Reconnecting Exchange Rate and the General Equilibrium Puzzle

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Difficulty in Modeling Open Economies

- Quantities and prices
  - Kehoe, Midrigan and Pastorino (JEP2018): The Real Business Cycle models "were remarkably successful in matching these aggregate variables" such as output, consumption, investment, and hours
  - Smets and Wouters (AER2007): "[W]e have shown that modern micro-founded NNS models are able to fit the main US macro data very well"
- Asset prices
  - Kliem and Uhlig (QE2016): "It can be challenging to specify a dynamic stochastic general equilibrium (DSGE) model with reasonable macroeconomic implications as well as asset-pricing implications. ... The results move the model closer to reproducing observed risk premia, but at increasing cost to its macroeconomic performance"
- Asset price (exchange rate) equation is at the heart of the international spillover of shocks in open economies
  - Separation between real quantities and asset prices is impossible when modeling open economies

Exchange Rate Disconnect

- Nominal exchange rate is an important driver of aggregate fluctuations
  - Key link between international goods and asset markets
- But, endogenizing realistic exchange rate dynamics is a challenge
  - Lubik and Schorfheide (NBERMA2006): estimation efforts of general equilibrium models find fluctuations in nominal exchange rates to be unrelated to macroeconomic forces
    - The UIP shock u_t explains most of exchange rate fluctuations

$$\mathbb{E}_t \hat{e}_{t+1} - \hat{e}_t = \hat{R}_t - \hat{R}_t^* + u_t$$

- One form of the *exchange rate disconnect*

Reconnecting Exchange Rate

- To reconnect the exchange rate to the rest of the macroeconomy, we incorporate
  - (1) Macroeconomic volatility shocks that induce an endogenous time-varying currency risk premium
    - Asset pricing / macro-finance approach
- Evaluate the impacts from a direct shock to the exchange rate
  - (2) A direct shock to the international risk-sharing condition
    - Lubik and Schorfheide (NBERMA2006); Gabaix and Maggiori (QJE2015); Itskhoki and Mukhin (2019)

(1) Endogenous Risk Premium

- The empirical failure of UIP may be the result of linear approximation
  - Endogenous risk premium may arise from covariance between the SDFs and returns to international financial investments

- Second-order approximation of UIP condition

$$\begin{aligned}\mathbb{E}_t\hat{e}_{t+1} - \hat{e}_t &= \hat{R}_t - \hat{R}_t^* + u_t \\ &+\frac{1}{2}\left[cov_t(\hat{M}_{t+1}^*, -\Delta\hat{e}_{t+1}) - cov_t(\hat{M}_{t+1}, \Delta\hat{e}_{t+1})\right]\end{aligned}$$

  - Because of endogenous feedback through the covariance terms, the contribution of UIP shock u_t may decrease
  - Role of monetary policy: Backus et al. (2010); Benigno, Benigno and Nisticò (NBERMA2011)

(2) Limits-of-Arbitrage

- Gabaix and Maggiori (QJE2015): An adverse shock to the financial system can lead to positive *ex ante* returns from the carry trade, since financiers cannot fully engage in international arbitrage

- Itskhoki and Mukhin (2019) assume a direct exogenous shock which hinders the perfect international financial transactions
    - Note that Itskhoki and Mukhin (2019) also offer the micro foundations of such shocks

- We model the wedge in the international arbitrage condition as an exogenous shock, without imposing a specific micro foundation

$$\Omega_t u'\left(C_t^*\right) = u'\left(C_t\right) s_t$$

    - works like the UIP shock in Lubik and Schorfheide (NBERMA2006)

What We Do

- Estimate a two-country DSGE model with recursive preference and stochastic volatilities for the US and the Euro area, instead of using simulations or partial equilibrium methods
  - Third-order approximation
  - Full-information Bayesian approach with Sequential Monte Carlo (SMC) algorithm
- Let the data distinguish directly the relative contributions of various transmission mechanisms and which shocks can account for exchange rate fluctuations
  1. Shocks to stochastic volatilities of fundamental shocks
  2. Shock to the risk-sharing condition
- Test whether the estimated model can replicate *unconditional* properties found in the data such as the deviation from UIP

Need for GE Estimation I

- Benigno, Benigno and Nisticò (NBERMA2011): "the estimation of the model is really needed to evaluate its fit. To this purpose, an appropriate methodology should be elaborated to handle the features of our general second-order approximated solutions"
- Uribe (NBERMA2011): "I would like to [suggest] an alternative identification approach. It consists of a direct estimation of a DSGE model. ... Admittedly, estimating DSGE models driven by time-varying volatility shocks is not a simple task"
- Backus et al. (2010): the policy inertia parameter must be larger than the persistence of the volatility shock to produce the negative coefficient in the Fama regression
    - This condition can be only tested by GE estimation

