilon_{j,t}\left(\ln c_t - \psi \frac{n_t^{1+\eta}}{1+\eta}\right)$ and hence $U_c = \varepsilon_{j,t} c_t^{-1}$ with our model, international risk sharing implies the RP condition:

$$\widehat{q}_t = \left(\widehat{c}_t - \widehat{c}_t^*\right) - \left(\widehat{\varepsilon}_{j,t} - \widehat{\varepsilon}_{j,t}^*\right) \tag{24}$$

which ties the real exchange rate to the relative consumption of the two economies, subject to the difference in the two economies' time preference shocks. Hence, the

RP equivalent of the standard UIP model simply replaces the UIP Eq. (11) with (24), ceteris paribus.

3.3 Empirical IRFs of the Two Model Versions

Figure 1 compares the key impulse response functions of the two models assigned the same parameter values.[5] Plainly the two models solve identically, as predicted by the theory; so RP (red, marked) and UIP (blue, unmarked) work in exactly the same manner.

This verification is of some importance, as it has been widely believed in previous work that the two models are different. In this previous work, risk-pooling by consumers under state-contingent asset markets has been regarded as a stronger hypothesis about consumption than UIP enforced by arbitrage and rational expectations in non-contingent debt markets. This includes both our previous papers, Gali and Monacelli (2005), and Gali (2020). In this they follow Chari et al. (2002) and Obstfeld and Rogoff (1995) who also show that UIP under non-contingent debt delivers risk-pooling only in expected form. Others who examine the effects of financial market incompleteness (i.e. the lack of state-contingent assets) in models different from these New Keynesian ones include Baxter and Crucini (1995) and Levine and Zame (2002); however, these models are rather different from ours so their results are not comparable with ours.[6]

It might be asked whether the specific assumptions used in our New Keynesian two-country model make any difference to our conclusion that the two model set-ups are equivalent. It seems they do not: if we substitute a production function with capital for our restricted labour-only production function, it makes no difference to the equivalence of UIP and risk-pooling, even though it adds the investment shock to aggregate demand. Further, though we assume both countries' utilities are logarithmic in consumption, substituting CRRA utility with different intertemporal elasticities makes no difference, either; nor do the differences in openness and other trade coefficients (which in our tests below are all estimated).[7] Hence the proposition is robust to these assumptions.

[5] For the purpose of illustration we only show the IRFs of a selected set of home variables in response to the home shocks. The other IRFs are available on request.

[6] The BC model assumes an integrated world bond market with the same (world) interest rate everywhere which implies a fixed real exchange rate, and the model has neither a nominal exchange rate nor an inflation rate in either country. LZ is a general model of a closed economy in which only riskless bonds are traded at all dates; it lacks a second open economy with a varying real exchange rate, but is similar to BC with a fixed real exchange rate and a common real interest rate. Our models differ from these set-ups as it allows for a variable real exchange rate, with a floating nominal exchange rate, different inflation rates and different monetary policies for the two economies; the real exchange rate, being the relative price of the two commodities in this two-country world, acts as a price of risk-sharing. It is the movement of this price and the associated change in real interest rates that equilibrate the financial market in this two-country world.

[7] This can be seen from the generalisation of the equivalence proposition to different CRRA intertemporal elasticities, which we elaborate in the appendix.

Table 1 Average (OLS) estimates of UIP regressions

UIP regression: $E_t\hat{q}_{t+1} - \hat{q}_t = a + b\left[\left(R_t - E_t\pi_{t+1}\right) - \left(R_t^* - E_t\pi_{t+1}^*\right)\right] + e_t$		
	a	b
'True' values	0	1
Mean OLS estimates	-0.4147	0.8380
(and standard errors)	(0.4488)	(0.1006)
Rejection rate of $H_0 : a = 0, b = 1$ at the 5% level		94.7%

4 Single-Equation Tests of Risk-Pooling and UIP

The mass of the existing literature testing UIP and risk-pooling is based on single-equation tests. It is carefully reviewed in our previous paper, MOZ1, which we update here, using our current model. On the issue of consumer risk-pooling across borders it is generally agreed according to a variety of direct empirical tests that there is no evidence of it or of uncovered interest parity, UIP. Examples are for UIP Delcoure, et al. (2003) and Isard (2006), and for consumption risk-pooling Obstfeld (1989), Backus and Smith (1993), Canova and Ravn (1996), Crucini (1999), Hess and Shin (2000), Razzak (2013). The empirical testing in this work is reviewed below.

