Real Exchange Rates and Primary Commodity Prices

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INTRODUCTION

- Real exchange rates (RER) among large developed economies are:
  - very volatile.
  - very persistent.
  - notoriously hard to relate to fundamentals.
- The RER disconnect puzzle. Engel (1999), Obstfeld and Rogoff (2001).

Introduction

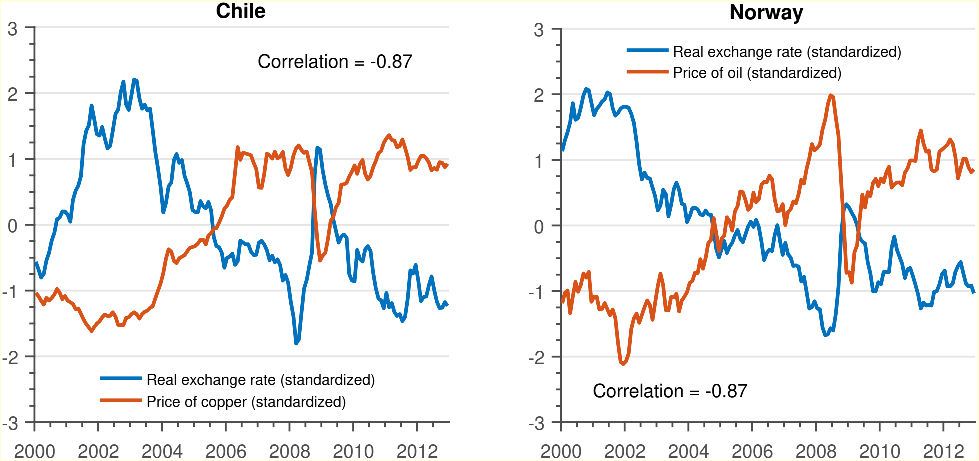
- Sticky prices and wages. (Chari, Kehoe, and McGrattan (2002))

- Segmented markets. (Itskhoki and Mukhin (2017))

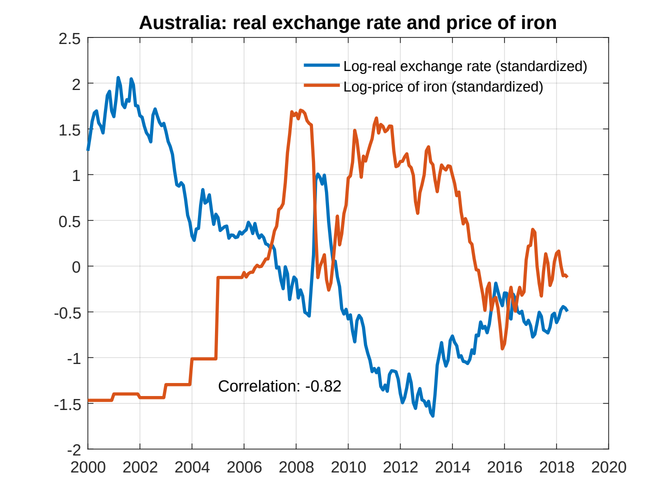
Introduction

- No such disconnect in **small** open economies.
- Betts and Kehoe (2004), Chen and Rogoff (2003), and Hevia and Nicolini (2013), Ricci, Milessi-Ferreti and Lee (2013).
- Commovement between RER and primary commodity prices (PCP):
  - Chile (Copper).
  - Norway (Oil).
  - Australia (Iron, Coal).

Two small open economies: Chile and Norway



AUSTRALIA



Australia: real exchange rate and price of iron
Log-real exchange rate (standardized)
Log-price of iron (standardized)
Correlation: -0.82
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020

Introduction

- We show that PCP can solve the disconnect puzzle for developed economies.
- Existing literature for large developed economies ignores primary commodities.
- It should not.

Introduction

- **Theoretical exercise:** incorporates primary commodity production.
  - Calibrate model to match volatility and persistence of PCPs (and other macro aggregates).
  - Equilibrium RERs almost as volatile and persistent as in the data.
  - RER and PCP highly correlated.
- **Data exercise:** substantial comovement between a few PCPs and RERs between Japan, UK and Germany against the US.
  - Model interpretation: shocks that move PCPs can account for a large fraction of the volatility and persistence of RERs.

Introduction

Why primary commodities?

- The top 10 commodities account for 18% of world trade in 2012 (12% in 1990).
    - Only the **direct** measure.
- Traded in competitive markets, where the law of one price holds.
- Very volatile and persistent.

