1. Introduction

The Expectations Hypothesis of the Term Structure (EHTS) of interest rates postulates an equilibrium relationship among interest rates of different maturities. According to the EHTS, the yield to maturity on a long-term financial asset is an average of current and expected short-term interest rates on this asset over the corresponding maturity.

The idea that market expectations play a crucial role in explaining the shape of the yield curve has a firmly established tradition in the economic literature, dating back to the seminal work of Fisher (1930). This focus on market expectations stands in sharp contrast with alternative explanations of the term structure, such as the segmented markets theory (Culbertson, 1957), relying on the supply and the demand for bonds of different maturities. Moreover, while earlier versions of this theoretical framework emphasized the exclusive role of market expectations (the so called “Pure Expectations” theory), subsequent extensions introduced a risk premium component as a further relevant factor affecting long-term interest rates (the so called “Liquidity Premium” theory).

The EHTS has widespread implications involving macroeconomics, finance and economic policy issues. Focusing on the latter topic, the empirical relevance of the EHTS is crucial in order to properly evaluate the effectiveness of the transmission mechanism of monetary policy. The standard modern approach to monetary policy relying on inflation targeting assumes in fact that the Central Bank controls a short-term policy rate, and that monetary impulses are transmitted to the real sector through the no arbitrage long-run equilibrium condition implied by the EHTS (Bernanke and Blinder, 1992, Clarida et al., 1999).

The wide ranging implications associated with the EHTS prompted a large body of empirical literature. While earlier contributions mainly focused on industrialized countries, more
recent research concentrated on emerging market economies, given the liberalization of money and capital markets occurred in these countries since the mid-90’s. In a more competitive financial environment, where asset returns directly respond to market forces, the term structure of interest rates should obviously move in closer connection with the predictions of the EHTS.

Applied research testing the EHTS for developing economies provides usually highly variegated results. Konstantinou (2005) and Koukouritakis and Michelis (2008) find strong support for the EHTS, respectively for Poland and a large group of countries recently joining the European Union. However, even emerging market economies tend quite often to reject parameters restrictions associated with the EHTS (see respectively, among others, Cooray, 2003 for Sri Lanka and Tabak, 2009 for Brazil).

In a recent paper, I have explored the validity of the EHTS for India since the end of the financial repression era (see Tronzano, 2014). This research supports the existence of one-to-one co-movements between short and long-term interest rates, but rejects the “Pure” version of the EHTS, documenting the existence of significant risk premia components at all temporal horizons. Moreover, causality tests in a VECM framework provide strong evidence of unidirectional causality from the short-term policy rate to longer term interest rates.

Although providing new results, the econometric approach taken in Tronzano (2014) has some limitations, since theoretical restrictions implied by the EHTS are assessed inside a bivariate framework, namely performing cointegration tests on bilateral pairs of interest rates maturities. Since term structure innovations are expected to spread almost instantaneously across the yield curve, jointly affecting the whole spectrum of interest rate maturities, a multivariate cointegration approach would yield substantial efficiency gains relative to a bivariate framework (see, among others, Arshanapalli and Doukas, 1994; Konstantinou, 2004; Masih and Ryan, 2005).

The present paper extends the empirical investigation carried out in Tronzano (2014) following this line of research. More specifically, I address the validity of the EHTS for India since the post-liberalization period inside a multivariate cointegration framework, where the existence of long-run equilibrium conditions and parameters restrictions suggested by theory are explored using a multi-dimensional set of interest rates maturities.

The outline of the paper is as follows. The next section describes the data set and explores the cointegration structure of a four-dimensional system of nominal interest rates. Using this
multivariate approach, I assess the robustness of the results obtained in Tronzano (2014), testing the validity of the “symmetry” and “no risk premium” restrictions associated with the “Pure” version of the EHTS. Section 3 complements previous findings from VECM causality tests, implementing a forecast error variance decomposition analysis. Moreover, this section provides further evidence about the dynamics of the cointegrating VAR, estimating generalized impulse response functions and persistency profiles of cointegrating vectors after a system-wide shock. Section 4 summarizes the main findings and outlines some relevant policy implications.

2. Testing EHTS in a Multivariate Framework

2.1 Data Base and Preliminary Data Analysis

The data set is identical to Tronzano (2014) and includes monthly observations on 3-year, 5-year, 8-year, and 10-year government bond yields. The sample extends from 1996.4 to 2014.1 (214 observations).

Nominal interest rates are end-of-month yields expressed in percent per annum (source: Bank of India, “Handbook of Statistics on Indian Economy”, Part II, Table 183).