As discussed in our previous paper the largescale bias found in these tests renders them quite untrustworthy.

4.1 Single-Equation UIP Tests

Here we show first how the UIP forecasting regression is highly biased.

Table 1 details the results of a Monte Carlo experiment on this single-equation forecasting test used in this literature. The experiment carries out the test on the assumption that our DSGE model which contains UIP/risk-pooling is the true model. Thus, by estimating the UIP equation alone as a regression using 1000 sets of parallel pseudo data generated by the DSGE model, we find that the OLS estimate of the predicted coefficient for the change in the real exchange rate from the current real interest rate differential (b) is on average biased downwards by 16% (Thus, while the theoretical true value of this coefficient should be 1, the average OLS estimate is 0.84). When the null hypothesis that '$H_0 : a = 0, b = 1$' (which implies the existence of UIP) is tested against the pseudo data at the 5% significance level, the hypothesis is rejected 94.7% of the time, while if the test is unbiased the rejection rate should be 5% only. Hence, this single-equation test is highly biased towards the rejection of UIP (For a reference we also show the distributions of the estimates of a and b of this regression in Fig. 2).

This single-equation bias comes from small sample bias in OLS, as can be seen from the scatter diagrams, illustrated by Fig. 3, for 11 examples of the OLS sample regressions, each varying greatly in slope and intercept.

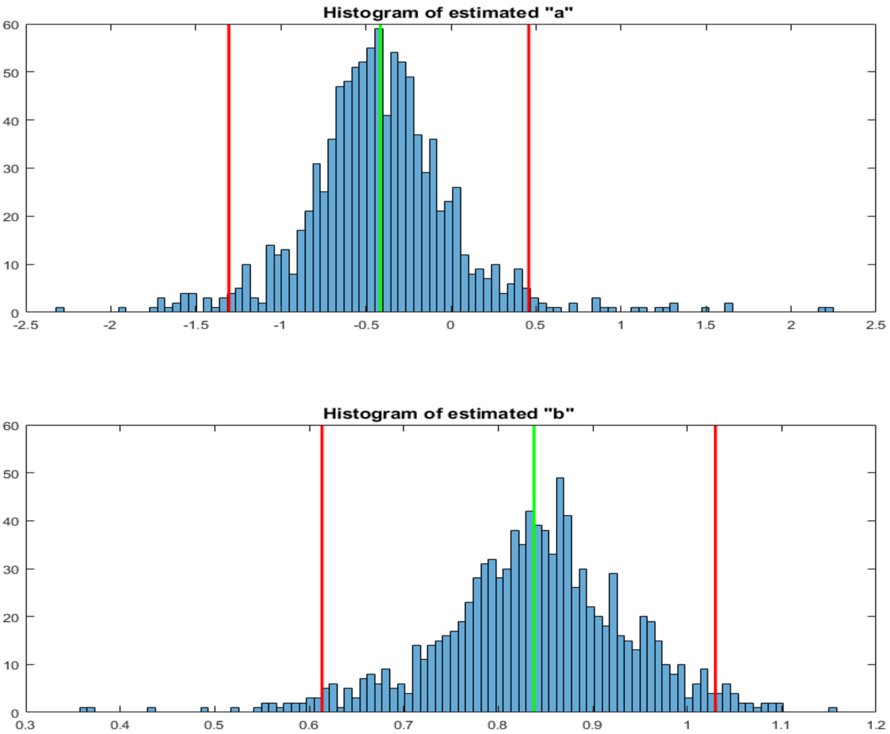

Fig. 2 Distributions of (OLS) estimates of UIP regressions

4.2 Risk-Pooling Hypothesis Tests

If we turn now to the single-equation tests of the risk-pooling hypothesis, we see that the literature usually examines two time series – of the consumption differential and the real exchange rate – allowing for a random *iid* error: $\left(\hat{c}_t - \hat{c}_t^*\right) = a + b\hat{q}_t + e_t$. Two approaches are usually used: one is based on cointegration tests; the other is based on testing the RP equation directly.