Introduction

Potential mechanism

- Primary commodities are at the bottom of the production chain.
- Movements in PCP change costs.
- Assume:
  - Input-output matrices of the two countries are different enough.
  - Countries produce different commodities.
- Then, PCP changes affect final good prices asymmetrically:
  - the RER ought to change.

Model

- Two-country model plus: USA, Japan, and rest of the world (ROW).
- Three sectors: final goods (nontradable), intermediate goods, primary commodities.
  - Country 1 (USA) produces final good Y^1, intermediate good Q_1, and primary commodities X_1 and X_3.
  - Country 2 (Japan) produces final good Y^2, intermediate good Q_2, and primary commodities X_2 and X_3.
  - Country 3 (ROW) produces final good Y^3, and primary commodities X_1, X_2, and X_3.
- Financial autarky: trade balance is zero in each period.
- No capital accumulation and labor inelastically supplied.
- Household preferences don't play any role.

Model: Production in country $i = 1, 2$ {USA,JPN}

- Final good production:

$$Y_t^i = Z_t^i \left(q_{1,t}^i\right)^{\alpha_1^i} \left(q_{2,t}^i\right)^{\alpha_2^i} \left(n_{y,t}^i\right)^{\alpha_3^i}$$

- Intermediate-good production:

$$Q_t^i = Z_t^i \left(x_{1,t}^i\right)^{\beta_1^i} \left(x_{2,t}^i\right)^{\beta_2^i} \left(x_{3,t}^i\right)^{\beta_3^i} \left(n_{q,t}^i\right)^{\beta_4^i}$$

- Primary-commodity production:

$$X_{i,t}^i = Z_t^i \left(e_i^i\right)^{1-\phi_i^i} \left(n_{x_i,t}^i\right)^{\phi_i^i}$$

$$X_{3,t}^i = Z_t^i \left(e_3^i\right)^{1-\phi_3^i} \left(n_{x_{3,t}}^i\right)^{\phi_3^i}$$

- e_i^i and e_3^i are endowments of natural resources.

- There is also an endowment n^i of labor (inelastically supplied)

Model: Log - real exchange rate

- Log RER: $\xi_t \equiv p_t^{y_1} + e_t^{1,2} - p_t^{y_2}$.
- Prices equal marginal costs,
- which are Cobb-Douglas functions of input prices (linear in logs).
- Law of one price holds for primary commodities and intermediate goods.

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- Law of one price holds for primary commodities and intermediate goods.
- One representation of ξ_t that holds in equilibrium is given by

$$\begin{aligned}\xi_t = {} & \gamma_{z_2} z_t^2 - \gamma_{z_1} z_t^1 + \gamma_{e_1} p_t^{e_1} + \gamma_{e_2} p_t^{e_2} + \gamma_{x_2} p_t^{x_2} + \gamma_{x_3} p_t^{x_3} \\ & + \left[\left(\alpha_1^1 - \alpha_1^2\right) \beta_1^1 + \left(\alpha_2^1 - \alpha_2^2\right) \beta_1^2 + \frac{\left(\alpha_1^1 - \alpha_1^2\right) \beta_4^1 + \alpha_3^1}{\phi_1^1} \right] p_t^{x_1}\end{aligned} \quad (1)$$

Model: Log - real exchange rate

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$$\xi_t = z_t^2 - z_t^1$$

if $\alpha_1^1 = \alpha_1^2$ and $\alpha_2^1 = \alpha_2^2$ and $\alpha_3^1 = \alpha_3^2 = 0$.

Model: Production in ROW

- Device to generate volatile and persistent commodity prices.

- Final-good production:

$$Y_t^3 = \left(x_{1t}^3\right)^{\pi_1} \left(x_{2t}^3\right)^{\pi_2} \left(x_{3t}^3\right)^{\pi_3} \left(n_{y,t}^3\right)^{\pi_4}$$

- Stochastic endowment of the three commodities: $X_{1t}^3, X_{2t}^3, X_{3t}^3$
  - Captures world contingencies that affect PCP such as the weather, natural disasters, monopolistic behavior by the OPEC, etc.

- **Shocks**: (Z_t^1, Z_t^2) and $(X_{1t}^3, X_{2t}^3, X_{3t}^3)$ follow AR1 processes in logs.
  - Shocks to Z and X are orthogonal to each other.
  - But innovations in each block of shocks may be correlated.