Figure 1 plots all interest rates series.
Strong co-movements in asset returns are apparent for all interest rates maturities. Actually, correlations coefficients always oscillate around 0.98 - 0.99. Visual inspection of Figure 1 provides therefore some informal support for the EHTS.

The term structure of interest rates exhibits a pronounced downward trend from the beginning of the post-liberalization period up to the end of 2004, while a clear trend reversal is apparent in the following months. The sharp drop observed at the end of 2008 captures the strongly expansionary monetary policy implemented by the Reserve Bank of India (RBI) as a response to the global financial crisis. The moderate increase in the term structure observed during the last part of the sample mainly reflects a build-up of inflationary pressures in the Indian economy.

Cointegration analysis requires a preliminary investigation about the time series properties of data. Standard unit root tests were therefore carried out on all interest rates examined in the present paper. The results from these tests (not shown but available upon request) provide overwhelming evidence that all series are integrated of order one (I(1)).

2.2 Multivariate Cointegration and EHTS Parameters Restrictions

Let $i_{t}^{(l)}$, $i_{t}^{(s)}$ denote, respectively, the long period and the short period interest rates ($s < l$). Assuming the existence of a (constant) risk premium component ($\theta_{ls}$) that may vary with the maturity of the rates, the EHTS may be formally expressed as:

$$i_{t}^{(l)} = \frac{1}{k} \sum_{i=0}^{k-1} E_{t} (i_{t+i}^{(s)}) + \theta_{ls}$$

where $k=l/s$ is an integer and $E_{t}$ is the expectations operator.

Equation (1) can be easily derived by log-linearizing a no arbitrage equilibrium condition according to which the return on a long period investment must be equal to the return on a shorter period investment rolled over $k$ times. Most of the applied literature exploring the EHTS relies on tests obtained reparametrizing equation (1) in a linear regression framework.

As widely discussed in the literature, the EHTS implies that nominal returns are linked through a long-run equilibrium relationship. More specifically, since nominal interest rates are usually I(1), the validity of the EHTS can be assessed testing for the existence of a cointegration relationship between $i_{t}^{(l)}$ and $i_{t}^{(s)}$ with a cointegrating vector (1, -1) (Campbell and Shiller, 1987; Hall et al.,
1992; Taylor, 1992). Therefore, from the perspective of cointegration theory, the EHTS suggests that asset returns closely move together and that the interest rate spread \((i_t^{(l)} - i_t^{(s)})\) is mean-reverting.

The above discussion can be generalized to a system of (n) interest rates. More specifically, in this case the EHTS predicts that each yield series is cointegrated with the short term yield. Therefore, in a system of (n) yields, the \((n - 1)\) spread vectors belonging to the set

\[
\begin{bmatrix}
(-1, 1, 0, \ldots, 0)', 
(-1, 0, 1, 0, \ldots, 0)', 
\ldots, 
(-1, 0, \ldots, 0, 1)' 
\end{bmatrix}
\]

are linearly independent and underlie a cointegration space of rank \((n - 1)\) (see e.g. Hall et al., 1992).

Testing EHTS in a multivariate cointegration framework exploits one basic implication of this theory, namely that a system of (n) non-stationary yields should have one common trend driving interest rates. Moreover, this approach delivers more accurate and robust statistical inferences than the applied literature investigating interest rates in pairs, since term structure innovations jointly affect the whole spectrum of interest rates maturities.

Drawing on the above discussion, three important hypotheses are explored in the present section. The former refers to the rank of the cointegration space. The latter two hypotheses are instead related to different restrictions on the parameters of cointegrating vectors. More specifically, the second testable hypothesis assesses the validity of the one-to-one relationship between \(i_t^{(l)}\) and \(i_t^{(s)}\) postulated by the EHTS, usually known as the “symmetry” or “zero-sum” restriction. The third testable hypothesis, finally, explores the empirical relevance of the “Pure Expectations” version of this theory, thus jointly testing the “symmetry” restriction and the absence of risk premia components in a multidimensional system of nominal interest rates.