Need for GE Estimation II

- Itskhoki and Mukhin (2019): “A natural deficiency of any one-shock model is that it can only speak to the relative volatilities of variables, while implying counterfactual perfect correlations between them”
  - Productivity and monetary shocks, “if too important in shaping the exchange rate dynamics, result in conventional exchange rate puzzles. To be clear, however, these shocks are still central for the dynamics of other macro variables, such as consumption, employment, output and prices levels”
- Engel (NBERMA2011): “[W]e need to know how well the model accounts for many other aspects of the macroeconomy—the volatility, comovement and time-series behavior of, for example, output, inflation, consumption, investment, and many other standard macro variables”
- Tension in accounting for between macro variables and the exchange rate (asset price) can be evaluated only by GE estimation
  - The forward discount puzzle is an *unconditional* phenomenon

Key Takeaways

- Using the estimated parameters, *conditionally*, several volatility shocks (to e.g. monetary policy and aggregate demand) can generate the negative correlation observed in the Fama regression
- By approximating the model to 3rd-order, the macro shocks begin to play a larger role in our variance decompositions; together with shocks to their volatilities, they explain 43% of the variance of nominal exchange rate changes
  - Exchange rate is not disconnected from the rest of the macroeconomy, once we move beyond linearization assumptions
- Still, the direct financial shock, reflecting limits-of-arbitrage, remain the key driver behind most (57%) of the variations in the nominal exchange rate
  - *Conditionally*, the direct shock to risk-sharing can also replicate the negative UIP correlations
- *The general equilibrium puzzle*

General Equilibrium Puzzle

- GE estimations illustrate the limitations of partial or conditional analyses in providing full resolutions to these empirical puzzles
- Even though the risk sharing shock and several volatility shocks can individually generate the observed Fama coefficient (close to or below zero), simulation data using our GE estimations and all shocks together do not replicate the observed pattern in the data - UIP holds
    - In GE estimations, there are multiple dynamics to fit, not just the exchange rate
- Ultimate quantitative relevance in resolving the unconditional empirical puzzles observed in data ought to be assessed in the GE framework
    - Additional elements into the model to explain one targeted empirical pattern must not come at a cost of deteriorating fit in other parts of the GE system

5 Puzzles Solved by Itskhoki and Mukhin (2019)

- Itskhoki and Mukhin (2019) solve 5 major puzzles in international finance only by incorporating the limits-of-arbitrage

1. ✓ Random walk in nominal exchange rates: Meese and Rogoff (JIE1983); Engel and West (JPE2005)
2. ✓ Very persistent real exchange rate dynamics: Rogoff (JEL1996)
    - Change in the real exchange rate dynamics between peg and float: Mussa (CR1986)
3. Law of one price violation - less volatile ToT: Engel (JPE1999); Atkeson and Burstein (AER2008)
4. Mildly negative correlation between real exchange rates and relative consumption: Backus and Smith (JIE1993)
5. ✓ UIP does not hold: Fama (JME1984)
    - Over-reaction in the reversal of the UIP puzzle: Engel (AER2016); Valchev (AEJM2020)

Related Literature: Exchange Rate Disconnect

- Gains from carry trade - delayed overshooting
  - Eichenbaum and Evans (QJE1995); Lustig and Verdelhan (AER2007); Burnside, Eichenbaum and Rebelo (JEEA2008); Brunnermeier, Nagel and Pedersen (NBERMA2008)
- Inability in accounting for exchange rate volatility
  - Engel and West (AER2004) and Bacchetta and Wincoop (AER2006)
- Macro-finance approach with habit or Epstein-Zin-Weil preference
  - Backus, Foresi, and Telmer (JoF2001); Backus et al. (2010); Verdelhan (JpF2010); Colacito and Croce (JPE2011); Benigno, Benigno and Nisticò (NBERMA2011); Bansal and Shaliastovich (RFS2012); Gourio, Siemer and Verdelhan (JIE2013); Engel (AER2016)
- Limits of arbitrage
  - Shleifer and Vishny (JoF1997); Adolfson et al. (JIE2007); Alvarez, Atkeson and Kehoe (REStud2009); Bacchetta and van Wincoop (AER2010); Gabaix and Maggiori (QJE2015); Itskhoki and Mukhin (2019)
- Deviation from rational expectations
  - Chakraborty and Evans (JME2008); Gourinchas and Tornell (JIE2004); Burnside et al. (REStud2011); Ilut (AEJM2012)
- Monetary policy and UIP puzzle
  - McCallum (JME1984); Backus et al. (2010); Benigno, Benigno and Nisticò (NBERMA2011)

Related Literature: Methodology

- GE estimation of two country model
  - Lubik and Schorfheide (NBERMA2006)
- Higher order approximation of two country model
  - Benigno, Benigno and Nisticò (NBERMA2011)
- Uncertainty (volatility) shocks
  - Bloom (ECMA2009); Fernández-Villaverde et al. (AER2015)
- Bayesian estimation of higher orderly approximated models
  - Fernández-Villaverde et al. (AER2011); Kliem and Uhlig (QE2016)
- The Central Difference Kalman filter
  - Andreasen (JAE2013)

