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DECOMPOSING LONG-TERM INTEREST RATES: AN INTERNATIONAL COMPARISON[*]

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Abstract

This work analyzes the behavior of long-term interest rates for several economies, identifying the risk neutral and term premium components under different methodologies. With this, we analyze which of these two channels affected interest rate movements in different monetary policy regimes. Also, we quantify the transmission of US long-term yield to others economies using the spillovers index proposed by Diebold & Yilmaz (2009). We find that movements in long-term interest rates (respect to the pre-crisis period 2003-2007) in different monetary policy regimes are related to changes in the term premium for most countries. Also, our findings suggest a heterogeneous behavior in the US to other economies. In developed economies, long-term interest rates are affected in both components (risk neutral and term premium) mainly through the US risk-neutral channel; whereas in developing countries, the evidence suggests that the relevant transmission channel is the term premium which is affected by US term premium.

Resumen

Este trabajo analiza el comportamiento de las tasas de interés de largo plazo para varias economías, identificando el componente de tasas neutral y de premio por plazo bajo diferentes metodologías. Con esto, analizamos cuales de estos dos canales afectaron movimiento en las tasas de interés en diferentes regímenes de política monetaria. También, cuantificamos el efecto derrame (spillovers) de movimientos de tasas largan en EEUU a otras economías usando la metodología propuesta por Diebold y Yilmaz (2009). Se reporta que movimientos en tasas de largo plazo (respecto al periodo pre-crisis 2003-2007) en diferentes regímenes de política monetaria están relacionados a cambios en los premios por plazo en la mayoría de los países. También, nuestros resultados sugieren un comportamiento heterogéneo del efecto derrame de tasas largas en EE.UU. En economías desarrolladas, las tasas de largo plazo son afectadas en ambos componentes (tasa neutral y premio por plazo) principalmente a través del canal de tasa neutral de EE.UU.; mientras en economías en desarrollo, la evidencia sugiere que el canal relevante de transmisión es el premio por plazo el cual es afectado por el premio por plazo de EE.UU.

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1 Introduction

The term structure of interest rates provides relevant information to central banks about market expectations regarding future economic activity, the outlook for monetary policy path and inflation expectations. Furthermore, given its high frequency feature, central banks can monitor how market expectations evolve when market conditions change, and also it serves as a source of feedback to central banks after policy decisions or communicates. However, a well understating of long-term interest rates requires an identification and separation of the expected short-term interest rate component and the term premium components.

In principle, the monetary authority can influence long-term interest rates via the expected path of the short-term interest rate. This is called the Expectation Hypothesis (EH), which states in its strong form, that long-term rates are determined solely by the current and expected path of the short-term interest rate by market participants. However, empirical evidence suggest that the EH does not hold (see Gürkaynak & Wright (2012) for a revision). In practice, an investor who holds long-term bonds requires a compensation for taking the risk of uncertainty on its return. Thus, the term premium concept is referred to the deviation of observed interest rates from yields under the expectations hypothesis.

In an attempt to decompose the observed interest rate into the expected short-term interest rate and the term premium component several approaches have emerged (regression-based estimates, survey forecast, among others). However, a common approach used in the empirical literature has been the so called no-arbitrage models, in which the main feature is that securities with similar risk should be priced exactly. In the case of bonds, a functional form of risk factors and market price of risk dynamics allows to price any bond at different maturities under the condition of no-arbitrage, which has been called affine models. The affine models assume that bond interest rates are linear in some risk factors and these factors follow a Gaussian distribution. However, there has been reported some issues with the empirical estimation of these models. First, the standard technique to compute the affine models requires numerical procedures (maximum likelihood estimation), which are sensitive to initial values and difficult to find a global maximum, which may lead to an inaccurate estimation of risk neutral interest rates. Second, the risk factors considered may affect the identification of risk neutral rates (and therefore the term premium). Third, the highly persistence feature of interest rates may induce a bias in parameter estimation, leading an inaccurate estimation of the risk neutral and term premium components.

On the other hand, the scope and application of these models have been mostly applied to developed countries. For example Wright (2011) estimates the term premium for ten industrialized countries, Dahlquist & Hasseltoft (2013) for US, UK, Germany and Switzerland, Wu (2014) for US, among many others. For developing countries, the empirical analysis has been covered by Espinosa et al. (2014) for the Colombian market, Ceballos et al. (2015) for the Chilean market, Almeida et al. (2014) for the Brazilian market. However, the procedure estimation and risk factors considered are different which may account in an incorrect interpretation when comparing the term premium and risk neutral rates among these countries.