In order to investigate the validity of the above hypotheses, I implement the standard FIML approach outlined in Johansen (1995). Although alternative methodologies are available to determine the number of common trends (Stock and Watson, 1988), Johansen’s methodology provides the natural framework to assess other hypotheses implied by the EHTS through standard likelihood ratio test statistics. Since nominal interest rates are not trended along the sample (see Fig. 1), the cointegrating VAR model is estimated imposing the usual restriction on the constant term (see e.g. Engsted and Tanggaard, 1994, section 2). The optimal VAR order \((p)\) is selected through standard Akaike and Schwarz information criteria. On this basis, all multivariate cointegrating VARs estimated in the present paper assume \(p = 1\). It is well known that residuals
autocorrelation has adverse effects on inferences from the Johansen approach. Diagnostic checks on single equations reveal that, imposing a lag length of $p = 1$, allows to exclude the existence of residuals serial correlation.

Table 1 summarizes the results from the Likelihood Ratio tests developed in Johansen (1995) to determine the number ($r$) of cointegrating vectors, namely the Maximal Eigenvalue test ($\lambda_{\text{max}}$) and the Trace test ($\lambda_{\text{trace}}$).

| Null | Alternative | $\lambda_{\text{max}}$ |
|------|-------------|----------------|----------------|
| $r = 0$ | $r = 1$ | 69.86** |
| $r \leq 1$ | $r = 2$ | 52.97** |
| $r \leq 2$ | $r = 3$ | 22.89** |
| $r \leq 3$ | $r = 4$ | 6.42 |

<table>
<thead>
<tr>
<th>Null</th>
<th>Alternative</th>
<th>$\lambda_{\text{trace}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$r = 0$</td>
<td>$r \geq 1$</td>
<td>152.15**</td>
</tr>
<tr>
<td>$r \leq 1$</td>
<td>$r \geq 2$</td>
<td>82.28**</td>
</tr>
<tr>
<td>$r \leq 2$</td>
<td>$r \geq 3$</td>
<td>29.31**</td>
</tr>
<tr>
<td>$r \leq 3$</td>
<td>$r = 4$</td>
<td>6.42</td>
</tr>
</tbody>
</table>

$\lambda_{\text{max}}$ and $\lambda_{\text{trace}}$ are the two statistics for the test of the cointegration rank. The data vector includes nominal interest rates at 10-year, 8-year, 5-year, and 3-year maturities. Cointegration with restricted intercepts and no trends in the VAR. Optimal lag length: $p = 1$.

** indicates significance at the 5% level.

The 95% critical values for $\lambda_{\text{max}}$ are: $r = 0$, 28.27; $r \leq 1$, 22.04; $r \leq 2$, 15.87; $r \leq 3$, 9.16.

The 95% critical values for $\lambda_{\text{trace}}$ are: $r = 0$, 53.48; $r \leq 1$, 34.87; $r \leq 2$, 20.18; $r \leq 3$, 9.16.

It is apparent from the above table that the null hypotheses that there are at most 0, 1, or 2 cointegrating vectors is rejected at standard significance levels. On the other hand, the empirical evidence does not reject the null hypothesis that $r \leq 3$, hence supporting the existence of three cointegrating vectors. Since I document that the rank of the cointegration space spanned by nominal interest rates is equal to three in a four-dimensional system of nominal yields, this result is fully consistent with the first theoretical implication of the EHTS addressed in this section.
The Indian term structure of interest rates during the post-liberalization period is therefore driven by one common stochastic trend\textsuperscript{1}. This evidence corroborates the empirical findings favourable to the EHTS obtained in Tronzano (2014), and is broadly in line with similar findings obtained through a multivariate cointegration approach for industrial and emerging market economies (see e.g. Hall \textit{et al.}, 1992; Arshanapalli and Doukas, 1994; Engsted and Tanggaard, 1994; Konstantinou, 2004; Masih and Ryan, 2005).

Table 2 displays the FIML estimates of the three exactly identified cointegrating vectors, normalized on nominal yields at different long-term maturities (see eq. [1] ).

\begin{table}
\centering
\begin{tabular}{|c|c|c|c|}
\hline
 & Vector 1 & Vector 2 & Vector 3 \\
\hline
\(i^{(3)}\) & 1.0112 (0.0171) & 1.0084 (0.0339) & 1.0245 (0.0442) \\
\hline
\(i^{(5)}\) & -1.000 (-) & 0.000 (-) & 0.000 (-) \\
\hline
\(i^{(8)}\) & 0.000 (-) & -1.000 (-) & 0.000 (-) \\
\hline
\(i^{(10)}\) & 0.000 (-) & 0.000 (-) & -1.000 \\
\hline
\(\theta_{ls}\) & 0.1641 (0.1423) & 0.4388 (0.2797) & 0.3554 (0.3645) \\
\hline
\end{tabular}
\caption{Exactly Identified Cointegrating Vectors}
\end{table}

Full Information Maximum Likelihood (FIML) estimates of exactly identified cointegrating vectors from a Cointegrating VAR model with restricted intercepts and no trends in the VAR. Conditional standard errors in parentheses below parameters estimates.