Model

- Basically follows from Benigno, Benigno and Nisticò (NBERMA2011)
  - Two-country extension of a New Keynesian model
    1. Home country: US
    2. Foreign country: Euro area
  - Recursive preferences à la Epstein and Zin (ECMA1989) and Weil (JME1989)
  - Stochastic volatilities in various structural shocks
- Three types of agents in each country:
  1. Household
  2. Firms
  3. Central Bank

Household

- The representative household maximizes the utility function

$$V_t = \left[u\left(C_t, N_t\right)^{1-\sigma} + \beta \left(\mathbb{E}_t V_{t+1}^{1-\varepsilon} \right)^{\frac{1-\sigma}{1-\varepsilon}} \right]^{\frac{1}{1-\sigma}}$$

subject to the budget constraint

$$P_t C_t + B_t + \mathbb{E}_t[m_{t,t+1} \frac{D_{t+1}}{\pi_{t+1}}] = R_{t-1} B_{t-1} + D_t + W_t N_t + T_t$$

and aggregators:

$$C_t := \left[(1-\alpha)^{\frac{1}{\eta}} C_{H,t}^{\frac{\eta-1}{\eta}} + \alpha^{\frac{1}{\eta}} C_{F,t}^{\frac{\eta-1}{\eta}} \right]^{\frac{\eta}{\eta-1}}$$

$$C_{H,t} := \left[\int_0^1 C_{H,t}(j)^{1-\frac{1}{\mu}} dj \right]^{\frac{\mu}{\mu-1}}$$

$$C_{F,t} := \left[\int_0^1 C_{F,t}(j^*)^{1-\frac{1}{\mu}} dj^* \right]^{\frac{\mu}{\mu-1}}$$

Firms I

- Firm j produces one kind of differentiated goods $Y_t(j)$ subject to the production function

$$Y_t(j) = A_{W_t} A_t N_t(j)$$

  - A_t: Stationary and country-specific technology shock
  - $A_{W,t}$: Non-stationary worldwide technology component

$$\frac{A_{W,t}}{A_{W,t-1}} = \gamma$$

Firms II

- Firm j sets prices on a staggered basis à la Calvo (JME1983) to maximize the present discounted value of profits

$$\mathbb{E}_t \sum_{n=0}^{\infty} \theta^n m_{t,t+n} \frac{\Pi_{t+n}(j)}{P_{t+n}}$$

where

$$n\Pi_{t+n}(j) = nP_{H,t}(j) C_{H,t}(j) + (1-n) e_t P^*_{H,t}(j) C^*_{H,t}(j) - W_t N_t(j)$$

subject to the demand curves obtained from households' problem

$$C_{H,t}(j) = \left[\frac{P_{H,t}(j)}{P_{H,t}}\right]^{-\mu} (C_{H,t} + G_t)$$

$$C^*_{H,t}(j) = \left[\frac{P^*_{H,t}(j)}{P^*_{H,t}}\right]^{-\mu} C^*_{H,t}$$

the law of one price

$$P_{H,t}(j) = e_t P^*_{H,t}(j)$$

the firm-level resource constraint

$$nY_t(j) = n\left[C_{H,t}(j) + G_{H,t}(j)\right] + (1-n) C^*_{H,t}(j)$$

the indexation rule when its price is not re-optimized

$$P_{H,t+n}(j) = \tilde{P}_{H,t} \prod_{i=1}^{n} \bar{\pi}^{1-\iota} \pi^{\iota}_{H,t+i-1}$$

Central Bank

- Monetary policy rule is given by

$$\log\left(\frac{R_t}{R}\right) = (1-\phi_r)\left[\phi_\pi \log\left(\frac{\pi_t}{\bar{\pi}}\right) + \phi_y \log\left(\frac{Y_t}{\gamma Y_{t-1}}\right)\right] + \phi_r \log\left(\frac{R_{t-1}}{R}\right) + \log(\varepsilon_{R,t})$$

Aggregate Conditions

- Aggregating the firm-level resource constraint leads to

$$nY_t = \Delta_t \left[n\left(C_{H,t} + G_t\right) + (1-n)\, C^*_{H,t}\right]$$

where the price dispersion Δ_t is given by

$$\Delta_t := \int_0^1 \left[\frac{P_{H,t}(j)}{P_{H,t}}\right]^{-\mu} dj$$

- Same set of equilibrium conditions for the foreign country

International Risk Sharing

- International risk sharing condition is given by

$$\Omega_t Q_t = \left[\frac{u(C_t, N_t)}{u(C_t^*, N_t^*)}\right]^{1-\sigma} \frac{C_t^*}{C_t} \frac{e_t P_t^*}{P_t}$$

with

$$Q_{t+1} = Q_t \left(\frac{\left(V_{t+1}^*\right)^{1-\varepsilon} \mathbb{E}_t\left(V_{t+1}^{1-\varepsilon}\right)}{V_{t+1}^{1-\varepsilon} \mathbb{E}_t\left[\left(V_{t+1}^*\right)^{1-\varepsilon}\right]}\right)^{\frac{\sigma-\varepsilon}{1-\varepsilon}}$$