4.2.1 Tests of Cointegration

Here the question is whether the error created from the difference between the consumption differential and the real exchange rate, e_t, behaves in line with the risk-pooling hypothesis. Because both the consumption differential and the real exchange rate are non-stationary, one may here carry out a cointegration test, to see whether the two series vary together as the risk-pooling hypothesis states: this test tests whether the error from the risk-pooling equation is stationary or not. Typically, studies find a lack of cointegration, rejecting the hypothesis.

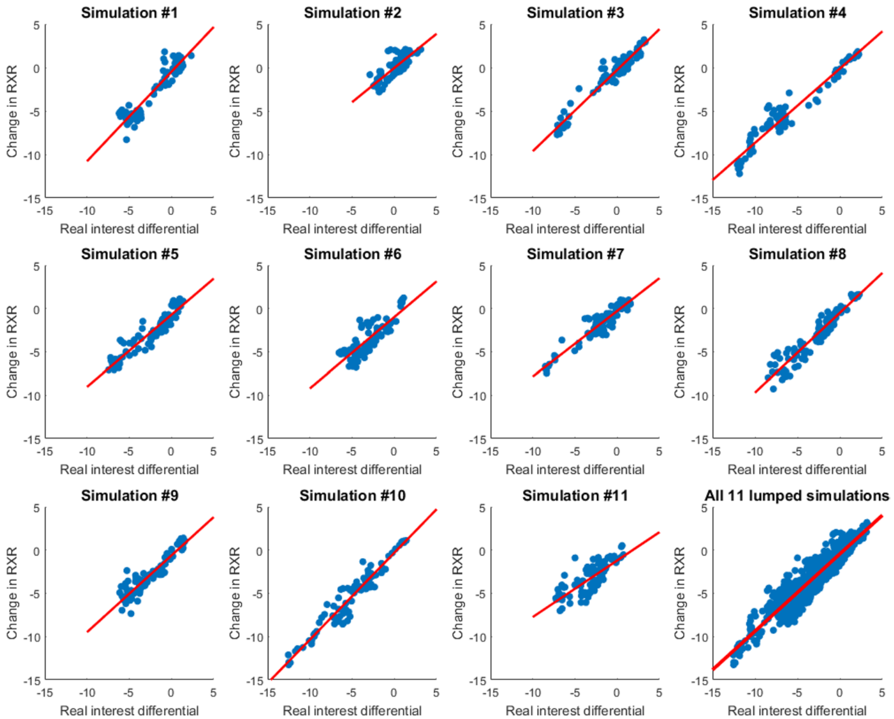

Fig. 3 Samples of (OLS) estimated UIP regressions

Table 2 Rejection rate of cointegration between consumption differential and real exchange rate

ADF test with drift							
lag = 1	lag = 2	lag = 3	lag = 4	lag = 5	lag = 6	lag = 7	lag = 8
34.3%	43.8%	50.2%	55.5%	59.7%	65.9%	70.2%	73.1%
ADF test with drift and trend							
lag = 1	lag = 2	lag = 3	lag = 4	lag = 5	lag = 6	lag = 7	lag = 8
57.3%	66.4%	70.2%	75.4%	79.1%	82.6%	84.4%	87.2%

The problem, however, is that the risk-pooling equation includes the relative shock to consumers' time preference $\left(\hat{\varepsilon}_{j,t} - \hat{\varepsilon}^{*}_{j,t}\right)$ as derived in the structural model. This is an exogenous variable, not an *iid* shock. It could be recovered from the two countries' Euler equations; but this is not usually done and if done would need to respect the rational expectations restrictions on expected future consumption in the Euler equations coming from the whole model solution. It is plainly an important time-series shock, which is included in the structural model. Simply leaving it out of the regression as in existing empirical work would create omitted variable bias for the estimated equation, which is a serious (and possibly fatal) specification error.