MODEL: CALIBRATION

- Factor shares: bilateral US-Japan input-output table from METI.
  - Primary commodities:
    - X_1: crude petroleum and natural gas,
    - X_2: fishing and seafood,
    - X_3: the rest.
- Endowments: match relative GDPs in 1960–2014 and size of commodity sector in ROW GDP.
- Stochastic processes:
  - (Z_1, Z_2): match volatility, persistence, and cross-country correlations of real GDP.
  - $(X^3_{1t}, X^3_{2t}, X^3_{3t})$: match volatility, persistence, and correlations of PCPs.

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- **Models II and III:** negligible contribution of commodities to value added: $\beta_{II} = \beta/100$ and $\beta_{III} = \beta/10000$.

Calibration of stochastic processes

- Use SMM to calibrate the stochastic processes of TFP and ROW-endowment shocks.
- Minimize distance between model-generated moments and same moments using (HP-filtered) data

Moments	**Data**	**Baseline**
standard deviation - RGDP USA (%)	**1.3**	**1.3**
standard deviation - RGDP JPN (%)	**1.6**	**1.6**
autocorrelation - RGDP USA	**0.31**	**0.31**
autocorrelation - RGDP JPN	**0.18**	**0.18**
correlation - USA and JPN RGDP	**0.41**	**0.41**
standard deviation - price of oil (%)	66.7	86.7
standard deviation - price of fish (%)	35.5	29.4
standard deviation - price of aluminum (%)	31.5	31.7
autocorrelation - price of oil	0.92	0.99
autocorrelation - price of fish	0.76	0.79
autocorrelation - price of aluminum	0.84	0.99
correlation - price of oil and fish	0.29	0.22
correlation - price of oil and aluminium	-0.22	-0.72
correlation - price of fish and aluminium	0.37	0.27

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Model results: Non-targeted moments

	Data	Baseline	Model II	Model III
(1) Share of country GDP (%)				
United States				
Final good Y_1	48.5	79.7	79.7	79.7
Intermediate good Q_1	47.9	18.0	20.3	20.3
Primary commodity X_1	1.2	0.8	0.01	0.00
Primary commodity X_3	2.4	1.5	0.01	0.00
Japan				
Final good Y_2	46.3	79.2	76.2	76.2
Intermediate good Q_2	49.9	20.5	23.8	23.8
Primary commodity X_2	0.4	0.0	0.0	0.0
Primary commodity X_3	3.4	0.2	0.0	0.0
(2) Standard deviation of RER (%)	37.0	27.8	5.9	1.5
(3) Autocorrelation of RER	0.96	0.99	0.95	0.23

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Empirical methodology

General setting

- Primary commodity prices, $\boldsymbol{p}_t^{X,USA} \in \mathbb{R}^m$.
- State of the economy represented by a vector $\omega_t \in \mathbb{R}^n$.
- Equilibrium PCPs and RERs are functions of ω_t. Linear approximation:

$$\begin{aligned} \xi_t^{USA,UK} &= \theta' \omega_t, \\ \boldsymbol{p}_t^{X,USA} &= \Omega \omega_t. \end{aligned}$$

- R^2 of the regression of $\xi_t^{USA,UK}$ on $\boldsymbol{p}_t^{X,USA}$ measures how much of the variability of the RER can be accounted for by *fundamental shocks that affect* PCPs. Details

Model results

Regression equation of the form

$$\xi_t = \eta_0 + \eta_1 p_t^{x_1} + \eta_2 p_t^{x_2} + \eta_3 p_t^{x_3} + \nu_t$$

Coefficients of the OLS regressions using model simulated data

	R^2	p^{x_1}	p^{x_2}	p^{x_3}
Baseline regression	0.98	-0.007	-0.008	-0.866
Regression without $p_t^{x_3}$	0.24	0.156	-0.040	
Coefficients implied by RER equation	-	2.983	-2.612	-0.017

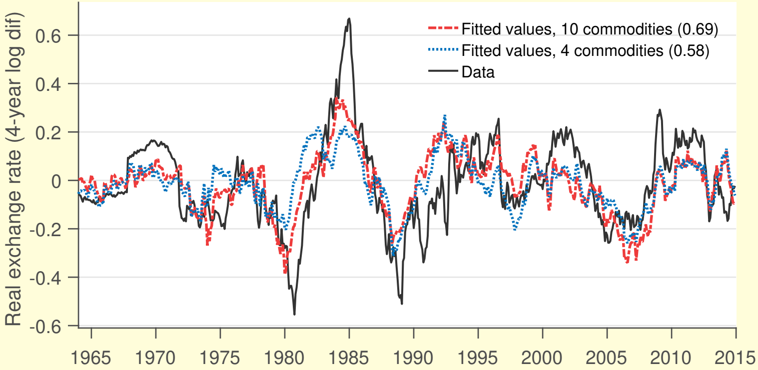
Table: Coefficients of determination R^2