Ω_t: Shock to the international risk sharing condition
  - Interpreted as the time varying financial frictions considered in Gabaix and Maggiori (QJE2015) and Itskhoki and Mukhin (2019)

- Linearization yields

$$\mathbb{E}_t \hat{e}_{t+1} - \hat{e}_t = \hat{R}_t - \hat{R}_t^* + \mathbb{E}_t \hat{\Omega}_{t+1} - \hat{\Omega}_t$$

  - $\mathbb{E}_t \hat{\Omega}_{t+1} - \hat{\Omega}_t$ works like a UIP shock

Structural (Level) Shocks

1. $\log(A_t) = \rho_A \log(A_{t-1}) + \sigma_{A,t} u_{A,t}$
2. $\log(g_t) = (1-\rho_g)\log\bar{g} + \rho_g \log(g_{t-1}) + \sigma_{g,t} u_{g,t}$
3. $\log(\varepsilon_{R,t}) = \sigma_{\varepsilon_R,t} u_{\varepsilon_R,t}$
4. $\log(A_t^*) = \rho_A^* \log(A_{t-1}^*) + \sigma_{A,t}^* u_{A,t}^*$
5. $\log(g_t^*) = (1-\rho_g^*)\log\bar{g} + \rho_g^* \log(g_{t-1}^*) + \sigma_{g,t}^* u_{g,t}^*$
6. $\log(\varepsilon_{R,t}^*) = \sigma_{\varepsilon_R,t}^* u_{\varepsilon_R,t}^*$
7. $\log(\Omega_t) = \rho_\Omega \log(\Omega_{t-1}) + \sigma_{\Omega,t} u_{\Omega,t}$

Volatility Shocks

1. $\log(\sigma_{A,t}) = (1-\rho_{\sigma_A})\log(\sigma_A) + \rho_{\sigma_A}\log(\sigma_{A,t-1}) + \tau_A z_{\sigma_A,t}$
2. $\log(\sigma_{g,t}) = (1-\rho_{\sigma_g})\log(\sigma_g) + \rho_{\sigma_g}\log(\sigma_{g,t-1}) + \tau_g z_{\sigma_g,t}$
3. $\log(\sigma_{\varepsilon_R,t}) = (1-\rho_{\sigma_{\varepsilon_R}})\log(\sigma_{\varepsilon_R}) + \rho_{\sigma_{\varepsilon_R}}\log(\sigma_{\varepsilon_R,t-1}) + \tau_{\varepsilon_R} z_{\sigma_{\varepsilon_R},t}$
4. $\log(\sigma^*_{A,t}) = (1-\rho^*_{\sigma_A})\log(\sigma^*_A) + \rho^*_{\sigma_A}\log(\sigma^*_{A,t-1}) + \tau^*_A z^*_{\tau_A,t}$
5. $\log(\sigma^*_{g,t}) = (1-\rho^*_{\sigma_g})\log(\sigma^*_g) + \rho^*_{\sigma_g}\log(\sigma^*_{g,t-1}) + \tau^*_g z^*_{\sigma_g,t},$
6. $\log(\sigma^*_{\varepsilon_R,t}) = (1-\rho^*_{\sigma_{\varepsilon_R}})\log(\sigma^*_{\varepsilon_R}) + \rho^*_{\sigma_{\varepsilon_R}}\log(\sigma^*_{\varepsilon_R,t-1}) + \tau^*_{\varepsilon_R} z^*_{\sigma_{\varepsilon_R},t}$
7. $\log(\sigma_{\Omega,t}) = (1-\rho_{\sigma_\Omega})\log(\sigma_\Omega) + \rho_{\sigma_\Omega}\log\sigma_{\Omega,t-1}) + \tau_\Omega z_{\sigma_\Omega,t}$

Estimation Strategy I

- Solve the model using a third-order approximation
  - Higher-order perturbation method with pruning: Andreasen, Fernández-Villaverde, and Rubio-Ramírez (REStud2018)
- Estimate the model with a full-information Bayesian approach
  - Standard Kalman filter is not applicable to evaluate likelihood
  - Approximate the likelihood function using the Central Difference Kalman Filter: Andreasen (JAE2013)
    - Much faster than a particle filter
    - A quasi-maximum likelihood estimator can be consistent and asymptotically normal for DSGE models solved up to the third order

Estimation Strategy II

- Adopt the SMC algorithm developed by Creal (2007) and Herbst and Schorfheide (JAE2014, 2015) to approximate posterior distributions
  - Amendable to parallel computing
- It takes about 40 days to estimate parameters using the UW server with 36 core processors!