Table 3 Average (IV) estimates of RP regressions

RP regression: $(\hat{c}_t - \hat{c}_t^*) = a + b\hat{q}_t + e_t$		
	a	$b(= 1/\sigma)$
'True' values	0	1
Mean IV estimates	-0.1087	0.9692
(and standard errors)	(0.0886)	(0.0339)
Rejection rate of $H_0 : a = 0, b = 1/\sigma$ at the 5% level		88.7%

To find out what this problem might do to these cointegration tests, we again run a Monte Carlo experiment as above, noting that by construction there is cointegration between the consumption differential and the real exchange rate. We then compute how frequently cointegration is rejected by testing the stationarity of the residual of the risk-pooling regression for each sample; cointegration is rejected if the ADF test fails to reject the null hypothesis of unit root.

Table 2 shows that, depending on the lag and trend assumptions used in the test, the rejection rate of cointegration at the 5% significance level lies between 34% and87%.[8] Thus, the test is very strongly biased against cointegration: the risk-pooling model from which these errors come implies cointegration on the true equation, but the general lack of cointegration comes from the omitted relative shock to consumers' time-preference in the risk-pooling regression. Effectively, it is this omitted shock that ensures cointegration.

4.2.2 Regression Equations for Risk-Pooling

Another widely used test of the risk-pooling hypothesis tests the estimates of a and b of the risk-pooling regression, in a similar way to the test applied to the UIP regression reviewed above. The difference is that on this occasion the null hypothesis changes to '$H_0 : a = 0, b = 1/\sigma$', as implied by the macro model. We can use the same Monte Carlo experiment as above to examine the bias of the test at the 5% significance threshold.

Table 3 shows the mean IV estimate of a to be -0.11 against the true value of zero, and that of b to be 0.97 against the true value of one.[9] Clearly, both these estimates are biased downwards. The rejection rate of the null hypothesis of '$H_0 : a = 0, b = 1/\sigma$' at the 5% significance level is 88.7%; hence, again, we see that the single-equation test massively over-rejects the risk-pooling hypothesis while it is in fact true (Again, we show the distributions of the estimates of a and b in Fig. 4 for references).

What we have found therefore is that, if the risk-pooling model is correct, the regressions performed on the pseudo data generated from it will spuriously

[8] Given the real exchange rate is endogenous, when estimating $(\hat{c}_t - \hat{c}_t^*) = a + b\hat{q}_t + e_t$ to find the regression residuals, we use the IV method in place of the OLS method; the instruments are chosen to be the most recent four lagged values of the real exchange rate itself.

[9] Note that with log utility $\sigma = 1$ so that $b = \frac{1}{\sigma} = 1$.