	1960–2014	1960–1972	1973–1985	1986–1998	1999–2014
(a) 10 commodities, 4-year differences					
United Kingdom	0.48	0.90	0.90	0.81	0.60
Germany	0.63	0.95	0.87	0.83	0.75
Japan	0.57	0.92	0.84	0.92	0.82
(b) 4 commodities (best fit), 4-year differences					
United Kingdom	0.33	0.72	0.82	0.63	0.58
Germany	0.56	0.84	0.87	0.81	0.74
Japan	0.48	0.88	0.76	0.86	0.80

Empirical results

Benchmark regression: United Kingdom

Figure: Real exchange rates and fitted values, four-year differences



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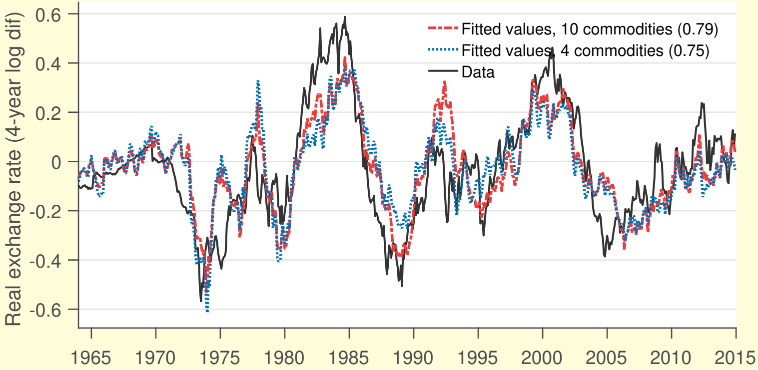
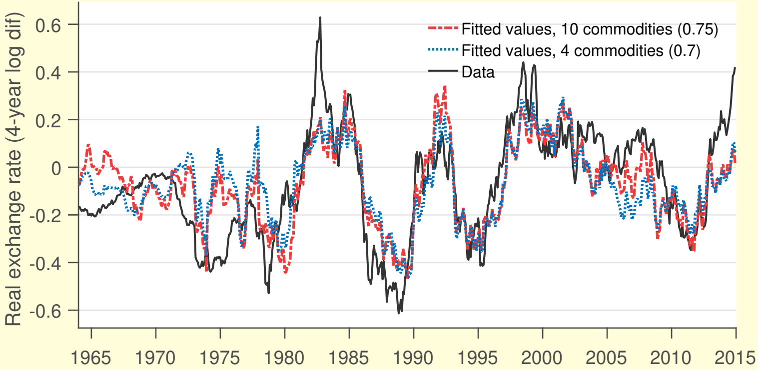


Empirical results

Benchmark regression: Japan

Figure: Real exchange rates and fitted values, four-year differences

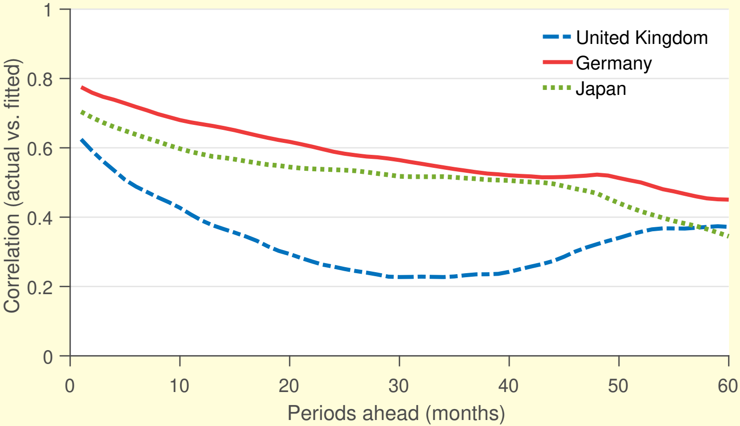


Empirical results

Out-of-sample fit

- Now we perform an out-of-sample exercise.
- Run the regression from Jan-1960 to Dec-1972. Choose the 4 commodities with the highest t-stats.
- Use data for those 4 PCP from Jan-1973 to Jan-1973+h and the estimated coefficients to fit value of the RER.
- Add one observation and repeat.
- Compare with data.