In this paper we employ two different approaches to estimate affine models for several countries. In particular, we decompose the nominal 10-years bond rates for 22 countries using the standard procedure applied in the literature (Ang & Piazzesi (2003), Wright (2011), Bauer et al. (2014)) which consists in maximum likelihood estimation for the model. Also, a recent approach proposed by Adrian et al. (2013) is computed, which requires an ordinary OLS regression in order to compute dynamic term structure models (henceforth DTSM). With this we are able to study the historical behavior and co-movement of long-term interest rates in different monetary policy regimes such as the pre-crisis period, during the financial crisis of 2008 and after the implementation of unconventional monetary policies. We separate our analysis in these periods because the drivers behind the movements of interest rates may be affected by the monetary policy tool carried out. Finally, as a way to explore the role of US interest rate transmission, we employ the spillover index proposed by Diebold & Yilmaz (2009) which allow us to measure the linkages of interest rates in each economy to the US and identifying the relevant channel (risk-neutral or term premium) in which the transmission is carried out.

To measure international spillovers on interest rates, several authors have used the windows event approach using high frequency data such daily or even intraday movements on interest rates over different assets such as interest rates, equities, currencies, among others. For instance, Rogers et al. (2014) focus on the impact of the unconventional monetary policy applied by several central banks (Federal Reserve, Bank of England, Central Bank of Europe and Bank of Japan). To this, the authors analyze the passthrough of changes in some benchmark for interest rates in others assets using a windows event framework. Similar approach is used by Gilchrist et al. (2014) to measure the effect of US monetary policy in others economies. The authors report the passthrough of US to other advanced and emerging market economies in different samples where conventional and unconventional monetary policies were carried out. Recently, Georgiadis (2015) analyzes global spillovers from US to different economies under a VAR approach. However, our approach to measure spillovers departs from the passthrough measures reported in several studies.

This paper contributes to the literature in several dimensions. First, presents a revision of the most used estimation's approaches to compute DTSM as well as recent techniques which lead to more accurate results and therefore a better interpretation of the term premium and risk neutral components. Second, under the separation of the risk-neutral component (associated to the monetary policy) and the term premium, we attempt to analyze historical movements in long-term yields during episodes of financial distress and different monetary policy regimes. Third, under the spillover methodology proposed by Diebold & Yilmaz (2009) we complement our analysis measuring the interdependence of developed and developing long-term interest rates to US yields. Moreover, we identify the relevant channel of US long-term yield transmission (risk-neutral rates and term premium) to others economies.

Our results suggest that the affine model decomposition of long-term interest rates reveals similar results when two different approaches are used in 22 economies. With the long-term interest rates decomposition we proceed to analyze interest rate movements in different monetary policy regimes. In the financial crisis period (June 2007 to November 2008) long-term interest rates showed an increase in most countries explained mainly by an increase in the term premium components and a reduction in the risk-neutral rates. In the period where unconventional monetary policies were applied (December 2008 to May 2013) we observe a reduction in both risk-neutral rates and term premium. Finally, we report a heterogeneous behavior during the normalization period (after May 2013).

Also, the transmission of US interest rate movements suggest that in G7 countries, the US transmission to these economies had a significant impact in both channels (risk-neutral and term premium) mainly by the US risk-neutral rates channel, which was observed in the pre-crisis period (before January 2003 to June 2007) and after the ongoing of the sub-prime and financial crisis period. In other developed economies, the evidence suggest a lower transmission of US interest rates with mixed results. For developing countries, the US term premium is the relevant channel affecting those economies through term premiums.

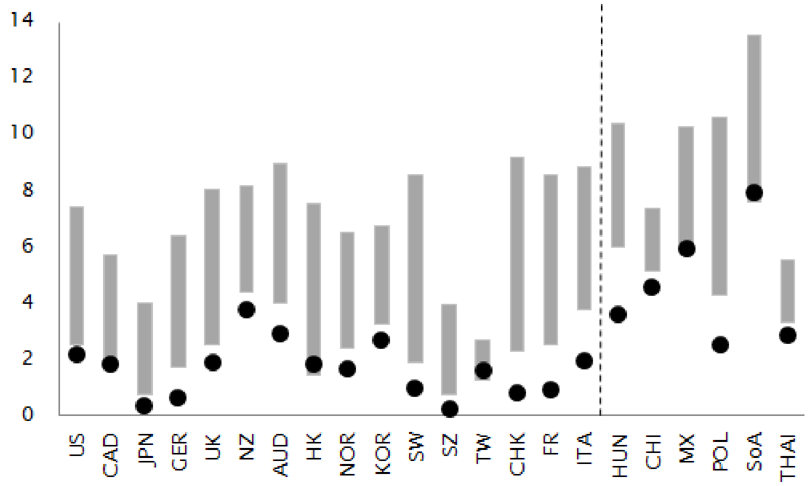
This paper is organized as follows. Section 2 presents two empirical facts in global interest rates in order to motivate the relevance of decomposing interest rates. Section 3 presents a revision of the two approaches employed in this paper to estimate the DTSM model. In section 4 we describe the spillover index proposed by Diebold & Yilmaz (2009). Section 5 presents the data used in the paper and the decomposition of the long-term yields as well as a discussion of these findings. Finally, section 6 concludes.