\textsuperscript{1} Stock and Watson (1988) show that when there are (n-1) linearly independent cointegrating vectors in a system of (n) I(1) variables, each of these variables can be expressed as the sum of an I(1) stochastic common factor and a stationary I(0) component. In this perspective, the empirical evidence of Table 1 could in principle be consistent with Cox \textit{et al.} (1985) general equilibrium model of the term structure, where the instantaneous interest rate is the single common factor driving the whole dynamics of the term structure. It must be underlined, however, that the common factor does not necessarily correspond to the instantaneous interest rate, but can more generally be interpreted as any other period yield, or even as some variable exogenous to the term structure, such as inflation or monetary growth (Hall \textit{et al.}, 1992, section 2). This taken into account, the cointegration results of Table 1 are broadly consistent with the EHTS, without providing specific support to any particular theoretical model of the term structure.
Point estimates of the slopes coefficients are highly significant in all cases, and very close to the unitary value predicted by theory (see first row of Table 2). The estimates of the intercept term ($\theta_{ls}$), on the other hand, are highly imprecise for all cointegrating vectors and never statistically significant (see last row of Table 2). These preliminary results provide some informal support to the EHTS pointing to the existence of long run one-to-one co-movements between short and long-term interest rates, but suggest that the presence of risk premia components might eventually invalidate the “Pure Expectations” version of this theory.

I now proceed to formally assess the restrictions implied by the EHTS by means of two separate LR tests. The former test involves the “symmetry” or “long-run zero restriction”, which assumes proportional co-movements of all yields across the whole spectrum of assets maturities, treating the intercepts terms as free parameters. The latter test imposes the above restriction, but includes a further restriction setting intercepts terms to zero at all maturities ($\theta_{ls} = 0$).

The empirical findings obtained from these two LR statistics are summarized in Table 3.

Focusing on the upper section of Table 3, the joint hypothesis that the three cointegrating vectors satisfy the “symmetry” conditions cannot be rejected by the LR test at standard significance levels. This finding corroborates the evidence discussed in Tronzano (2014), where analogous results were obtained assessing the validity of the “symmetry” restriction on single bilateral pairs of asset returns. The unrestricted estimates of intercepts terms in Table 3 reveal moreover that liquidity premia are monotonically increasing with maturity, in line with the predictions of the Liquidity preference hypothesis (Hicks, 1946).

Turning to the lower section of Table 3, the joint hypothesis of symmetry and zero risk premia on the three cointegrating vectors is instead strongly rejected. This finding mimics analogous results obtained in Tronzano (2014) for single pairs of interest rates maturities, thus providing further robust evidence against the validity of the “Pure” version of the EHTS for the Indian term structure.

To sum up, the analysis carried out in this section relies on the cointegration properties of a system of four interest rates to explore the validity of the EHTS in a multivariate framework. Drawing on this approach, the empirical evidence fully corroborates previous results obtained in Tronzano (2014) focusing on single pairs of assets returns. More specifically, I document that the Indian term structure of interest rates exhibits one-to-one co-movements between
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Cointegration with restricted intercepts and no trend in the VAR. Conditional standard errors in parentheses below parameters estimates. The Likelihood Ratio test for the symmetry restriction (a) is distributed as a $\chi^2$ with three degrees of freedom. The Likelihood Ratio test for the joint restriction (b) is distributed as a $\chi^2$ with six degrees of freedom. p values in square brackets behind Likelihood Ratio test statistics.

short and long-run interest rates across all assets maturities, and that the “Pure” version of the EHTS is at odds with the empirical evidence due to the existence of significant risk premia at all temporal horizons.

