Where are the Markets Heading? Evidence from the Interest Rate-Exchange Rate Linkage in India

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Outline

Theoretical Background

The Taylor Rule

- The Taylor Rule is a simple monetary policy rule:
- $ir_t = \beta + \beta_\pi \pi_t + \beta_y y_t + \epsilon_t$
- The Taylor Principle states that $\beta_\pi > 1$ is required for inflation stabilisation
- Christiano and Gust (1999) argue that $\beta_y = 0$ is optimal - many disagree
- Forward-looking and dynamic terms are often added to improve the rule's empirical performance
- Many other extensions have been pursued in the literature
- Our interest:
  - Does the exchange rate affect interest rate setting in India?
  - Is the relationship asymmetric?

The Interest Rate-Exchange Rate Linkage in India

- The UIP, CIP and PPP relationships are well known
- In India, the relationship may be more complex
- The RBI seems to permit gradual swings in the exchange rate but to resist sharp movements
- A minimum volatility policy?
- We should observe a strong interest rate response immediately following an exchange rate shock and then smooth onward adjustment - *i.e.* coarse-tuning, not fine-tuning
- If this is the case then the level of the exchange rate should not enter the reaction function but its second moment should enter negatively
- This relationship may not be symmetric though
- These observations provide us with an obvious testing strategy

Two Modelling Strategies

- CVARX* - CVAR model with weakly exogenous I(1) variables
  - good for modelling small open economies due to the inclusion of trade-weighted global exogenous variables
  - first stage of GVAR modelling
  - allows rich dynamic analysis
  - we can impose and test theoretical restrictions
  - we will use it to look at the effect of an exchange rate shock on the interest rate
- ARDL-GARCH - asymmetric ARDL with GARCH(p,q) errors
  - models asymmetric cointegration/long-run relationships
  - models asymmetric equilibrium correction
  - accounts for residual heteroskedasticity which is often problematic in asymmetric ARDL models
  - we will use it to model the reaction function of the RBI

Model 1: Long-Run Structural Model for India

- Given the general structural VECM of the form:

$$\boldsymbol{A}\Delta \boldsymbol{z}_t = \widetilde{\boldsymbol{a}} + \widetilde{\boldsymbol{b}}t + \widetilde{\boldsymbol{\Pi}}\boldsymbol{z}_{t-1} + \sum_{i=1}^{p-1} \widetilde{\boldsymbol{\Gamma}}_i \boldsymbol{\Delta} \boldsymbol{z}_{t-i} + \boldsymbol{\epsilon}_t \qquad (1)$$

- Garratt, Lee, Pesaran and Shin (2006, GLPS) write:

$$\begin{pmatrix} \boldsymbol{A}_{yy} & \boldsymbol{A}_{yx} \\ \boldsymbol{0} & \boldsymbol{A}_{xx} \end{pmatrix} \begin{pmatrix} \Delta \boldsymbol{y}_t \\ \Delta \boldsymbol{x}_t \end{pmatrix} = \widetilde{\boldsymbol{a}} + \widetilde{\boldsymbol{b}}t + \widetilde{\boldsymbol{\Pi}} \begin{pmatrix} \boldsymbol{y}_{t-1} \\ \boldsymbol{x}_{t-1} \end{pmatrix}$$

$$+ \sum_{i=1}^{p-1} \widetilde{\boldsymbol{\Gamma}}_i \begin{pmatrix} \Delta \boldsymbol{y}_{t-i} \\ \Delta \boldsymbol{x}_{t-i} \end{pmatrix} + \begin{pmatrix} \epsilon_{yt} \\ \epsilon_{xt} \end{pmatrix}$$

where:

$$\widetilde{\boldsymbol{\Pi}} = \begin{pmatrix} \widetilde{\boldsymbol{\Pi}}_y \\ \boldsymbol{0} \end{pmatrix} = \begin{pmatrix} \widetilde{\boldsymbol{\alpha}}_y \\ \boldsymbol{0} \end{pmatrix} \boldsymbol{\beta}'$$