2 Empirical facts

International long-term interest rates (10-year nominal interest rates) have exhibited two interesting empirical facts: current levels of long-term yields have reached its minimal historical values and have exhibited a high co-movement with the US long-term interest rate. The latter raises the question of what has been the role of the US monetary policy and what are the transmission channels to others developed markets as well as developing economies.

The first empirical fact is related with current levels of long-term yields, which in most countries have reached its historical minimum value. Figure 1 shows the range in which long-term interest rates have fluctuated (percentiles 10 and 90) since 1990 and the mean during the whole period. Also, the current level of these yields are reported as a way to compare the deviation of current values from its historical range. Figure 1 shows that in most developed countries the current value of long-term yields are below the historical range in which have fluctuated, and in some cases as Czech Republic, Italy and France, the deviation from its low range is significant (in order of 170 bps). In the case of developing countries, the current value of long-term yields have reached its minimum levels and in cases such as Hungary and Poland, the yields are in order of 200 bps below of its historical range. The latter may be explained by the fact that many central banks have cut its monetary policy rate to the lowest level in response to the financial crisis as a way to recover economic growth and therefore affecting long-term interest rates via expectation channel.

FIGURE 1: Historical movements on long-term interest rates



Countries denoted as United States (US), Canada (CAD), Japan (JPN), Germany (GER), United Kingdom (UK), New Zealand (NZ), Australia (AUD), Hong Kong (HK), Norway (NOR), South of Korea (KOR), Sweden (SW), Switzerland (SZ), Taiwan (TW), Czech Republic (CZK), France (FR), Italy (ITA), Hungary (HUN), Chile (CL), Mexico (MX), Poland (POL), South of Africa (SOA) and Thailand (THAI). Bars represent the long-term yield fluctuation defined as the 10 and 90 percentil in the sample 1990-2014. Dots correspond the latest value (December-14) of long-term interest rate in each country. The dashed line separates developed (left) and developing (right) countries. All variables are in monthly frequency and expressed in percentage points. Sources: Bloomberg and author's calculations.

The second empirical fact concerns the high co-movement of international yields with the US interest rates, especially in the period after the ongoing of the sub-prime crisis in the US. To show this pattern more clearly, we perform a simple regression between monthly change in long-term interest rates of each economy and the change in the US long-term interest rate. With this, we attempt to illustrate the high co-movements among the countries with the US yield[1]. Figure 2 reports the adjusted R^2 as a measure of goodness-of-fit of our simple regression, and also we consider two subsamples explained previously as a way to show how international linkages have increased after the financial crisis. To account for the relevance of financial turmoil exhibited during the financial crisis of 2008, we proceed to split the sample in two parts: (a) January 1990 to June 2007 which we considered as the pre-crisis sample, and (b) the period posterior to June 2007 which according to Nowak et al. (2011) and Ait-Sahalia et al. (2012) marks the onset

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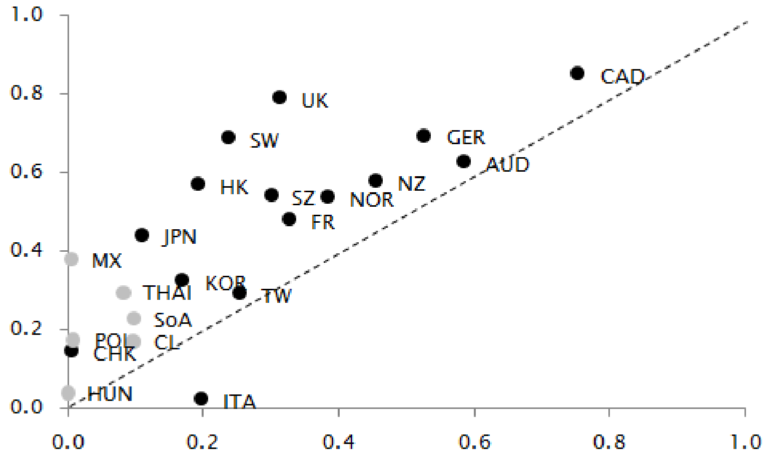
[1] In Appendix A we report OLS coefficients.

of the sub-prime and financial crisis. The X-axis corresponds to the sample previous to the financial crisis, and the Y-axis the posterior sample, where is shown how the international linkage of interest rates increased, measured by the adjusted R^2.

FIGURE 2: Adjusted R^2 of a linear regression of each country with the US interest rate



NOTE: This figure reports the adjusted R^2 of the regression of monthly changes in long-term yield of each country against a constant and changes in the US long-term interest rate. The X-axis considers the sample January 1990 to June 2007, and the Y-axis the sample starting from July 2007 to December 2014. Black dots denote developed countries and gray dots developing economies. Source: author's calculations.

In both cases, we attempt to explore the potential role of the term premium behind these facts. Moreover, under a decomposition of the yield curve (identifying the expected short-term interest rate and the term premium component) we are able to characterize these facts regarding the recent movements and trends as well as the high co-movement reported in the last years.