### Table 3

**EHTS Restrictions: (a) Symmetry**

<table>
<thead>
<tr>
<th></th>
<th>Vector 1</th>
<th>Vector 2</th>
<th>Vector 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>$i^{(3)}$</td>
<td>1.000</td>
<td>1.000</td>
<td>1.000</td>
</tr>
<tr>
<td>$i^{(5)}$</td>
<td>-1.000</td>
<td>-0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>$i^{(8)}$</td>
<td>0.000</td>
<td>-1.000</td>
<td>0.000</td>
</tr>
<tr>
<td>$i^{(10)}$</td>
<td>0.000</td>
<td>-0.000</td>
<td>-1.000</td>
</tr>
<tr>
<td>$\theta_{ls}$</td>
<td>0.2548</td>
<td>(0.0348)</td>
<td>0.5045</td>
</tr>
</tbody>
</table>

Likelihood Ratio Test of Symmetry Restriction: 5.13377 [0.162]

**EHTS Restrictions: (b) Symmetry + Zero Risk Premia**

<table>
<thead>
<tr>
<th></th>
<th>Vector 1</th>
<th>Vector 2</th>
<th>Vector 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>$i^{(3)}$</td>
<td>1.000</td>
<td>1.000</td>
<td>1.000</td>
</tr>
<tr>
<td>$i^{(5)}$</td>
<td>-1.000</td>
<td>-0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>$i^{(8)}$</td>
<td>0.000</td>
<td>-1.000</td>
<td>0.000</td>
</tr>
<tr>
<td>$i^{(10)}$</td>
<td>0.000</td>
<td>-0.000</td>
<td>-1.000</td>
</tr>
<tr>
<td>$\theta_{ls}$</td>
<td>0.000</td>
<td>0.000</td>
<td>-0.000</td>
</tr>
</tbody>
</table>

Likelihood Ratio Test of Symmetry and Zero Risk Premia Restrictions: 28.476 [0.000]
3. Further Empirical Evidence

3.1 Forecast Error Variance Decomposition

This analysis shows to what extent the k-step ahead forecast error variance of each nominal yield can be decomposed in the percentage due to its own shocks and in the percentage due to innovations in other variables in the VAR.

Variance decomposition analysis represents a useful complement of VECM causality tests on the Indian term structure of interest rates carried out in Tronzano (2014). Actually, while the standard VECM approach is a within sample causality test, variance decomposition represents an out-of-sample test providing further information about the Granger exogeneity or endogeneity of each variable in the VAR.

Table 4 reports the results from orthogonalized forecast error variance decomposition tests on the Indian term structure of interest rates up to a 6-month ahead forecast horizon.

It is apparent from this table that, for all nominal yields, the bulk of forecast error variance is explained by shocks occurring to the short-term interest rate (i^{(3)}). Moreover, this result holds for all k-step ahead forecast horizons displayed in Table 4\(^2\).

The prominent role exerted by innovations to i^{(3)} suggests that the short-term interest rate is the most exogenous variable in this VAR system. This result is in line with VECM causality tests implemented in Tronzano (2014), which pointed out that i^{(3)} is strongly exogenous and detected significant unidirectional causal effects from the policy rate to long-term interest rates.

A further peculiar feature of Table 4 is that innovations in i^{(5)} account for a not negligible fraction of forecast error variances. This is evident for the short-term policy rate (particularly at longer forecast horizons) and, to a much greater extent, for nominal yields at longer maturities, where shocks to i^{(5)} explain about 15% - 20% of forecast error variances in the VAR.

These results suggest that, although the short-term rate (i^{(3)}) has a prominent role in driving the term structure of Indian interest rates, i^{(5)} is the next most exogenous variable in the VAR. This conclusion is again consistent with Tronzano (2014) where, for some interest rates pairs, the policy rate was found to be only weakly exogenous due to a feedback effect originating from i^{(5)}.

\(^2\) Similar results are obtained for the 8-year government bond yield (i^{(8)}), but these results are not shown in order to save space.
Overall, therefore, the results from variance decomposition tests fully corroborate the evidence from VECM causality tests obtained in Tronzano (2014).

**Table 4**

Orthogonalized Forecast Error Variance Decomposition for $i^{(3)}$

<table>
<thead>
<tr>
<th>Horizon</th>
<th>$i^{(3)}$</th>
<th>$i^{(5)}$</th>
<th>$i^{(8)}$</th>
<th>$i^{(10)}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>1</td>
<td>0.988</td>
<td>0.010</td>
<td>0.8E-3</td>
<td>0.7E-3</td>
</tr>
<tr>
<td>2</td>
<td>0.971</td>
<td>0.024</td>
<td>0.001</td>
<td>0.002</td>
</tr>
<tr>
<td>3</td>
<td>0.956</td>
<td>0.036</td>
<td>0.002</td>
<td>0.003</td>
</tr>
<tr>
<td>4</td>
<td>0.943</td>
<td>0.047</td>
<td>0.003</td>
<td>0.005</td>
</tr>
<tr>
<td>5</td>
<td>0.932</td>
<td>0.056</td>
<td>0.004</td>
<td>0.006</td>
</tr>
<tr>
<td>6</td>
<td>0.923</td>
<td>0.063</td>
<td>0.005</td>
<td>0.008</td>
</tr>
</tbody>
</table>