Figure: Out-of-sample fit, four commodities, correlations as a function of *h*



Large versus Small Economies

Moments	Data	Benchmark	Model III	Model IV
share of US and Japan in world GDP (%)	40.1	40.1	20.1	4.0
standard deviation - price of oil (%)	66.7	86.7	85.8	85.6
standard deviation - price of fish (%)	35.5	29.4	31.8	31.2
standard deviation - price of aluminum (%)	31.5	31.7	33.1	34.7
autocorrelation - price of oil	0.92	0.99	0.99	0.99
autocorrelation - price of fish	0.76	0.79	0.77	0.80
autocorrelation - price of aluminum	0.84	0.99	0.99	0.99
correlation - price of oil and fish	0.29	0.22	0.23	0.23
correlation - price of oil and aluminium	-0.22	-0.72	-0.71	-0.71
correlation - price of fish and aluminium	0.37	0.27	0.29	0.31
standard deviation - RER (%)	37.0	27.8	29.1	30.4
autocorrelation - RER	0.96	0.99	0.99	0.99

Mussa Puzzle

Linear trend

Moments	before 1973 Data	Model	after 1973 Data	Model
standard deviation - price of oil (%)	12.7	12.7	51.3	52.0
standard deviation - price of fish (%)	26.1	26.0	36.6	36.9
standard deviation - price of aluminum (%)	3.9	4.8	22.9	22.3
autocorrelation - price of oil	0.64	0.74	0.88	0.93
autocorrelation - price of fish	0.35	0.30	0.80	0.67
autocorrelation - price of aluminum	0.63	0.74	0.61	0.91
correlation - price of oil and fish	0.59	0.46	0.72	0.07
correlation - price of oil and aluminium	-0.74	-0.98	0.48	-0.82
correlation - price of fish and aluminium	-0.50	-0.45	0.59	0.09
standard deviation - RER (%)	6.4	4.2	17.4	19.9
autocorrelation - RER	0.65	0.73	0.80	0.91

Conclusions

- A simplifying – and somehow unfair – summary of the literature on exchange rates is that it has evolved according to a certain dichotomy.
- The role of trade in primary commodities has been explicitly modeled in studying developing economies.
- But models used to analyze large developed economies focuses on trade in differentiated final products exclusively and ignore trade in primary commodities.
- Maybe they should not.....

APPENDIX

LOG - REAL EXCHANGE RATE

$$\xi_t = \left[1 - \left(\alpha_2^1 - \alpha_2^2\right) + \frac{\left(\alpha_2^1 - \alpha_2^2\right)\beta_4^2 + \alpha_3^2}{\phi_2^2}\right] z_t^2$$

$$- \left[1 + \left(\alpha_1^1 - \alpha_1^2\right) - \frac{\left(\alpha_1^1 - \alpha_1^2\right)\beta_4^1 + \alpha_3^1}{\phi_1^1}\right] z_t^1$$

$$+ \left[\left(\alpha_1^1 - \alpha_1^2\right)\beta_1^1 + \left(\alpha_2^1 - \alpha_2^2\right)\beta_1^2 + \frac{\left(\alpha_1^1 - \alpha_1^2\right)\beta_4^1 + \alpha_3^1}{\phi_1^1}\right] p_t^{x_1}$$

$$+ \left[\left(\alpha_1^1 - \alpha_1^2\right)\beta_2^1 + \left(\alpha_2^1 - \alpha_2^2\right)\beta_2^2 + \frac{\left(\alpha_2^1 - \alpha_2^2\right)\beta_4^2 + \alpha_3^2}{\phi_2^2}\right] p_t^{x_2}$$

$$+ \left[\left(\alpha_1^1 - \alpha_1^2\right)\beta_3^1 + \left(\alpha_2^1 - \alpha_2^2\right)\beta_3^2\right] p_t^{x_3}$$

$$- \left[\left(\alpha_1^1 - \alpha_1^2\right)\beta_4^1 + \alpha_3^1\right] \frac{1 - \phi_1^1}{\phi_1^1} p_{1,t}^{e_1} - \left[\left(\alpha_2^1 - \alpha_2^2\right)\beta_4^2 - \alpha_3^2\right] \frac{1 - \phi_2^2}{\phi_2^2} p_{2,t}^{e_2}$$