3 Dynamic Term Structure Methodologies

In this section we briefly describe the methodologies employed in this paper. First, we present the main features of the more standard methodology which are summarized in the papers of Wright (2011) and Bauer et al. (2012, 2014). Then, we discuss the methodology proposed by Adrian et al. (2013) (henceforth ACM), which is actually employed by the Federal Reserve Bank of New York as a new benchmark of the term premium estimation at daily frequency[2]. The main differences among these methodologies corresponds to the way that they compute market prices of risk and the assumptions behind these models.

3.1 General framework

The basic framework to understand the behavior and cross-section dependence of interest rates at different maturities is covered in the expectation's hypothesis of interest rates. First of all, the price of a bond maturing in n periods in time t is equal to:

$$P_t(n) = \exp(-ny_t(n))$$

where $y_t(n)$ corresponds to the continuously compounded interest rate of the bond at time t, and n the maturity. A conversion of previous expression to the interest rate is equivalent to:

$$y_t(n) = -\frac{1}{n}\log(P_t(n))$$

The expectations hypothesis (EH) states that long-term interest rates are equivalent to the average expected short-term interest rates until its maturity. This implies that the interest rate of any zero-coupon bond correspond to[3]:

$$y_t(n) \simeq \frac{1}{n}E_t\left(\int_0^n r(t+s)ds\right)$$

where $r(t+s)$ denotes the short-term interest rate at time $t+s$ and E_t corresponds to the expectation operator in t. Therefore interest rates at time t is equal to the expected path of the short-term interest rate until maturity n. This leads an important feature of the EH: investors price bond instruments as they were risk neutral, which implies that

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[2] See `http://www.newyorkfed.org/research/data_indicators/term_premium.html`

[3] This result ignores the Jensen's inequality term which exists because the log of an expectation is different than the expectation of a log, implying than long-term interest rates are lower than the expected short-term interest rates. However, Gürkaynak & Wright (2012) state that Jensen's term is modest for instruments with maturities lower than ten years as in this paper.

two different bonds with same expected returns but different uncertainty or standard deviation of its outcomes are indifferent to investors. However, in practice, investors are not indifferent to uncertainty, where is expected that instruments which offers same return than another asset but with higher uncertainty, investors will demand a compensation for taking such extra risk position. Empirically, the EH has been rejected for many authors (see Campbell & Shiller (1991), Bekaert & Hodrick (2001), among others). With this, affine term structure models are an alternative to the EH[4]. Now, we describe the specification of dynamic term structure models.

Dynamic Term Structure Models (DTSM). The standard DTSM is determined by the existence of K risk factors, summarized in vector X_t which follow a first-order VAR under the probability measure $\mathbb{P}$:

$$X_{t+1} = \mu + \Phi X_t + v_{t+1}, \qquad v_{t+1} \sim N(0, \Sigma) \tag{1}$$

It is assumed that the short-term interest rate r_t is an affine linear function of the risk factors:

$$r_t = \delta_0 + \delta_1' X_t \tag{2}$$

Finally, it is assumed that there exists an unique stochastic discount factor (SDF) that prices all assets under no arbitrage, which is affine as in Duffee (2002):

$$-\log M_{t+1} = r_t + \frac{1}{2}\lambda_t' \lambda_t + \lambda_t' v_{t+1} \tag{3}$$

where the vector of risk prices (λ) are also affine to risk factors: $\lambda_t = \lambda_0 + \lambda_1 X_t$. Under the risk-neutral probability measure $\mathbb{Q}$, the price of an n-period zero coupon bond is determined by $P_t^n = E_t^{\mathbb{Q}}(\exp(-\sum_{h=0}^{n-1} r_{t+h}))$ and the risk factors under neutrality also follow a Gaussian VAR:

$$X_{t+1} = \mu^{\mathbb{Q}} + \Phi^{\mathbb{Q}} X_t + v_{t+1}^{\mathbb{Q}}$$

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[4] Gürkaynak & Wright (2012) present an extensive revision of the EH hypothesis as well as the implication for DTSM estimation.

where $\mu^{\mathbb{Q}} = \mu - \Sigma\lambda_0$ and $\Phi^{\mathbb{Q}} = \Phi - \Sigma\lambda_1$. With this, the price of bonds at different maturities can be summarized into $P_t^n = \exp(\mathcal{A}_n + \mathcal{B}_n' X_t)$, where $\mathcal{A}_n$ and $\mathcal{B}_n$ follow the recursions[5]:

$$\mathcal{A}_{n+1} = \mathcal{A}_n + \left(\mu^{\mathbb{Q}}\right)' \mathcal{B}_n + \frac{1}{2}\mathcal{B}_n' \Sigma\Sigma' \mathcal{B}_n - \delta_0 \tag{4}$$

$$\mathcal{B}_{n+1} = \left(\phi^{\mathbb{Q}}\right)' \mathcal{B}_n - \delta_1 \tag{5}$$