Data

- Data: Lubik and Schorfheide (NBERMA2006)
  - Real GDP growth rate
  - Inflation rate of GDP deflator
  - Three-month TB/Euribor rate for the US and the Euro area
  - Depreciation of USD/Euro exchange rate
- Sample period: 1987Q1–2008Q4
  - Inflation was relatively stable
  - Not constrained by the ZLB

Priors

Parameter	Distribution	Mean	S.D.
ε	Gamma	5.000	0.500
σ	Gamma	2.000	0.250
θ	Beta	0.667	0.100
ι	Beta	0.500	0.150
θ^*	Beta	0.667	0.100
ι^*	Beta	0.500	0.150
ϕ_r	Beta	0.750	0.100
ϕ_π	Gamma	1.500	0.200
ϕ_y	Gamma	0.125	0.050
ϕ_r^*	Beta	0.750	0.100
ϕ_π^*	Gamma	1.500	0.200
ϕ_y^*	Gamma	0.125	0.050
$\rho_A, \rho_g, \rho_A^*, \rho_g^*, \rho_\Omega$	Beta	0.500	0.150
$\rho_{\sigma_A}, \rho_{\sigma_g}, \rho_{\sigma_{\epsilon_R}}, \rho_{\sigma_A}^*, \rho_{\sigma_g}^*, \rho_{\sigma_{\epsilon_R}}^*, \rho_{\sigma_\Omega}$	Beta	0.500	0.150
$100\sigma_A, 100\sigma_g, 100\sigma_A^*, 100\sigma_g^*, 100\sigma_\Omega$	Inverse Gamma	5.000	2.590
$100\sigma_{\epsilon_R}, 100\sigma_{\epsilon_R}^*$	Inverse Gamma	0.500	0.260
$\tau_A, \tau_g, \tau_{\epsilon_R}, \tau_A^*, \tau_g^*, \tau_{\epsilon_R}^*, \tau_\Omega$	Inverse Gamma	1.000	0.517

Posterior Estimates I

	Linear		2nd order	
Parameter	Mean	90% interval	Mean	90% interval
ε	5.127	[4.308, 5.999]	5.007	[4.389, 5.705]
σ	2.184	[1.875, 2.501]	2.180	[1.962, 2.419]
θ	0.594	[0.495, 0.707]	0.710	[0.665, 0.761]
ι	0.193	[0.048, 0.313]	0.143	[0.048, 0.236]
θ^*	0.672	[0.603, 0.748]	0.633	[0.581, 0.680]
ι^*	0.119	[0.030, 0.199]	0.140	[0.047, 0.234]
ϕ_r	0.790	[0.754, 0.831]	0.817	[0.785, 0.850]
ϕ_π	1.946	[1.715, 2.190]	1.947	[1.703, 2.160]
ϕ_y	0.274	[0.164, 0.383]	0.207	[0.139, 0.275]
ϕ_r^*	0.768	[0.717, 0.815]	0.771	[0.732, 0.816]
ϕ_π^*	2.017	[1.812, 2.244]	2.113	[1.911, 2.307]
ϕ_y^*	0.249	[0.147, 0.347]	0.207	[0.130, 0.288]

Posterior Estimates II

	Linear		2nd order	
Parameter	Mean	90% interval	Mean	90% interval
ρ_A	0.667	[0.494, 0.813]	0.652	[0.560, 0.732]
ρ_g	0.943	[0.910, 0.977]	0.839	[0.786, 0.884]
ρ_A^*	0.618	[0.530, 0.722]	0.551	[0.453, 0.643]
ρ_g^*	0.954	[0.927, 0.979]	0.968	[0.947, 0.989]
ρ_Ω	0.997	[0.995, 0.999]	0.997	[0.996, 0.999]
$100\sigma_A$	2.138	[1.337, 2.969]	3.003	[2.126, 3.868]
$100\sigma_g$	8.339	[6.913, 9.566]	8.864	[7.495, 10.060]
$100\sigma_{\epsilon_R}$	0.159	[0.135, 0.185]	0.154	[0.133, 0.176]
$100\sigma_A^*$	2.980	[1.916, 4.115]	2.781	[2.055, 3.417]
$100\sigma_g^*$	7.781	[6.613, 8.969]	4.706	[4.108, 5.333]
$100\sigma_{\epsilon_R}^*$	0.160	[0.137, 0.185]	0.161	[0.140, 0.183]
$100\sigma_\Omega$	6.885	[6.059, 7.711]	8.591	[7.538, 9.648]
$\log p(\mathcal{Y}^T)$	-673.902		-683.774	