Orthogonalized Forecast Error Variance Decomposition for $i^{(5)}$

<table>
<thead>
<tr>
<th>Horizon</th>
<th>$i^{(3)}$</th>
<th>$i^{(5)}$</th>
<th>$i^{(8)}$</th>
<th>$i^{(10)}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.836</td>
<td>0.163</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>1</td>
<td>0.838</td>
<td>0.160</td>
<td>0.4E-4</td>
<td>0.6E-3</td>
</tr>
<tr>
<td>2</td>
<td>0.841</td>
<td>0.156</td>
<td>0.2E-3</td>
<td>0.001</td>
</tr>
<tr>
<td>3</td>
<td>0.844</td>
<td>0.152</td>
<td>0.4E-3</td>
<td>0.002</td>
</tr>
<tr>
<td>4</td>
<td>0.846</td>
<td>0.149</td>
<td>0.8E-3</td>
<td>0.003</td>
</tr>
<tr>
<td>5</td>
<td>0.848</td>
<td>0.145</td>
<td>0.001</td>
<td>0.004</td>
</tr>
<tr>
<td>6</td>
<td>0.849</td>
<td>0.142</td>
<td>0.001</td>
<td>0.005</td>
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</tbody>
</table>

Orthogonalized Forecast Error Variance Decomposition for $i^{(10)}$

<table>
<thead>
<tr>
<th>Horizon</th>
<th>$i^{(3)}$</th>
<th>$i^{(5)}$</th>
<th>$i^{(8)}$</th>
<th>$i^{(10)}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.615</td>
<td>0.200</td>
<td>0.101</td>
<td>0.083</td>
</tr>
<tr>
<td>1</td>
<td>0.647</td>
<td>0.210</td>
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</tr>
<tr>
<td>2</td>
<td>0.675</td>
<td>0.213</td>
<td>0.064</td>
<td>0.046</td>
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<tr>
<td>3</td>
<td>0.699</td>
<td>0.212</td>
<td>0.052</td>
<td>0.035</td>
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<tr>
<td>4</td>
<td>0.719</td>
<td>0.209</td>
<td>0.042</td>
<td>0.028</td>
</tr>
<tr>
<td>5</td>
<td>0.735</td>
<td>0.204</td>
<td>0.035</td>
<td>0.023</td>
</tr>
<tr>
<td>6</td>
<td>0.750</td>
<td>0.199</td>
<td>0.030</td>
<td>0.019</td>
</tr>
</tbody>
</table>
3.2 Generalized Impulse Response Functions and Persistence Profiles

This section complements my previous analysis providing further evidence about the dynamics of the Indian term structure through the estimate of generalized impulse response functions (GIRFs) and of the persistence profile of the effect of a system-wide shock to cointegrating vectors (CVs).

GIRF analysis describes the time profile of the effect of a unit shock to a single equation of the VAR on all variables of the system. The main advantage of this approach, as opposed to orthogonalized impulse response functions, is that it is invariant to the ordering of variables, since it relies on their historical correlations without imposing any *a priori* restrictions. However, since the shocks are not identified, differently from the analysis of the previous section this approach does not provide any information about causality among VAR variables.

Figures 2, 3, 4, 5 display, respectively, GIRFs to one standard deviation shock in the VAR equations for $i^{(3)}$, $i^{(5)}$, $i^{(8)}$, $i^{(10)}$.

All simulations analyze the response of the term structure of interest rates over a 3-year horizon.

*Figure 2 - Generalized Impulse Responses to one S.E. Shock in the Equation for I3*
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Figure 3 - Generalized Impulse Responses to one S.E. Shock in the Equation for I5

Figure 4 - Generalized Impulse Responses to one S.E. Shock in the Equation for I8
The response of yields at all maturities is always statistically significant and highly persistent. After a positive shock to the VAR, the term structure of interest rates increases in all cases, although slightly larger effects are observed for shocks to short and median maturities after the adjustment process has fully taken place (compare Figures 2 - 3 with Figures 4 - 5). Focusing on the adjustment process, shocks to the variables $i^{(3)}$ and $i^{(5)}$ are much slowly dissipated than shocks to longer interest rates maturities. Actually, the results point out that the adjustment process lasts for about three years in the former case and only about one year and a half in the latter. Although, as discussed before, this simulation analysis cannot provide exact inferences about causality, this evidence is broadly consistent with previous results, documenting the major role exerted by $i^{(3)}$ and $i^{(5)}$ in driving the Indian term structure.