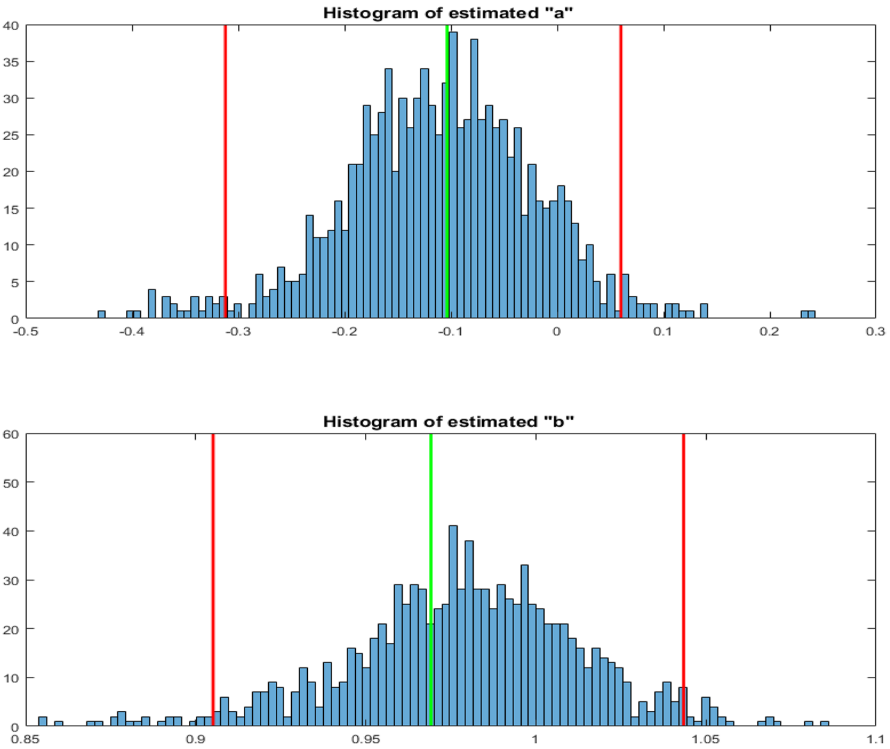

Fig. 4 Distributions of (IV) estimates of RP regressions

reject the true relationship between the real exchange rate and relative consumption, and also spuriously suggest a lack of cointegration between them because a key error in this relationship (i.e., the relative shock to consumers' time-preference) is omitted – an important mis-specification. In addition, small sample bias will occur here as for UIP, with data variation in the small samples being high relative to that in the population. This strong bias towards the rejection of risk-pooling in single-equation tests is therefore coming from omitted variable bias on top of the small sample bias that also bedevils the UIP tests.

Interestingly, Brandt et al. (2006) exhibit similar skepticism over the literature's rejection of risk-pooling – they cite the evidence from financial asset market relationships, to argue that the small marginal utility differential implied by the real exchange rate as compared with high domestic equity premium volatility suggests that cross-border insurance is playing a key role and, as they put it, 'international risk-sharing is better than you think'. However, as they show, there are many puzzles in reconciling this with other ways of measuring international risk-sharing in asset market behaviour.

Table 4 P-values of DSGE model by currency pair against USD

Currency	Country	Indirect inference full-model test of UIP/risk-pooling	Burnside (2019) single-equation test of UIP
AUD	Australia	0.150	0.006
CAD	Canada	0.099	0.009
DKK	Denmark	0.090	0.001
EUR	Euro Area	0.117	0.093
JPY	Japan	0.079	0.003
NOK	Norway	0.063	0.047
NZD	New Zealand	0.102	0.000
SEK	Sweden	0.079	0.904
CHF	Switzerland	0.098	0.014
GBP	UK	0.133	0.002

5 Is There Consumer Risk-Pooling in the Data? The Indirect Inference Test Revisited

As reviewed earlier, by single-equation tests Burnside (2019) rejected UIP – proven here as identical to having full risk-pooling – for a dozen pairs of industrialised economies. In this section we report our indirect inference, full-model test results for the same currency pairs against the US dollar based on pretty much the same sample period. The data, observed between 1971Q1 and 2018Q4, are collected from Euro-area statistics, FRED, the IMF and the OECD; and are processed in the standard manner for them to be used by DSGE models. Values of the structural parameters are selected by a grid search over the permissible parameter space for them to minimise the distance between the model and the data.[10] The p-values of the tests are reported in comparison with Burnside's in Table 4.