Posterior Estimates III

	3rd order		3rd order with S.V.		No risk-sharing shock	
Parameter	Mean	90% interval	Mean	90% interval	Mean	90% interval
ε	4.388	[4.129, 4.625]	4.331	[3.993, 4.669]	4.139	[3.775, 4.439]
σ	2.615	[2.502, 2.774]	1.879	[1.682, 2.118]	2.427	[2.200, 2.628]
θ	0.708	[0.675, 0.742]	0.525	[0.473, 0.575]	0.521	[0.469, 0.565]
ι	0.140	[0.053, 0.256]	0.340	[0.212, 0.442]	0.587	[0.482, 0.673]
θ^*	0.495	[0.439, 0.539]	0.766	[0.713, 0.827]	0.840	[0.824, 0.858]
ι^*	0.330	[0.260, 0.416]	0.389	[0.248, 0.548]	0.616	[0.471, 0.792]
ϕ_r	0.749	[0.715, 0.793]	0.772	[0.703, 0.836]	0.685	[0.632, 0.725]
ϕ_π	2.208	[2.041, 2.360]	2.103	[1.893, 2.348]	1.803	[1.655, 1.946]
ϕ_y	0.123	[0.096, 0.152]	0.196	[0.164, 0.232]	0.103	[0.069, 0.139]
ϕ_r^*	0.745	[0.714, 0.772]	0.794	[0.733, 0.866]	0.699	[0.655, 0.739]
ϕ_π^*	1.428	[1.329, 1.489]	1.651	[1.462, 1.819]	1.380	[1.245, 1.499]
ϕ_y^*	0.085	[0.054, 0.116]	0.151	[0.099, 0.204]	0.089	[0.056, 0.122]
ρ_A	0.542	[0.456, 0.620]	0.481	[0.363, 0.590]	0.332	[0.126, 0.473]
ρ_g	0.983	[0.965, 1.000]	0.862	[0.757, 0.972]	0.553	[0.356, 0.701]
ρ_A^*	0.562	[0.486, 0.644]	0.822	[0.733, 0.928]	0.930	[0.903, 0.953]
ρ_g^*	0.947	[0.920, 0.988]	0.390	[0.245, 0.507]	0.581	[0.502, 0.649]
ρ_Ω	0.997	[0.995, 0.999]	0.955	[0.927, 0.990]	-	-
ρ_{σ_A}	-	-	0.683	[0.588, 0.780]	0.251	[0.090, 0.373]
ρ_{σ_g}	-	-	0.513	[0.373, 0.692]	0.386	[0.268, 0.512]
$\rho_{\sigma_{\epsilon_R}}$	-	-	0.739	[0.612, 0.882]	0.378	[0.304, 0.462]

Posterior Estimates IV

	3rd order		3rd order with S.V.		No risk-sharing shock	
Parameter	Mean	90% interval	Mean	90% interval	Mean	90% interval
$\rho^*_{\sigma_A}$	-	-	0.567	[0.454, 0.710]	0.105	[0.061, 0.146]
$\rho^*_{\sigma_g}$	-	-	0.337	[0.193, 0.461]	0.241	[0.156, 0.335]
$\rho^*_{\sigma_{\epsilon_R}}$	-	-	0.362	[0.189, 0.528]	0.356	[0.196, 0.501]
ρ_{σ_Ω}	-	-	0.389	[0.262, 0.498]	-	-
$100\sigma_A$	2.948	[2.218, 3.630]	2.048	[1.452, 2.528]	1.396	[1.014, 1.728]
$100\sigma_g$	8.108	[6.955, 9.136]	9.235	[8.100, 10.928]	4.616	[3.417, 5.520]
$100\sigma_{\epsilon_R}$	0.217	[0.172, 0.268]	0.144	[0.106, 0.186]	0.200	[0.143, 0.253]
$100\sigma^*_A$	1.749	[1.370, 2.117]	5.293	[4.034, 6.461]	11.140	[9.235, 13.468]
$100\sigma^*_g$	4.038	[3.405, 4.580]	7.734	[6.522, 8.799]	8.034	[6.393, 9.945]
$100\sigma^*_{\epsilon_R}$	0.285	[0.148, 0.430]	0.168	[0.107, 0.223]	0.179	[0.133, 0.227]
$100\sigma_\Omega$	6.589	[5.940, 7.360]	4.652	[3.833, 5.407]	-	-
τ_A	-	-	0.538	[0.408, 0.674]	1.087	[0.782, 1.427]
τ_g	-	-	0.862	[0.545, 1.115]	1.227	[0.851, 1.573]
τ_{ϵ_R}	-	-	1.339	[1.016, 1.686]	0.736	[0.570, 0.888]
τ^*_A	-	-	0.720	[0.582, 0.877]	0.987	[0.894, 1.121]
τ^*_g	-	-	1.162	[0.972, 1.338]	1.430	[1.142, 1.725]
$\tau^*_{\epsilon_R}$	-	-	1.287	[1.032, 1.553]	1.245	[0.930, 1.591]
τ_Ω	-	-	0.635	[0.486, 0.774]	-	-
$\log p(\mathcal{Y}^T)$	-775.060		-807.321		-919.449	

Summary: Posterior Estimates

- The estimates for the structural parameters do not differ much across the four specifications
  - As the degree of approximation becomes higher, the AR(1) coefficients for structural shocks tend to decrease
- The risk-sharing shock is absorbing some key empirical properties of the exchange rate (its persistence or random walk-like behavior)
  - Even in the baseline model (the third-order approximation with stochastic volatilities), the persistence coefficient on the risk-sharing shock to be very large and close to unity
  - When estimated without the risk sharing shock, the price indexation parameters and several $AR(1)$ coefficients all become larger
  - The log marginal data density $\log p(\mathcal{Y}^T)$ is also substantially lower (-919.4) than that in the baseline estimation (-807.3)