with initial values $\mathcal{A}_0 = \mathcal{B}_0 = 0$. Thus, the model-implied yields are $y_t^n = -\frac{\log(P_t^n)}{n} = A_n + B_n' X_t$, with $A_n = \frac{\mathcal{A}_n}{n}$ and $B_n = \frac{\mathcal{B}_n}{n}$. On the other hand, the risk-neutral yield (the observed yield if investors would price bonds under risk neutrality) corresponds to:

$$\tilde{y}_t^n = \tilde{A}_n + \tilde{B}_n' X_t \tag{6}$$

$$\mathcal{A}_{n+1} = \mathcal{A}_n + \mu' \mathcal{B}_n + \frac{1}{2}\mathcal{B}_n' \Sigma\Sigma' \mathcal{B}_n - \delta_0 \tag{7}$$

$$\mathcal{B}_{n+1} = \Phi' \mathcal{B}_n - \delta_1 \tag{8}$$

The risk-neutral yield denoted in (6) are related mainly to the expected path of the future monetary policy rate, and therefore, reflects the part of the interest rates that are driven by expectations. Furthermore, the derivation of the expected short rate allows us to identify the term premium (tp) component, which corresponds to the difference between the model-implied yield and the risk-neutral yield, as follows:

$$tp_t^n = y_t^n - \tilde{y}_t^n \tag{9}$$

3.2 Standard estimation procedure

An important issue in the estimation of affine models is the high number of parameters to be estimated under maximum likelihood estimation (MLE) which carries out an intensive computational estimation of these models. Also, another potential issue in the models calibration is related to the flat surface of the likelihood function, which may produce inconsistent parameters estimates of the model.

Recently, innovations in the way of how to achieve an accurate and quicker global optimum under MLE have been proposed. In particular, Joslin et al. (2011) (henceforth

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[5] For a proof, see Ang & Piazzesi (2003) or Cochrane & Piazzesi (2005).

JSZ) show that a normalization of the model can be re-parameterized in terms of μ, Φ, Σ, $r_\infty^{\mathbb{Q}}$ and $\lambda^{\mathbb{Q}}$, where $r_\infty^{\mathbb{Q}}$ is the risk-neutral unconditional mean of the short-term interest rate and $\lambda^{\mathbb{Q}}$ contains the eigenvalues of $\Phi^{\mathbb{Q}}$. With this, the basic steps to compute the DTSM model are carried out as same as Wright (2011)[6]:

1. Run the VAR(1) process (1) and obtain parameters governing the evolution of pricing factors under the historical measure (μ and Φ). Joslin et al. (2011) shows that the MLE estimator is the same as the OLS estimate of an unrestricted VAR(1).
2. The relation between pricing factors and the short-term interest rate (specifically the 3-month nominal interest rate) is calculated using (2). This estimation step leads to the calibration of δ vector ($\delta = [\delta_0 \quad \delta_1]$).
3. The remaining model's parameters of the DTSM are numerically estimated taking as given the parameters of previous steps. To do this, the JSZ normalization is carried out. This procedure estimates the fitted term structure model in terms of $r_\infty^{\mathbb{Q}}$, $\lambda^{\mathbb{Q}}$ and Σ.
4. The risk-neutral interest rate can be estimated using the expected short-term interest rate at time T. This is done using equation (2) and the parameters of the second step to convert the forecast pricing factors into the forecast short-term interest rate.
5. Compute the term premium as the difference between the model implied denoted in the step 3 and expected short-term interest rate of step 4 (see equation 9).

3.3 ACM methodology

The methodology of Adrian et al. (2013) tries to exploit the log excess holding return predictability showed in empirical studies[7]. As Cochrane & Piazzesi (2005) mention, exists a relevant fraction of excess returns on bonds that could be captured with some specific factors[8]. Based on that idea, Adrian et al. (2013) propose a simple methodology

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[6] The Matlab code are publicly available at Bauer et al. (2014) `https://www.aeaweb.org/articles.php?doi=10.1257/aer.104.1.323`.

[7] For example Fama & Bliss (1987), Campbell & Shiller (1991) and Cochrane & Piazzesi (2005, 2008). See Gürkaynak & Wright (2012) for a review.

[8] In particular, in their analysis, they find that a single factor helps to predict more than 44% of one-year returns.

to construct market prices of risk into an affine model, that are consistent with this excess return forecasting power, in the line of Cochrane & Piazzesi (2005). In what follows, we describe the basic framework, which assumes that the observable state variables (or factors) used to price bonds consists just on linear combinations of observed yields from the term structure.

Basic framework. As we mentioned earlier, the main differences proposed by Adrian et al. (2013) regards the way to compute market prices of risk. To obtain those prices, the authors propose the following three steps procedure:

1. Estimate the VAR(1) process for the observable state variables given by (1). With these estimates, collect residuals in vector $\hat{V}$ and compute its variance-covariance matrix ($\hat{\Sigma} = \hat{V}\hat{V}'/T$).