A further interesting result is that, in most cases, nominal yields exhibit a gradual monotonic increase after a positive shock to the term structure. One relevant exception is represented by the effects of a shock at the longer edge of the yield curve, where the short-term policy rate follows a monotonic increase, whereas all other variables display a short run overshooting process before converging to their new long run equilibrium values (see Figure 5).
I now turn to the analysis of persistence profiles of the three cointegrating vectors following a system-wide shock to the term structure of interest rates.

Pesaran and Shin (1996) outline this approach as a useful complement to the standard VECM analysis, in order to obtain further inferences about the speed of adjustment towards equilibrium once the long-run relationships of the model are altered by a system-wide disturbance. The persistence profile of each cointegrating vector is formally defined as the difference between the conditional variance of the \((t + n)\) and the \((t + n - 1)\) step ahead forecast after a shock.

This profile is scaled to take a unitary value at the impact of the shock \((n = 0)\). In a system of cointegrated variables, the effects of a shock will tend to progressively disappear as \((n)\) becomes larger, while in the absence of cointegration these effects will indefinitely persist over time.

The persistence profiles for the three cointegrating vectors identified in the present paper are reproduced in Figure 6 for a time horizon of thirty-six months.

The first cointegrating vector (CV1) corresponds to the long-run equilibrium relationship between the short-term rate \(i_3\) and

**Figure 6 - Persistence Profile of the Effect of a System-Wide Shock to Cointegrating Vectors**
the 5-year government bond yield \((i_5)\). The remaining cointegrating vectors correspond to the equilibrium relationships between \((i_5)\) and longer nominal maturities. i.e., respectively, \((i_8)\) (CV2) and \((i_{10})\) (CV3) (see section 2.2, Table 2).

As revealed by Figure 6, all persistence profiles gradually converge towards zero as the time horizon is increased. Overall, the full adjustment to the new long-run equilibrium for all CVs requires slightly less than two years. This result confirms the existence of three stationary relationships in this 4-dimensional system of nominal interest rates, thus corroborating the empirical evidence supporting the EHTS obtained in section 2.2.

A closer inspection of Figure 6 reveals, however, significant differences in the speed of adjustment of various cointegrating vectors after a system-wide shock. More specifically, the cointegrating vector corresponding to the shorter spread maturity (CV1) exhibits a faster convergence towards equilibrium, completing the largest part of the adjustment process in less than three months, whereas the CVs corresponding to larger maturities display a slower response. This evidence is similar to results obtained in the recent applied literature (see, e.g. Masih and Ryan, 2005), although in the present paper we do not observe a tendency of CVs associated with larger maturities to over-react in the opposite direction after a shock to the system.

Overall, these results point out that nominal interest rates are significantly connected, and that a shock to the term structure generates less destabilizing effects at the shortest edge of the maturities spectrum.

It may be interesting to observe, finally, that while supporting the evidence of the previous section, these results are closely in line with the VECM estimates for single bilateral yields reported in Tronzano (2014). Estimated error correction terms obtained in Tronzano (2014) are quantitatively higher for shorter maturities and decrease monotonically for larger maturities (see ibidem, Table 5), suggesting that temporary deviations from equilibrium are more quickly absorbed at shorter maturities. The analysis carried out in the present section is fully in line with the above evidence, pointing out that the effects on CVs of a system-wide shock are relatively more persistent at longer spreads maturities.

4. Concluding remarks

This paper extends inside a multivariate cointegration framework the analysis on the term structure of Indian interest rates carried
out in Tronzano (2014). This approach significantly improves on bilateral cointegration tests implemented in previous research, since term structure innovations are expected to spread very quickly across the yield curve, jointly affecting the whole spectrum of interest rates maturities.

The main empirical findings may be summarized as follows.

I document the existence of three cointegrating vectors in a four-dimensional system of nominal interest rates, thus showing that the Indian term structure during the post-liberalization period is driven by one common stochastic trend. Moreover, while the “symmetry” condition on cointegrating vectors is supported by data, the “Pure” version of the EHTS is strongly rejected due to significant risk premia components at all temporal horizons. All these results are closely in line with those obtained in Tronzano (2014).

Further investigation provides additional evidence corroborating previous results.