Relative Variances I

		$\Delta \log Y_t$	$\log \pi_t$	$\log R_t$	$\Delta \log Y_t^*$	$\log \pi_t^*$	$\log R_t^*$	d_t
Linear								
w/o:	u_A	0.690	0.280	0.382	0.994	0.954	0.940	0.977
	u_g	0.423	0.962	0.793	1.000	0.992	0.997	0.970
	u_{ϵ_R}	0.959	0.920	0.984	1.000	0.996	1.000	0.983
	u_A^*	0.985	0.933	0.919	0.667	0.242	0.307	0.963
	u_g^*	0.999	0.995	0.997	0.456	0.966	0.840	0.968
	$u_{\epsilon_R}^*$	1.000	0.996	0.999	0.955	0.952	0.985	0.989
	u_Ω	0.925	0.920	0.940	0.929	0.896	0.921	0.141
2nd order								
w/o:	u_A	0.837	0.331	0.377	0.986	0.952	0.913	0.979
	u_g	0.351	0.943	0.807	1.000	0.992	0.989	0.989
	u_{ϵ_R}	0.952	0.934	0.971	1.000	0.992	0.998	0.979
	u_A^*	0.979	0.936	0.951	0.590	0.262	0.270	0.965
	u_g^*	0.999	0.999	1.003	0.717	0.992	0.945	0.988
	$u_{\epsilon_R}^*$	1.000	0.997	0.999	0.949	0.947	0.984	0.990
	u_Ω	0.886	0.815	0.880	0.730	0.903	0.923	0.105
3rd order								
w/o:	u_A	0.830	0.315	0.290	0.936	0.935	0.910	0.936
	u_g	0.342	0.946	0.868	0.975	0.985	0.967	0.898
	u_{ϵ_R}	0.931	0.925	0.959	0.999	0.995	0.998	0.970
	u_A^*	0.986	0.934	0.942	0.621	0.355	0.394	0.989
	u_g^*	0.999	0.998	1.000	0.765	0.976	0.885	0.991
	$u_{\epsilon_R}^*$	0.999	0.988	0.997	0.821	0.790	0.964	0.932
	u_Ω	0.952	0.855	0.917	0.825	0.957	0.865	0.279

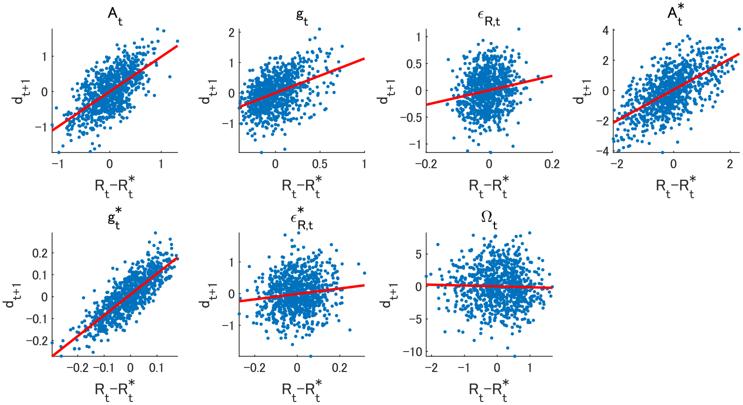
Relative Variances II

		$\Delta \log Y_t$	$\log \pi_t$	$\log R_t$	$\Delta \log Y_t^*$	$\log \pi_t^*$	$\log R_t^*$	d_t
3rd order with SV								
w/o:	$z_{\sigma A}$	0.905	0.734	0.815	0.998	0.991	0.997	0.984
	$z_{\sigma g}$	0.480	0.952	0.808	1.000	0.996	0.998	0.967
	$z_{\sigma \epsilon_R}$	0.913	0.692	0.957	1.000	0.996	1.000	0.920
	$z_{\sigma A}^*$	0.996	0.963	0.871	0.823	0.457	0.427	0.877
	$z_{\sigma g}^*$	0.999	0.999	0.998	0.475	0.994	0.993	0.998
	$z_{\sigma \epsilon_R}^*$	1.000	0.987	0.992	0.946	0.938	0.976	0.933
	$z_{\sigma \Omega}$	0.986	0.971	0.940	0.997	0.964	0.959	0.711
	$u_A, z_{\sigma A}$	0.830	0.523	0.664	0.998	0.984	0.993	0.975
	$u_g, z_{\sigma g}$	0.295	0.932	0.722	1.000	0.994	0.994	0.956
	$u_{\epsilon_R}, z_{\sigma \epsilon_R}$	0.907	0.673	0.956	1.000	0.996	1.000	0.915
	$u_A^*, z_{\sigma A}^*$	1.003	0.936	0.777	0.717	0.169	0.108	0.816
	$u_g^*, z_{\sigma g}^*$	0.999	0.998	0.998	0.338	0.992	0.988	0.997
	$u_{\epsilon_R}^*, z_{\sigma \epsilon_R}^*$	1.000	0.985	0.992	0.940	0.927	0.975	0.926
	$u_\Omega, z_{\sigma \Omega}$	0.976	0.932	0.859	0.995	0.934	0.941	0.425

