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

Kausik Chaudhuri & Matthew Greenwood–Nimmo

Department of Economics
Leeds University Business School & Madras School of Economics

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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:

$$A \Delta z_t = \tilde{a} + \tilde{b}t + \tilde{\Pi} z_{t-1} + \sum_{i=1}^{p-1} \tilde{\Gamma}_i \Delta z_{t-i} + \epsilon_t$$  \hspace{1cm} (1)

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

$$
\begin{pmatrix}
A_{yy} & A_{yx} \\
0 & A_{xx}
\end{pmatrix}
\begin{pmatrix}
\Delta y_t \\
\Delta x_t
\end{pmatrix}
= \tilde{a} + \tilde{b}t + \tilde{\Pi}
\begin{pmatrix}
y_{t-1} \\
x_{t-1}
\end{pmatrix}
+ \sum_{i=1}^{p-1} \tilde{\Gamma}_i
\begin{pmatrix}
\Delta y_{t-i} \\
\Delta x_{t-i}
\end{pmatrix}
+ \begin{pmatrix}
\epsilon_{yt} \\
\epsilon_{xt}
\end{pmatrix}
$$

where:

$$\tilde{\Pi} = \begin{pmatrix}
\tilde{\Pi}_y \\
0
\end{pmatrix} = \begin{pmatrix}
\tilde{\alpha}_y \\
0
\end{pmatrix} \beta'$$
- $A_{yy}$ and $A_{yx}$ represent the contemporaneous effects of the endo and exo variables on the endo variables.
- The null matrix in the lower triangle of $A$ ensures that there are no contemporaneous impacts of the variables in $y_t$ on those in $x_t$.
- The matrix $\tilde{\Pi}$ defines how the long-run errors $\xi_t$ feed back onto the system. The lower $m_x \times m$ submatrix of $\tilde{\Pi}$ is a null matrix to ensure that the long-run errors do not feed back onto the exogenous variables.
- The null matrices in $A$ and $\tilde{\Pi}$ together ensure the exogeneity of the variables in $x_t$.
- 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 $\Delta y_t$ and a marginal VAR for $\Delta x_t$, GLPS write the full system as:

$$A^* \Delta z_t = \tilde{a}^* + \tilde{b}^* t - \tilde{\Pi}z_{t-1} + \sum_{i=1}^{p-1} \tilde{\Gamma}_i \Delta z_{t-i} + \epsilon_t^*$$  \hspace{1cm} (2)

denoting:

$$A^* = \begin{pmatrix} A_{yy} & A_{yx}^* \\ 0 & A_{xx}^* \end{pmatrix}, \quad \tilde{\Pi} = \begin{pmatrix} \tilde{\Pi}_{yy} & \tilde{\Pi}_{yx} \\ 0 & \tilde{\Pi}_{xx} \end{pmatrix}$$

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

and $$\epsilon_t^* = \begin{pmatrix} \eta_{yt} \\ \epsilon_{xt} \end{pmatrix}$$
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
- $\Delta p$: 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
- $\Delta p^*$: 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, $\text{MLL}_U$.

ii. Estimate the model subject to the over-identified structure. Save the maximised LL, $\text{MLL}_R$.

iii. Compute the LR statistic as $-2 \times \{\text{MLL}_U - \text{MLL}_R\}$, which is $\chi^2$ 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

$\Delta p$ 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 $\Delta p$: 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:

$$\Delta y_t = \rho y_{t-1} + \theta^+ x^+_{t-1} + \theta^- x^-_{t-1} + \sum_{i=1}^{p-1} \varphi_i \Delta y_{t-i}$$

$$+ \sum_{i=0}^{p} \left( \pi^+_i \Delta x^+_{t-i} + \pi^-_i \Delta x^-_{t-i} \right) + e_t,$$

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) $e_t \sim iid(0, \sigma^2_e)$; (ii) $e_t$ is uncorrelated with $\varepsilon_{2t}$; (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 symmetric adjustment may be investigated using standard $\chi^2_k$ distributed Wald tests
3. The OLS estimators of the long-run parameters ($\hat{\beta}^+ = -\hat{\theta}^+ / \hat{\rho}$ and $\hat{\beta}^- = -\hat{\theta}^- / \hat{\rho}$) are $T$-consistent and follow the mixture normal distribution
4. Hence, the null hypotheses of a symmetric long-run relationship ($\beta^+ = \beta^-$) can be tested using the Wald statistic following the $\chi^2_k$ 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...:

$$m_h^+ = \sum_{j=0}^{h} \frac{\partial y_{t+j}}{\partial x_t^+} = \sum_{j=0}^{h} \lambda_j^+,$$

$$m_h^- = \sum_{j=0}^{h} \frac{\partial y_{t+j}}{\partial x_t^-} = \sum_{j=0}^{h} \lambda_j^-$$ (4)

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

$$m_h^+ \to \beta^+ \text{ and } m_h^- \to \beta^-$$

where $\beta^+ = -\theta^+ / \rho$ and $\beta^- = -\theta^- / \rho$ 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 $-2\left\{ MLL_U - MLL_R \right\}$ which should be distributed $\chi^2_{p+q+1}$ 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!
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Questions & Comments?