2. Construct the log excess holding return of a bond maturing in n periods as:

$$rx_{t+1}^{n-1} = \log P_{t+1}^{n-1} - \log P_t^n - r_t, \qquad n = 2, ..., N \tag{10}$$

   where P_t^n is the price of an n period bond and r_t is the risk free rate and N is the maximum maturity considered. In this regard, the main difference between Adrian et al. (2013) and Cochrane & Piazzesi (2005) is that the latter work with one-year excess return while the first uses one-month excess returns. Stacking the system across the N maturities and T time periods we can construct the vector rx and run the following regression:

$$rx = \alpha\iota_T' + \beta'\hat{V} + cX_- + E \tag{11}$$

   where ι_T is T vector of ones and X_- is the lagged value of factors. The idea of this regression is to recover the fundamental components of the data generating process of the log excess holding return. Adrian et al. (2013) shows that the fundamental decomposition of these returns could be written as[9]:

$$rx = \text{Expected return} + \text{Priced return innovation} + \text{Return pricing error}$$

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[9] See that paper for details.

After running (11), collect residuals in the $N \times T$ matrix $\hat{E}$ and estimate the return pricing error variance as $\hat{\sigma}^2 = \mathrm{tr}(\hat{E}\hat{E}')/NT$.

3. Using the estimated parameters in (11), compute the market prices of risk as:

$$\hat{\lambda}_0 = (\hat{\beta}\hat{\beta}')^{-1}\hat{\beta}[\hat{a} + \frac{1}{2}(\hat{B}^*\mathrm{vec}(\hat{\Sigma}) + \hat{\sigma}^2)] \tag{12}$$

$$\hat{\lambda}_1 = (\hat{\beta}\hat{\beta}')^{-1}\hat{\beta}\hat{c} \tag{13}$$

where $\hat{B}^* = [\mathrm{vec}(\beta^1\beta^{1'}), ..., \mathrm{vec}(\beta^N\beta^{N'})]'$ and β^i is the covariance between log excess holding return at maturity n and the VAR innovations.

Following the previous algorithm and the common elements between methodologies (see section 3.1), the pricing can be done and the risk-neutral rates could be computed. The difference between the model-implied and risk-neutral yields corresponds to the term premium[10]

Unspanned factors. Here we present how Adrian et al. (2013) adapt the basic framework to the presence of unspanned factors. Unspanned factors (such as macroeconomics variables) have predictive ability for the term structure but not on the pricing of bonds. This assumption can be implemented imposing the zero-restrictions on the elements of the loading B_n in the pricing recursion. This assumption is common both to the standard methodology and to the ACM methodology. In fact, this is the only restriction that should be imposed in the standard methodology. In the case of ACM, some additional arrangements should be done. First, we partition the vector of state variables into spanned and unspanned components: $X_t = [X_t^s, X_t^u]'$. Those factors still follow a VAR(1) process under the historical measure. Second, the short rate does not load on any unspanned factor, which represent zero restrictions on the δ_1 vector. Third, the risk-neutral transition matrix is restricted to:

$$\Phi^* = \begin{bmatrix} \Phi_{ss} - \lambda_1 ss & 0 \\ \Phi_{us} - \lambda_1^{us} & \Phi_{uu} - \lambda_1^{uu} \end{bmatrix}$$

With those assumptions the algorithm could be re-written as:

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[10] Note from (11) that exists a measuring error that could produce a difference between observed yields and model implied yields. Empirically, those differences are negligible but to be precise, the risk premium should be computed from fitted yields instead of observed ones, as Bauer et al. (2014) does.

1. Run the VAR(1) using OLS as in the previous case but incorporating the unspanned factors. Denote X^s and X^s_- as the stacked contemporaneous and lagged values of spanned factors.

2. Estimate the regression

$$rx = \alpha_s \iota_T' + c_s X^s_- + \beta_s' X^s + E \tag{14}$$

where the main difference between (11) and (14) is the inclusion of contemporaneous values of spanned variables instead of contemporaneous errors.

3. Given previous estimates, we can compute the risk-neutral spanned constant and transition sub-matrix as:

$$\begin{aligned} \mu^*_s &= -(\hat{\beta}_s \hat{\beta}_s')^{-1} \hat{\beta}_s (\hat{a}_s + \frac{1}{2}(\hat{B}^{*s} \text{vec}(\hat{\Sigma}_{ss}) + \hat{\sigma}^2)) \\ \Phi^*_{ss} &= -(\hat{\beta}_s \hat{\beta}_s')^{-1} \hat{\beta}_s \hat{c}_s \end{aligned}$$

Denoting $\Psi = [\mu \quad \Phi]$ and $\Psi^*_{ss} = [\mu^*_s \quad \Phi^*_{ss}]$, where μ and Φ are the estimates in (1), we compute the market prices of risk as $\Lambda \equiv [\hat{\lambda}^s_0 \quad \hat{\lambda}^s_1] = \Psi_{ss} - \Psi^*_{ss}$. Also, set $\hat{\lambda}_{su} = \hat{\Phi}_{su}$. Parameters μ^*_u and Φ^*_u are not identified in the model but are not relevant for pricing. For that reason, the prices of risk ($\hat{\lambda}^u_0$ and $\hat{\lambda}^u_1$) are set equal to zero[11].