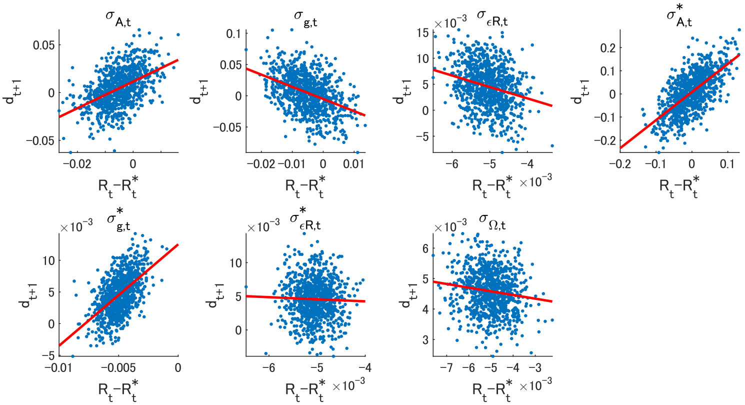
Summary: Relative Variances

- Excluding the international risk-sharing shock
  - 1st-order (linear): remaining macroeconomic shocks can explain only 14% of the exchange rate volatility
  - 2nd-order: 11%
  - 3rd order: 28%
  - 3rd order with SVs: 43%
- This result is consistent with findings in Benigno, Benigno and Nisticò (NBERMA2011) based on simulations
  - Macroeconomic uncertainties can induce a time-varying exchange rate risk premium that acts as a key source behind exchange rate fluctuations
- The direct risk-sharing shock still accounts for more than half (57%) of the exchange rate fluctuations
  - consistent with findings in Itskhoki and Mukhin (2019)
- The risk sharing shock is, however, not an important driver of fluctuations in output and inflation rates
  - Shocks except for the risk sharing shock can account for around 90% of volatilities in output and inflation rates

UIP Regressions I



UIP Regressions II



Summary: UIP Regressions

- While *all* of the macro level shocks generate a *positive* slope coefficient even with the third-order approximation, the risk-sharing shock generates a Fama coefficient in line with the empirics: close to and slightly below zero
- Volatility shocks to monetary policy both at home and abroad, to home demand, and to the risk-sharing wedge all replicate the negative UIP slope coefficients observed in the literature

Fama Coefficients in Actual vs Simulated Data

	Fama Coeff. $\widehat{a}_1$	95%CI	R^2
data	0.0477	$[-1.4919, \quad 1.5873]$	0.00
simulation with all shocks	0.7049	$[0.5302, \quad 0.8796]$	0.06
simulation without Ω_t	1.0839	$[0.9945, \quad 1.1732]$	0.36

General Equilibrium Puzzle I

- Several shocks can replicate the empirical regularity of a mildly negative Fama coefficient
    - They, however, rely on simulations with calibrated parameters and partial equilibrium or conditional analyses
    - All shocks but the proposed one are assumed to be absent
- The actual empirical UIP puzzle, on the other hand, is a pattern that manifests *unconditionally* in general equilibrium
    - Their relative contributions in general equilibrium need to be assessed in order to determine whether the proposed mechanisms are empirically relevant and significant
- In our GE estimates, all parameter values are obtained to fit not just one target variable (e.g. the exchange rate) but the full set of relevant open-economy macro dynamics

General Equilibrium Puzzle II

- Incorporating the risk-sharing shock does only lower the Fama coefficient (from 1.08 to 0.70) and the baseline model with the full set of shocks all together still generate a Fama slope coefficient close to unity
  - Other shocks than representing the limits-of-arbitrage (and some volatility shocks) are still important in accounting for open-economy macro dynamics
- The finding leaves us with *the general equilibrium puzzle* of exchange rate dynamics
  - The exchange rate is not disconnected from macro fundamentals, and that the risk-sharing shock can explain a large fraction of the exchange rate volatility, but their collective impact on actual exchange rate, unconditionally, is not quantitatively large enough to resolve the UIP puzzle

Others

- Broadly consistent results with the empirical regularities shown in Benigno, Benigno and Nisticò (NBERMA2011)

1. an increase in the volatility of the productivity shock depreciates the exchange rate
2. an increase in the volatility of the monetary policy shock appreciates the exchange rate
3. an increase in the volatility of the monetary policy shock produces excess foreign currency returns and deviations from the UIP

Conclusion

- The exchange rate is reconnected with the macroeconomy
  - Macroeconomic shocks, together with shocks to their volatility, can explain a significant portion of dollar-euro dynamics
  - The direct shock to the international risk-sharing condition, which represents the time-varying financial frictions that hinder the international arbitrage, is, however, a major driver for the observed exchange rate dynamics
- Their collective impact on actual exchange rate, *unconditionally*, is not quantitatively large enough to resolve the UIP puzzle
  - The general equilibrium puzzle

Future Studies

- The exact micro-foundation behind the direct shock to the risk sharing condition
- The stochastic volatilities of *news shocks*
- The local currency pricing
- A mechanism to resolve the UIP puzzle conditional on conventional shocks, such as technology and monetary policy shocks