- $\boldsymbol{A}_{yy}$ and $\boldsymbol{A}_{yx}$ represent the contemporaneous effects of the endo and exo variables on the endo variables
- The null matrix in the lower triangle of $\boldsymbol{A}$ ensures that there are no contemporaneous impacts of the variables in $\boldsymbol{y}_t$ on those in $\boldsymbol{x}_t$
- The matrix $\widetilde{\boldsymbol{\Pi}}$ defines how the long–run errors $\boldsymbol{\xi}_t$ feed back onto the system. The lower $m_x \times m$ submatrix of $\widetilde{\boldsymbol{\Pi}}$ is a null matrix to ensure that the long–run errors do not feed back onto the exogenous variables
- The null matrices in $\boldsymbol{A}$ and $\widetilde{\boldsymbol{\Pi}}$ together ensure the exogeneity of the variables in $\boldsymbol{x}_t$
- This structure means that the exogenous variables are long-run forcing for the system (Granger and Lin, 1995) - *i.e.* they can effect the endogenous magnitudes in the long-run

- Based on their decomposition of the system into a conditional VECM for $\Delta \boldsymbol{y}_t$ and a marginal VAR for $\Delta \boldsymbol{x}_t$, GLPS write the full system as:

$$\boldsymbol{A}^* \Delta \boldsymbol{z}_t = \widetilde{\boldsymbol{a}}^* + \widetilde{\boldsymbol{b}}^* t - \widetilde{\boldsymbol{\Pi}} \boldsymbol{z}_{t-1} + \sum_{i=1}^{p-1} \widetilde{\boldsymbol{\Gamma}}_i^* \Delta \boldsymbol{z}_{t-i} + \boldsymbol{\epsilon}_t^* \qquad (2)$$

denoting:

$$\boldsymbol{A}^* = \begin{pmatrix} \boldsymbol{A}_{yy} & \boldsymbol{A}_{yx}^* \\ \boldsymbol{0} & \boldsymbol{A}_{xx} \end{pmatrix}, \; \widetilde{\boldsymbol{\Pi}} = \begin{pmatrix} \widetilde{\boldsymbol{\Pi}}_{yy} & \widetilde{\boldsymbol{\Pi}}_{yx} \\ \boldsymbol{0} & \widetilde{\boldsymbol{\Pi}}_{xx} \end{pmatrix}$$

$$\widetilde{\boldsymbol{a}}^* = \begin{pmatrix} \widetilde{\boldsymbol{a}}_y^* \\ \widetilde{\boldsymbol{a}}_x \end{pmatrix}, \; \widetilde{\boldsymbol{b}}^* = \begin{pmatrix} \widetilde{\boldsymbol{b}}_y^* \\ \widetilde{\boldsymbol{b}}_x \end{pmatrix}, \; \widetilde{\boldsymbol{\Gamma}}_i^* = \begin{pmatrix} \widetilde{\boldsymbol{\Gamma}}_{yi}^* \\ \widetilde{\boldsymbol{\Gamma}}_{xi} \end{pmatrix}$$

$$\text{and} \quad \boldsymbol{\epsilon}_t^* = \begin{pmatrix} \boldsymbol{\eta}_{yt} \\ \boldsymbol{\epsilon}_{xt} \end{pmatrix}$$

Variable List (part 1)

We include the following endogenous I(1) variables in our CVARX* system:

- re: real exchange rate
- ir: central bank base rate
- im: real imports
- ex: real exports
- q: domestic stock index
- Δp: CPI inflation
- y: real GDP

Variable List (part 2)

We also include the following exogenous I(1) variables in our CVARX* system:

- p^o: Oil price (UK Brent)
- r^*: Trade-weighted foreign interest rate
- q^*: Trade-weighted foreign stock indices
- Δp^*: Trade-weighted foreign inflation
- y^*: Trade-weighted foreign real GDP

- Trade weights for 33 countries are provided by the IMF direction of trade statistics.
- All other data is from IMF IFS with some interpolation as detailed in *Probability Event Forecasting and Global Imbalances in a GVAR Framework*, under review at JAE.