3.4 Bias correction

As we have shown, one of the main assumptions shared by both methodologies is the VAR(1) process of the risk factors. This assumption is key because it has effect on the statistical process of the stochastic discount factor, the capacity of the model to fit yields properly and the computation of risk-neutral yields and term premium. Because of that, it is fundamental to correctly estimate the parameters μ, Φ and Σ. Given the vector autoregressive nature of the model and the well-known bias related to these models, it is important to take into account procedures that could alleviate this bias. The effect of not take into account the bias produced by small-sample OLS estimation is the generation

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[11] This is equivalent to setting the risk-neutral parameters equal to the physical VAR estimates $\hat{\mu}^u$ and $\hat{\Phi}_u$.

of data artificially less persistent than the true process, which is reflected in risk-neutral rates with lower dynamic volatility than the true process. In that case, most of the variability on interest rates is attributed to term premium instead of risk-neutral rates, which is the case of Wright (2011) and the correction used in that paper and proposed by Bauer et al. (2014). The latter paper uses two methods proposed by Bauer et al. (2012) to this class of models. First, it is proposed a simple bootstrap bias correction, which re-sample residuals of the VAR process to create bootstrapped samples and compute the statistics of interests. This procedure can reduce the bias to order T^{-2}, i.e. the method reduces first order bias. Second, an indirect inference bias correction is proposed. The idea of this method is to choose parameter values which yields a distribution of the OLS estimator with a mean equal to the OLS estimate in the actual data[12]. For each methodology we estimate models with both procedures to correct bias and results do not change significantly. In what follows, we present results just with the indirect inference bias correction procedure[13,14].

3.5 Discussion

As we pointed out in section 3.2 and 3.3 there exists differences in the estimation procedure and assumptions under the standard approach and the proposed by Adrian et al. (2013). The main differences are:

1. The ACM approach does not impose the bond recursion stated in (4)-(5) and (7)-(8), so a simple linear regression can be implemented in order to estimate the model's parameters. In the standard estimation, a subset of parameters must be estimated considering such recursion using numerical methods, that are more complex than simple OLS regressions and sensitive to initial values.

2. The standard approach imposes the constraint that principal components must be priced perfectly, which minimize the error between the model-implied yield and the actual yields. The opposite occurs in Adrian et al. (2013) in which there is no imposed such constraint allowing the existence of a potential inconsistency between the model and actual yields. However, such differences are minimal as we present in the result section.

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[12] See the online Appendix of Bauer et al. (2012) for details.

[13] Results with the bootstrapping bias-correction are available upon request.

[14] The Matlab code to apply both bias correction procedures are publicly available at `http://faculty.chicagobooth.edu/jing.wu/`.

3. The ACM approach requires as an input interest rates at continuous horizons which in practice are not available. So an interpolation method is required previously as a way to compute the yield curve at different maturities not observed in practice. This may induce a measurement error between actual yield and the interpolation method used (in our case we used the Nelson Siegel model), besides the measurement error between the model implied DTSM and the interpolated interest rates. In the standard approach this is not required avoiding to carrying out another source of measurement error between the model and actual yields.

4. Finally, as we mentioned in section 3.2, the standard computation of DTSM is computationally intensive, which has been reduced implementing transformations such as Joslin et al. (2011). This procedure, assumes that there is no autocorrelation in the yield pricing errors, which allows to reduce the computational complexity estimates and leading to autocorrelation of pricing errors as Adrian et al. (2013) have described. The latter, generates excess returns predictability which is not captured by pricing factors.

4 International linkages and spillovers

In this section we describe the spillover index presented by Diebold & Yilmaz (2009) which has been applied in abroad financial assets and markets due its easy computation as well as its intuitive economic interpretation. The simple idea is to estimate a VAR which stacks the interest rates for several countries under consideration and then proceed to compute the forecast error variance decomposition considering a h windows step for each long-term interest rate quantifying how much of such error can be attributed to a shock in a specific country.

Formally, the spillover index corresponds to a tractable representation of a variance decomposition of an N-variable VAR system. In order to simplify the idea, we consider the case when two different assets are selected, and then we extend the analysis to N different assets:

$$x_t = \phi x_{t-1} + \varepsilon_t \tag{15}$$

where $x_t = [x_{1,t}, x_{2,t}]^T$ and ϕ is a 2×2 parameter matrix. With this, under covariance stationarity, the moving average representation of the VAR system can be written as follows:

$$x_t = \Theta(L)\epsilon_t$$

where $\Theta(L) = (I - \phi L)^{-1}$, and therefore the moving average representation of the VAR is $x_t = A(L)\,u_t$. In this case, $A(L) = \Theta(L)\,Q_t^{-1}$, $u_t = Q_t\varepsilon_t$, $E\left(u_t u_t^{'}\right) = I$ and Q_t^{-1} is the unique lower-triangular Cholesky factor of the matrix of ε_t. Thus, the one step ahead error forecast is determined by:

$$e_{t+1,t} = x_{t+1} - x_{t+1,t} = A_0 u_{t+1} = \begin{bmatrix} a_{0,11} & a_{0,12} \\ a_{0,21} & a_{0,22} \end{bmatrix} \begin{bmatrix} u_{1,t+1} \\ u_{2,t+1} \end{bmatrix}$$