As can be seen, while only two out of the 10 currency pairs (i.e., *EUR* and *EK*) in the Burnside test were found to comply with UIP at the 5% significance level, we find this to be the victim of bias to over-rejection by the single-equation method as when this bias is circumvented by our indirect inference fullmodel test the hypothesis of UIP/risk-pooling is upheld – for all the currency pairs – generally with a high p-value exceeding the 5% threshold. Hence, there is strong evidence of the wide existence of international risk-sharing for consumption smoothing. The earlier 'empirical consensus' that UIP fails to fit, or the 'puzzle' that consumer risk-pooling is hard to find in the data despite the completeness of the international financial market, appears to be a statistical artefact that came from the misuse of single-regression tests on this issue. Open economy macro models in their 'standard' form, as assessed here, suffice to explain the

[10] This is in essence the indirect inference method for estimation as detailed in MOZ1 and MOZ2. Due to the large number of economy pairs we estimate, we omit the sets of the estimated parameter values for conciseness. Both these parameter values and the data are available on request.

key data features including those of the real exchange rate in a formal probability test; the 'more advanced' models that attempt to resolve the 'puzzle' by complicating the model structure in various ways (such as Chari et al. 2002) only complicate it unnecessarily and may damage the fit to the data in the process.

6 Conclusion

In this note supplementing our previous work (MOZ1 and MOZ2) we have set out a full New Keynesian DSGE model of an open economy, paired with a model of another economy with which it trades and shares cross-border financial transactions—this economy is in all cases the US. We have shown, for the first time as far as we are aware, that the model behaves identically under risk-pooling with contingent assets and uncovered interest parity, UIP, with non-contingent bonds. We have tested the UIP/risk-pooling hypothesis in 10 developed country pairs under the powerful indirect inference testing procedure and in all cases we do not reject the hypothesis. While it has been usual to consider the hypothesis as not holding up empirically, this view has emerged from tests on single-equation studies which do not impose the full set of restrictions that bind in a full structural DSGE model. Thus when these are imposed, as is appropriate, the hypothesis is upheld by the data universally.

Appendix

A: Listing of the Linearised Model

Home Economy

• Demand for home goods:

$$\widehat{c}_{h,t} = E_t\widehat{c}_{h,t+1} + \Upsilon_1\left(E_t\widehat{im}_{t+1} - \widehat{im}_t\right) - \Upsilon_2\frac{1}{1+r}\left(r_t - r\right) - \Upsilon_2\left(E_t\widehat{\varepsilon}_{j,t+1} - \widehat{\varepsilon}_{j,t}\right) \tag{A.1}$$

where $\Upsilon_1 = \left[1 + \frac{1+\left(\frac{\alpha}{1-\alpha}\right)^{\frac{1}{v}}\left(\frac{im}{y}\right)^{\frac{v-1}{v}}\left(\frac{c_h}{y}\right)^{\frac{1-v}{v}}}{\left(\frac{v-1}{v}\right)\left(\frac{\alpha}{1-\alpha}\right)^{\frac{1}{v}}\left(\frac{im}{y}\right)^{\frac{v-1}{v}}\left(\frac{c_h}{y}\right)^{\frac{1-v}{v}}}\right]^{-1}, \Upsilon_2 = \left[1 + \frac{\left(\frac{v-1}{v}\right)\left(\frac{\alpha}{1-\alpha}\right)^{\frac{1}{v}}\left(\frac{im}{y}\right)^{\frac{v-1}{v}}\left(\frac{c_h}{y}\right)^{\frac{1-v}{v}}}{1+\left(\frac{\alpha}{1-\alpha}\right)^{\frac{1}{v}}\left(\frac{im}{y}\right)^{\frac{v-1}{v}}\left(\frac{c_h}{y}\right)^{\frac{1-v}{v}}}\right]^{-1}.$

• Demand for imports:

$$\widehat{im}_t = \Psi_1\widehat{c}_{h,t} - \Psi_2\widehat{q}_t \tag{A.2}$$

where $\Psi_1 = \left[\frac{\left(\frac{1}{q}\right)\left(\frac{c_h}{y}\right)\left(\frac{im}{y}\right)^{-1}+\left(\frac{1}{q}\right)\left(\frac{1}{v}\right)\left(\frac{\alpha}{1-\alpha}\right)^{\frac{1}{v}}\left(\frac{c_h}{y}\right)^{\frac{1}{v}}\left(\frac{im}{y}\right)^{-\frac{1}{v}}-\left(\frac{v-1}{v}\right)\left(\frac{1-\alpha}{\alpha}\right)^{\frac{1}{v}}\left(\frac{c_h}{y}\right)^{\frac{v-1}{v}}\left(\frac{im}{y}\right)^{\frac{1-v}{v}}}{1+\frac{1}{v}\left(\frac{1-\alpha}{\alpha}\right)^{\frac{1}{v}}\left(\frac{c_h}{y}\right)^{\frac{v-1}{v}}\left(\frac{im}{y}\right)^{\frac{1-v}{v}}-\frac{1}{q}\left(\frac{v-1}{v}\right)\left(\frac{\alpha}{1-\alpha}\right)^{\frac{1}{v}}\left(\frac{c_h}{y}\right)^{\frac{1}{v}}\left(\frac{im}{y}\right)^{-\frac{1}{v}}}\right]$

$, \Psi_2 = \left[\frac{1+\left(\frac{1-\alpha}{\alpha}\right)^{\frac{1}{v}}\left(\frac{c_h}{y}\right)^{\frac{v-1}{v}}\left(\frac{im}{y}\right)^{\frac{1-v}{v}}}{1+\frac{1}{v}\left(\frac{1-\alpha}{\alpha}\right)^{\frac{1}{v}}\left(\frac{c_h}{y}\right)^{\frac{v-1}{v}}\left(\frac{im}{y}\right)^{\frac{1-v}{v}}-\frac{1}{q}\left(\frac{v-1}{v}\right)\left(\frac{\alpha}{1-\alpha}\right)^{\frac{1}{v}}\left(\frac{c_h}{y}\right)^{\frac{1}{v}}\left(\frac{im}{y}\right)^{-\frac{1}{v}}}\right].$

- Supply of labour:

$$\hat{n}_t = \frac{1}{\eta}\hat{w}_t - \frac{1}{\eta}\Xi\hat{c}_{h,t} - \frac{1}{\eta}\left(\frac{1}{\Upsilon_2} - 1\right)\widehat{im}_t \tag{A.3}$$

where $\Xi = \left[\frac{1+\frac{1}{v}\left(\frac{\alpha}{1-\alpha}\right)^{\frac{1}{v}}\left(\frac{im}{y}\right)^{\frac{v-1}{v}}\left(\frac{c_h}{y}\right)^{\frac{1-v}{v}}}{1+\left(\frac{\alpha}{1-\alpha}\right)^{\frac{1}{v}}\left(\frac{im}{y}\right)^{\frac{v-1}{v}}\left(\frac{c_h}{y}\right)^{\frac{1-v}{v}}}\right]$.

- Production function:

$$\hat{y}_t = \hat{\varepsilon}_{z,t} + \hat{n}_t \tag{A.4}$$

- Real marginal cost:

$$\widehat{mc}_t = \hat{w}_t - \hat{\varepsilon}_{z,t} \tag{A.5}$$

- Domestic price inflation:

$$\pi_{h,t} = \beta E_t\pi_{h,t+1} + \kappa\widehat{mc}_t + \hat{\varepsilon}_{\pi,t} \tag{A.6}$$

where $\kappa = \frac{(1-\omega)(1-\beta\omega)}{\omega}$.

- CPI inflation:

$$\pi_t = (1-\alpha)\pi_{h,t} + \alpha\pi^*_{h,t} + \alpha\Delta\hat{Q}_t \tag{A.7}$$

where α is openness.

- Taylor rule:

$$R_t = \rho_R R_{t-1} + \left(1-\rho_R\right)\left[r + \phi_\pi\pi_t + \phi_y\left(\hat{y}_t - \hat{y}_{t-1}\right)\right] + \hat{\varepsilon}_{R,t} \tag{A.8}$$

- Government spending:

$$\hat{g}_t = \hat{\varepsilon}_{g,t} \tag{A.9}$$

- Market clearing:

$$\hat{y}_t = \frac{c}{y}\hat{c}_{h,t} + \frac{g}{y}\hat{g}_t + \frac{im^*}{y}\widehat{im}^*_t \tag{A.10}$$