Calibration: factor shares - bilateral IO table from METI

	Country 1 (USA)	Country 2 (JPN)
Final good		
intermediate good Q_1	$\alpha_1^1 = 20.2$	$\alpha_1^2 = 0.3$
intermediate good Q_2	$\alpha_2^1 = 0.1$	$\alpha_2^2 = 23.5$
labor n_y	$\alpha_3^1 = 79.7$	$\alpha_3^2 = 76.2$
Intermediate good		
primary commodity X_1	$\beta_1^1 = 6.5$	$\beta_1^2 = 5.9$
primary commodity X_2	$\beta_2^1 = 0.0$	$\beta_2^2 = 0.1$
primary commodity X_3	$\beta_3^1 = 4.7$	$\beta_3^2 = 11.5$
labor n_q	$\beta_4^1 = 88.8$	$\beta_4^2 = 82.5$
Primary commodity X_i		
labor $n_{x_i}^i$	$\phi_1^1 = 33$	$\phi_2^2 = 27$
natural resource e_i^i	$1 - \phi_1^1 = 67$	$1 - \phi_2^2 = 63$
Primary commodity X_3		
labor $n_{x_3}^i$	$\phi_1^1 = 52$	$\phi_3^2 = 34$
natural resource e_3^i	$1 - \phi_3^1 = 48$	$1 - \phi_3^2 = 66$

Calibration: Factor shares ROW

- We choose the share of labor in ROW to match share of agriculture and mining sector in ROW GDP in 2005.
- Then we choose shares of primary commodities according to their respective shares in total world trade in primary commodities.

	Rest of the world
Final good	
X_1: crude petroleum and natural gas	$\pi_1 = 5.8$
X_2: fishing and seafood	$\pi_2 = 0.5$
X_3: rest of commodities	$\pi_3 = 3.5$
n_y^3: labor	$\pi_4 = 90.2$

Calibration: Relative size of the countries

- Normalize size of country 1 (USA) by setting $n_1 = e_1^1 = e_3^1 = 1$.
- Choose size of countries 2 (JPN) and 3 (ROW) to match average shares in world GDP from 1960 to 2014.

Relative sizes in steady state

		Share of world GDP (%)	
	Parameters	**Data**	**Model**
Country 1 (USA)	$n_1 = e_1^1 = e_3^1 = 1$	30	30
Country 2 (Japan)	$n_2 = e_2^2 = e_3^2 = 0.33$	10	10
Country 3 (ROW)	$X_1^3 = 2.3;\ X_2^3 = 1.04;;\ X_3^3 = 0.32$	60	60

Calibration of stochastic processes

Parameter	Values	Parameter	Values
$100 \times \sigma\left(\varepsilon_t^{Z_1}\right)$	1.0	$100 \times \sigma\left(\varepsilon_t^{X_3^3}\right)$	1.8
$100 \times \sigma\left(\varepsilon_t^{Z_2}\right)$	1.2	$\rho^{x_1^3}$	0.99
ρ^{z_1}	0.29	$\rho^{x_2^3}$	0.00
ρ^{z_2}	0.17	$\rho^{x_3^3}$	0.99
$\rho\left(\varepsilon_t^{Z_1}, \varepsilon_t^{Z_2}\right)$	0.41	$\rho\left(\varepsilon_t^{X_1^3}, \varepsilon_t^{X_2^3}\right)$	-0.00
$100 \times \sigma\left(\varepsilon_t^{X_1^3}\right)$	6.6	$\rho\left(\varepsilon_t^{X_1^3}, \varepsilon_t^{X_3^3}\right)$	-0.77
$100 \times \sigma\left(\varepsilon_t^{X_2^3}\right)$	13.5	$\rho\left(\varepsilon_t^{X_2^3}, \varepsilon_t^{X_3^3}\right)$	0.08

Empirical methodology

General setting

- Primary commodity prices, $\boldsymbol{p}_t^{X,USA} \in \mathbb{R}^m$.
- State of the economy represented by a vector $\omega_t \in \mathbb{R}^n$.
- Equilibrium PCPs and RERs are functions of the state variables. Using a linear approximation (if necessary):

$$\begin{aligned} \xi_t^{USA,UK} &= \theta' \omega_t, \\ \boldsymbol{p}_t^{X,USA} &= \Omega \omega_t. \end{aligned}$$

- Treat ω_t as unobservable and interpret the state variables as orthogonal with an identity covariance matrix.