A forecast error variance decomposition analysis shows that the bulk of forecast error variance is explained by shocks occurring to the short-term interest rate ($i_3$). This points out that the above rate is the most exogenous variable in the VAR, thus corroborating VECM causality test implemented in Tronzano (2014). Generalized impulse response functions reveal, moreover, that shocks to shorter term interest rates ($i_3, i_5$) are much slowly dissipated than those occurring to longer yields, thus reiterating the major role exerted by these variables in driving the Indian term structure of interest rates. The persistence profiles of cointegrating vectors to a system-wide shock, finally, point out that spreads of shorter maturities display a faster adjustment towards long-run equilibrium. This result strongly corroborates the empirical estimates of error corrections coefficients obtained in Tronzano (2014), suggesting that temporary deviations from equilibrium are more quickly absorbed at relatively shorter maturities of the yield curve.

Overall, this paper documents that previous results on the Indian term structure are robust to a multivariate cointegration analysis, both as regards the degree of empirical support for the EHTS, and as regards the dynamic properties of the cointegrating VAR.

This empirical evidence has clear-cut implications for monetary policy. Tronzano (2014) documents that the short-term interest rate ($i_3$) is strongly exogenous for most interest rate pairs, and that there are significant unidirectional causal effects from this variable (which can be regarded as a proxy for the short-term policy rate)
to longer term interest rates. Forecast error variance decomposition tests provide further support to the above evidence, pointing out that \(i_t\) is the most exogenous variable in the VAR and exerts a prominent role in driving the Indian term structure. A monetary policy strategy relying on a short-term interest rate target is therefore highly appropriate for India, since the transmission of monetary impulses mimics the usual mechanism emphasized in the conventional approach to monetary policy (Clarida et al., 1999).

Although this paper follows one potential research line advocated in Tronzano (2014), many interesting topics in this area deserve further attention. A straightforward extension is the inclusion of a wider set of assets maturities, which would allow to further explore the robustness of these results, mainly when they are evaluated in a policy perspective. In a more general perspective, the existence of significant risk premia across the yield curve calls for a more accurate investigation about the nature of these components. The literature exploring the effects of macroeconomic fundamentals on term structure dynamics (see, among others, Ang and Piazzesi, 2003; Diebold et al., 2006) could greatly help in this regard, as documented in some recent contributions including macroeconomic variables as conditioning information in a general VAR specification (Sarno et al., 2007). A joint empirical investigation of India and other Asian countries implementing financial liberalization measures represents, finally, another fruitful research line. Panel cointegration tests provide significant increases in tests power with respect to a single-country approach, and robust efficiency gains when assessing the main restrictions on parameters associated with EHTS.

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REFERENCES


**ABSTRACT**

This paper extends the analysis of Tronzano (2014) inside a multivariate cointegration framework. I show that the Indian term structure of interest rates is driven by one common stochastic trend. Moreover, closely in line with Tronzano (2014), I document that the “symmetry” condition on cointegrating vectors is supported by data, whereas the “Pure” version of the Expectations Hypothesis is strongly rejected. Further investigation through variance decomposition tests and persistency profiles of cointegrating vectors corroborates other results obtained in Tronzano (2014) (i.e. short-term interest rate exogeneity and a faster adjustment speed of spreads at shorter maturities). Overall, these results provide strong empirical support for a monetary policy strategy relying on a short-term interest rate target.

Keywords: Term Structure of Interest Rates, Multivariate Cointegration, India, Monetary Policy

JEL Classification: C1, E43
RIASSUNTO

La struttura a termine dei tassi di interesse: ulteriore evidenza empirica per l’India (1996-2013)

Questo lavoro estende l’analisi condotta in Tronzano (2014) in un contesto di cointegrazione multivariata e mostra che la struttura a termine dei tassi di interesse in India è guidata da un trend stocastico comune. Inoltre, in linea con Tronzano (2014), si mostra che la condizione di “simmetria” sui vettori di contegrazione è supportata dai dati, mentre la versione “pura” della “Expectations Hypothesis” è fortemente rigettata dall’evidenza empirica. Ulteriori analisi attraverso i tests di decomposizione della varianza e i profili di persistenza dei vettori di cointegrazione supportano altri risultati ottenuti in Tronzano (2014) (cioè la esogeneità del tasso di interesse a breve termine e una maggiore velocità di aggiustamento dei differenziali dei tassi di interesse per le scadenze più brevi). Nel complesso, questi risultati forniscono un robusto supporto empirico a una strategia di politica monetaria basata sul controllo di un tasso di interesse a breve termine da parte della Banca Centrale.