Imposing a Long-Run Theory

We impose the following long-run relationships:

- Interest rate parity - essentially an identity
- Fisher inflation parity - again an identity
- Trade balance as I(0)

Other candidate relationships include:

- Modified Taylor rule (using $y - y^*$ instead of the output gap)
- Linkage between Indian and global stock markets
- Trade balance as I(1) - maybe more accurate for India?
- Output convergence

Testing the Long-Run Theory Restrictions

Following Pesaran and Shin (2002), the LR restrictions can be tested using the likelihood-ratio test as follows:

i. Estimate subject to any exact identifying structure (e.g. the Johansen eigenvalue estimates) or any other because the maximised log-likelihood should be invariant to any invertible transformation of the cointegrating space spanned by the cointegrating vectors. Save the maximised log-likelihood, MLL_U.
ii. Estimate the model subject to the over-identified structure. Save the maximised LL, MLL_R.
iii. Compute the LR statistic as $-2 \times \{MLL_U - MLL_R\}$, which is χ^2 distributed with $k - r^2$ degrees of freedom.
iv. This should be bootstrapped to generate asymptotically valid critical values as the power of the parametric test is low.

Some Results of the CVARX* Model

Results of the CVARX* Model

Δp shock on ir: Inflationary pressure leads the RBI to raise rates

y shock on ir: Economic overheating leads RBI to raise rates

re shock on ir: Weakening of the Rupee leads RBI to aggressively raise rates initially then no further response

q^* shock on y: Foreign stock boom leads to stronger domestic growth (foreign investments, export demand etc)

q^* shock on Δp: Foreign stock boom is inflationary (demand-pull)

q^* shock on ir: Foreign stock boom leads RBI to raise rates (following Taylor rule!)

q^* shock on re: Higher interest rate create real appreciation of the Rupee

Some Intuitive Reasoning

- Interest rate responses to inflation and output gap shocks are as expected
- Initial spike in interest rates following the exchange rate shock is consistent with the notion that the RBI combats sharp movements but lets gradual evolutions go through unimpeded
- Foreign stock market shock has a large positive effect on output - greater demand for exports and greater foreign investment inflows
- Foreign stock market shock has positive lagged effect on the interest rate as it sparks domestic inflationary pressures
- Foreign stock market shock strengthens the Rupee because the RBI raises the interest rate to combat inflation

Model 2: The ARDL-GARCH Model

The Asymmetric ARDL Model

- Following Shin, Yu and Greenwood-Nimmo (2009, SYG), the asymmetric ARDL model is written as:

$$\Delta y_t = \rho y_{t-1} + \theta^+ \mathbf{x}_{t-1}^+ + \theta^- \mathbf{x}_{t-1}^- + \sum_{i=1}^{p-1} \varphi_i \Delta y_{t-i} + \sum_{i=0}^{p} \left(\pi_i^+ \Delta \mathbf{x}_{t-i}^+ + \pi_i^- \Delta \mathbf{x}_{t-i}^- \right) + e_t, \quad (3)$$

- where superscript '+' and '-' symbols denote positive and negative partial sum processes.
- The case of an unknown threshold has been addressed by Greenwood-Nimmo, Shin and Van Treeck (2009) but the Davies problem remains fundamental so bootstrapping or jack-knifing is essential.

Assumptions: (i) $e_t \sim iid(0, \sigma_e^2)$; (ii) e_t is uncorrelated with ε_{2t}; (iii) $\rho < 0$ guarantees that the model is dynamically stable.

- Following Pesaran and Shin (1998), it is straightforward to show under these Assumptions that:
  1. The OLS estimators of all the short-run dynamic parameters are $\sqrt{T}$-consistent and have the asymptotic normal distribution
  2. Hence, the null hypotheses of additive or pairwise short-run symetric adjustment may be investigated using standard χ_k^2 distributed Wald tests
  3. The OLS estimators of the long-run parameters ($\hat{\boldsymbol{\beta}}^+ = -\hat{\boldsymbol{\theta}}^+/\hat{\rho}$ and $\hat{\boldsymbol{\beta}}^- = -\hat{\boldsymbol{\theta}}^-/\hat{\rho}$) are T-consistent and follow the mixture normal distribution
  4. Hence, the null hypotheses of a symmetric long-run relationship $\left(\boldsymbol{\beta}^+ = \boldsymbol{\beta}^-\right)$ can be tested using the Wald statistic following the χ_k^2 distribution

- SYG derive the asymmetric cumulative dynamic multiplier effects of unit changes in the regressors on the dependent variable
- It is straightforward to show that, for $h = 0, 1, 2...$:

$$\boldsymbol{m}_h^+ = \sum_{j=0}^{h} \frac{\partial y_{t+j}}{\partial \boldsymbol{x}_t^+} = \sum_{j=0}^{h} \boldsymbol{\lambda}_j^+, \ \boldsymbol{m}_h^- = \sum_{j=0}^{h} \frac{\partial y_{t+j}}{\partial \boldsymbol{x}_t^-} = \sum_{j=0}^{h} \boldsymbol{\lambda}_j^- \quad (4)$$