EMPIRICAL METHODOLOGY

GENERAL SETTING

- Consider the projection

$$\text{Proj}\left(\xi_t^{USA,UK} | \boldsymbol{p}_t^{X,USA}\right) = \eta' \boldsymbol{p}_t^{X,USA}$$

$$\eta' = (\theta'\Omega')(\Omega\Omega')^{-1}$$

- The projection decomposes the RER into two orthogonal components:

$$\xi_t^{USA,UK} = \eta'\Omega\omega_t + \left(\theta' - \eta'\Omega\right)\omega_t$$

- R^2 of the projection:

$$R^2 = \frac{\eta'\Omega\Omega'\eta}{\theta'\theta}$$

- R^2 measures how much of the variability of the RER can be accounted for by *fundamental shocks that affect* PCPs.

Empirical methodology

General setting

- Divide the state variables in two sets as $\omega_t = [\omega'_{1t}\ \omega'_{2t}]'$, so that

$$\xi_t^{USA,UK} = \theta_1' \boldsymbol{\omega}_{1t} + \theta_2' \boldsymbol{\omega}_{2t}$$

$$\boldsymbol{p}_t^{X,USA} = \Omega_1 \boldsymbol{\omega}_{1t} + \Omega_2 \boldsymbol{\omega}_{2t}.$$

- Sufficient condition for the R^2 of the regression to be zero:

$$\theta_1 = 0 \text{ and } \Omega_2 = 0$$

- Implies an equilibrium with a block-recursive structure in the model.
  - State variables that determine the RER ($\omega_{2,t}$) are different from and orthogonal ($\Omega_2 = 0$) to those that determine commodity prices.

Return

Empirical results: robustness

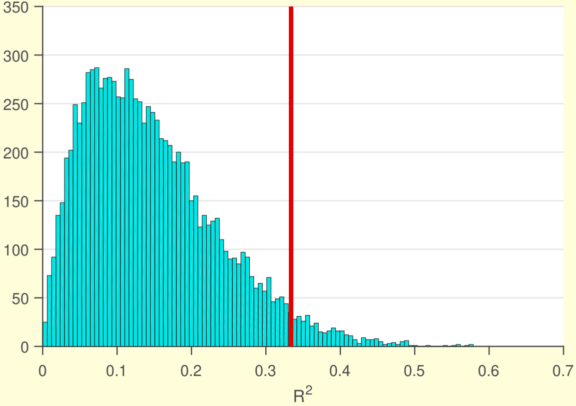
Are the results spurious?

- Estimate time series process for each RER.
- Estimate a VAR for the 10 PCP.
- Generate artificial data using Montecarlo under the null of orthogonality and reproduce the regressions.
- $R^2 \rightarrow 0$ as the sample size goes to ∞.
- Get 10.000 samples of size 660 and compute the distribution of the R^2.