- Fisher equation:

$$r_t = R_t - E_t\pi_{t+1} \tag{A.11}$$

- Balance of payment equation:

$$\frac{bf}{y}\widehat{bf}_t = \frac{bf}{y}\left(r^*_{t-1} - r^*\right) + (1+r^*)\frac{bf}{y}\widehat{bf}_{t-1} + \frac{1}{q}\frac{im^*}{y}\left(\widehat{im}^*_t - \hat{q}_t\right) - \frac{im}{y}\widehat{im}_t \tag{A.12}$$

- Uncovered interest parity:

$$\widehat{q}_t - E_t\widehat{q}_{t+1} = R_t^* - R_t - \left(E_t\pi_{t+1}^* - E_t\pi_{t+1}\right) \quad \text{(A.13)}$$

• Nominal exchange rate:

$$\Delta\widehat{Q}_t = \Delta\widehat{q}_t - \pi_{h,t}^* + \pi_{h,t} \quad \text{(A.14)}$$

Foreign Economy

The foreign economy equations are in-form the same as the home economy's, except that where the exchange rate terms are involved, the terms take an opposite sign. Similarly, all the steady-state exchange rate terms are inverted.

B: Generalisation of the Equivalence between UIP and RP to different CRRA Intertemporal Elasticities

From RP to UIP

Given the RP condition:

$$\sigma\widehat{c}_t - \sigma^*\widehat{c}_t^* = \widehat{q}_t - v_t \quad \text{(B.1)}$$

where $v_t = \widehat{\varepsilon}_{j,t}^* - \widehat{\varepsilon}_{j,t}$ is the difference in the preference shocks in the two economies. Substituting out consumption with the Euler equations yield:

$$\begin{aligned}
-\sigma\tfrac{1}{\sigma}\left(\tfrac{r_t}{1-B^{-1}} - \widehat{\varepsilon}_{j,t}\right) + \sigma^*\tfrac{1}{\sigma^*}\left(\tfrac{r_t^*}{1-B^{-1}} - \widehat{\varepsilon}_{j,t}^*\right) &= \widehat{q}_t - v_t \\
-\left[r_t - \left(1 - B^{-1}\right)\widehat{\varepsilon}_{j,t}\right] + \left[r_t^* - \left(1 - B^{-1}\right)\widehat{\varepsilon}_{j,t}^*\right] &= \left(1 - B^{-1}\right)\left(\widehat{q}_t - v_t\right) \\
-r_t + r_t^* - \left(1 - B^{-1}\right)v_t &= \left(1 - B^{-1}\right)\left(\widehat{q}_t - v_t\right) \\
-r_t + r_t^* &= \left(1 - B^{-1}\right)\widehat{q}_t \\
E_t\widehat{q}_{t+1} - \widehat{q}_t &= r_t - r_t^*
\end{aligned} \quad \text{(B.2)}$$

which is the UIP condition.

From UIP to RP

Given the UIP condition:

$$E_t\widehat{q}_{t+1} - \widehat{q}_t = r_t - r_t^* \quad \text{(B.3)}$$

Substituting out the two interest rates using the Euler equations yield:

$$\begin{aligned}
E_t\widehat{q}_{t+1} - \widehat{q}_t &= \left(1 - B^{-1}\right)\left[-\sigma\widehat{c}_t + \sigma^*\widehat{c}_t^* - v\right] \\
-\left(1 - B^{-1}\right)\widehat{q}_t &= \left(1 - B^{-1}\right)\left[-\sigma\widehat{c}_t + \sigma^*\widehat{c}_t^* - v\right] \\
\sigma\widehat{c}_t - \sigma^*\widehat{c}_t^* &= \widehat{q}_t - v
\end{aligned} \quad \text{(B.4)}$$

which is the RP condition.

Thus, assuming CRRA (instead of log) utilities and allowing the intertemporal consumption elasticities to differ across the two economies does not affect the equivalence between UIP and RP in this New Keynesian setting; nor do the other model parameters, such as openness and other trade coefficients, as can be seen.

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