- Notice that by construction as $h \to \infty$,

$$\boldsymbol{m}_h^+ \to \boldsymbol{\beta}^+ \text{ and } \boldsymbol{m}_h^- \to \boldsymbol{\beta}^-$$

  where $\boldsymbol{\beta}^+ = -\boldsymbol{\theta}^+/\rho$ and $\boldsymbol{\beta}^- = -\boldsymbol{\theta}^-/\rho$ are the asymmetric long-run coefficients
- Hence we can depict the traverse between a shock and the new equilibrium

- In a series of papers, Greenwood-Nimmo and Shin note that the homoskedasticity of e_t is rarely achieved in practice.
- Failing to account for an underlying ARCH process in the residuals is often thought to yield standard errors that are too narrow - *false precision*
- For now, we model the errors as a GARCH(1,1) process, overcoming the heteroskedasticity
- The extension to the asymmetric GARCH-in-mean model where the conditional volatility series is decomposed about an unknown threshold value, d, is our final goal but this is computationally very demanding
- It would allow us to characterise asymmetric volatility responses which may be very useful in monetary economics and financial applications as well as many others

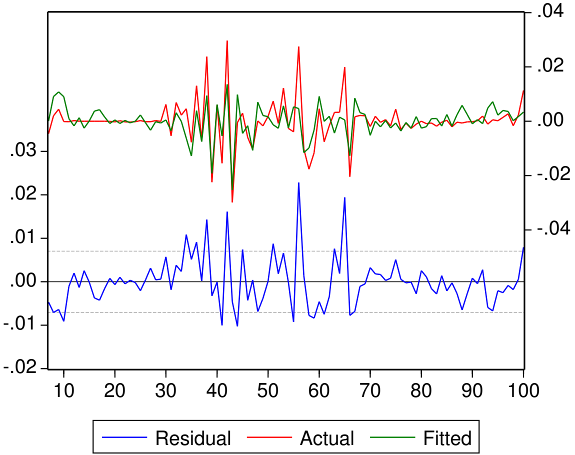

Figure: ARCH Effects in the ARDL(4,4) Residuals

Some Results of the ARDL-GARCH Model

- Estimation of the ARDL(4,4) model for the asymmetric Taylor rule gives bad results:
  - No apparent asymmetry
  - Poor pattern of significance
  - Volatility clustering in the residuals
- Estimation of the ARDL(4,4)-GARCH(1,1) model resolves these problems
- Improved pattern of significance does *not* reflect the false precision argument common in the literature
- Rather, it is because the objective function maximised by the ML procedure is not precisely equivalent to that of the OLS form once we add the conditional volatility equation
- We could construct a likelihood ratio test for the presence of ARCH effects as $-2\{MLL_U - MLL_R\}$ which should be distributed χ^2_{p+q+1} although testing power may be low

- Asymmetric Cumulative Dynamic Multipliers
  - Evidence of weak asymmetry in response to inflationary shocks
  - The Taylor Principle is observed in both cases
  - Evidence of strong and pronounced asymmetry in response to output gap shocks
  - The reaction coefficient is quite large indicating that the RBI works hard to stabilise output growth - not a pure inflation-targeter
  - The smoothness of the multipliers is encouraging given the long lag structure (4 lags in all cases)
- Estimation of the modified TR including the level of the nominal exchange rate shows no significant relationship - this agrees with our *ex ante* reasoning
- However we also find no stable long-run relationship when we include the exchange rate volatility - this needs further examination (*e.g.* testing other exchange rate indices)

Some Tentative Conclusions

- Real exchange rate *shocks* are smoothed by the RBI only on impact but with no ongoing interest rate intervention - volatility response
- The RBI policy rule seems to be an asymmetric Taylor rule
  - Stronger response to positive than negative inflation shocks
  - Stronger response to negative than positive output gaps
- This may be described as a *good performance bias*
- We find no evidence that the level of the nominal exchange rate enters the RBI rule
- At this stage we cannot find a stable relationship between the interest rate and nominal exchange rate volatility but there is evidence of some interaction - more work required!

Questions & Comments?