EMPIRICAL RESULTS: ROBUSTNESS

UNITED KINGDOM

FIGURE: Small sample distribution of the R^2 over the period 1960–2014

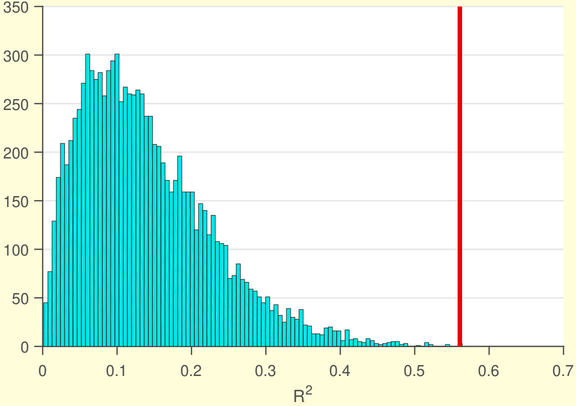


$$\Pr(R^2 > 0.33) = 0.037.$$

Empirical results: robustness

Germany

Figure: Small sample distribution of the R^2 over the period 1960–2014

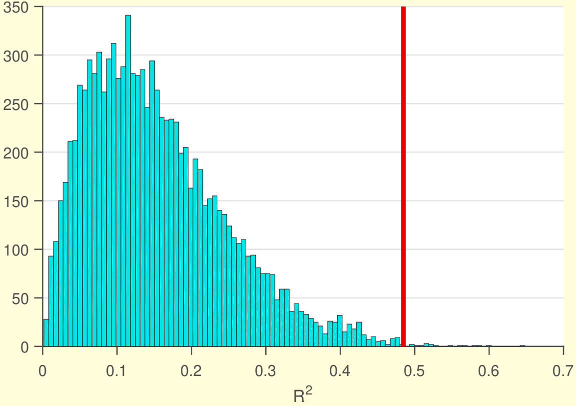


$$\Pr(R^2 > 0.56) = 0.000.$$

Empirical results: robustness

Japan

Figure: Small sample distribution of the R^2 over the period 1960–2014



$$\Pr(R^2 > 0.48) = 0.003.$$

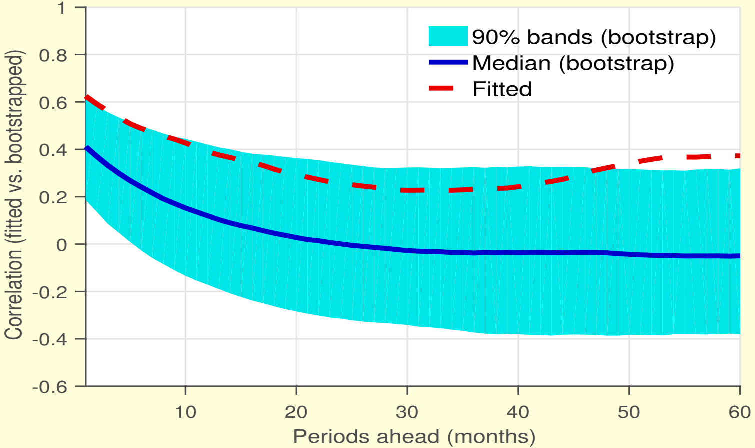
Bootstraped distributions of R^2 under the null hypothesis of orthogonality

	$\hat{R}^2$	Percentiles distribution of R^2				$\Pr(R^2 \geq \hat{R}^2)$
		Median	75	90	95	
United Kingdom						
1960-2014	0.33	0.13	0.20	0.27	0.31	0.037
1960-1972	0.72	0.52	0.66	0.75	0.80	0.143
1973-1985	0.82	0.37	0.52	0.64	0.70	0.004
1986-1998	0.63	0.37	0.50	0.61	0.67	0.077
1999-2014	0.58	0.29	0.41	0.53	0.59	0.059
Germany						
1960-2014	0.56	0.13	0.19	0.26	0.31	0.000
1960-1972	0.84	0.56	0.69	0.79	0.83	0.032
1973-1985	0.87	0.49	0.63	0.73	0.78	0.005
1986-1998	0.81	0.40	0.54	0.65	0.71	0.007
1999-2014	0.74	0.30	0.43	0.55	0.61	0.007
Japan						
1960-2014	0.48	0.14	0.21	0.29	0.34	0.003
1960-1972	0.88	0.59	0.72	0.81	0.85	0.022
1973-1985	0.76	0.46	0.60	0.70	0.75	0.045
1986-1998	0.86	0.41	0.55	0.66	0.71	0.001
1999-2014	0.80	0.33	0.46	0.57	0.63	0.002

Empirical results: robustness

United Kingdom

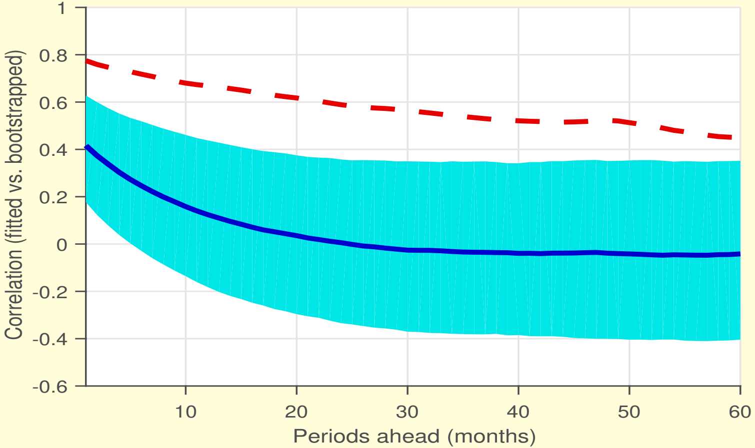
Figure: Fitted correlations and (Montecarlo) error bands under the null hypothesis of orthogonality



Empirical results: robustness

Germany

Figure: Fitted correlations and (Montecarlo) error bands under the null hypothesis of orthogonality



Empirical results: robustness

Japan

Figure: Fitted correlations and (Montecarlo) error bands under the null hypothesis of orthogonality