Thus, the spillover index aims to determine the share of a specific shock in a variable affecting the error in other variable. Specifically, the variance of the one-step-ahead error in forecasting $x_{1,t}$ is $a_{0,11}^2 + a_{0,12}^2$ and $a_{0,21}^2 + a_{0,22}^2$ is the variance error in forecasting $x_{2,t}$. With this, the variance decomposition allows us to separate the forecast error attributable to specific system shocks, so the contribution of error from x_1 to x_2 and from x_2 to x_1 are measured. With this, the spillover index is a ratio which denotes the relative contribution of a specific shock to the forecast error variance. So the total spillover is $a_{0,12}^2$ and $a_{0,21}^2$, which can be expressed relative to the total forecast error, which is denoted as $trace(A_0 A_0^{'})$, where $trace$ is the trace operator. Therefore, the spillover index can be denoted as a ratio as follows:

$$S = \frac{a_{0,12}^2 + a_{0,21}^2}{trace\left(A_0 A_0^{'}\right)} \times 100$$

When we tract with N possible assets in a p-order VAR system and h step-ahead forecast error decomposition can be expressed as:

$$S = \frac{\sum_{h=0}^{H-1} \sum_{i,j=1}^{N} a_{0,ij}^2}{\sum_{h=0}^{H-1} trace\left(A_h A_h^{'}\right)} \times 100$$

In our particular case we consider 44 interest rates (one risk neutral interest rate and a term premium for 22 countries). For each interest rate considered we compute the proportion of its error decomposition variance related to the US risk neutral and term premium component. So we are interested solely in the contribution and spillover from US to the rest of the economies, distinguish the relevant channel that affects such transmission, the risk neutral rates or term premium. Also, to be consistent with the decomposition of interest rates explained in previous section, we compare the result when macroeconomic factors are (not) considered. Finally, as we focus in the role of US interest rate to the rest of the world, we made the assumption that there exist an specific ordering in the VAR system, where US is the most exogenous variable of all cases, and therefore we avoid the problem to impose some ordering in the Cholesky factorization which would affect final results which is an important issue with this class of models.

5 Data and Results

5.1 Data

The data used in this paper includes several developed economies as well as some developing countries. In particular, we split our data in three groups: (a) G7 economies, (b) other developed economies and (c) developing economies, summarizing a total of 22 countries. Table 1 shows a brief detail of countries considered in each group, the source of interest rate data and macroeconomic variables used and the sample considered. The full sample considered in each country depends on availability of data. We consider monthly frequency starting from January 1990. Also, we consider the country classification as the International Monetary Fund (IMF) does in the World Economic Outlook 2014[15].

The nominal interest data used in this paper correspond to government bonds in local currency at 3-months, 6-months, 1-year, 2-years, 5-years and 10-years starting from January 1990 for countries with available data. The macroeconomic factors used for all countries correspond to the most common used in the literature, which is inflation and gross domestic product (GDP). For inflation, we considered the official Consumer Price Index in all cases, whereas GDP corresponds to an interpolation of the effective quarterly GDP for each country, into a monthly estimation[16].

In terms of the input of each specification described in section 3, is important to remark that the ACM methodology relies in a wide range of interest rate at different maturities (from 1 to 120 months), which is done under the interpolation method of Nelson &

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[15] The country classification is publicly available at `http://www.imf.org/external/pubs/ft/weo/2014/01/pdf/text.pdf/`.

[16] To this we use the Quadratic Match Average procedure, which performs a local quadratic interpolation of the quarterly data to fill in the monthly data (this was done in all countries excepting Canada and Chile because those countries report a monthly estimation of GDP).

Siegel (1987). In Wright (2011) and Bauer et al. (2014) estimation, just the observed interest rates are necessary.

TABLE 1: Data sources

Nemo	Name	Source	Sample
Panel A: G7			
US	United States	Bloomberg and Federal Reserve's website	Jan-90 to Dec-14
CAD	Canada	Bloomberg	Jan-98 to Dec-14
JPN	Japan	Bloomberg	Apr-95 to Dec-14
UK	United Kingdom	Bloomberg and IMF	Jan-92 to Dec-14
GER	Germany	Bloomberg and IMF	May-93 to Dec-14
ITA	Italy	Bloomberg and IMF	Feb-97 to Dec-14
FR	France	Bloomberg and IMF	Jan-90 to Dec-14
Panel B: Others developed			
AUD	Australia	Bloomberg and IMF	Mar-91 to Dec-14
NZ	New Zealand	Bloomberg and IMF	Mar-91 to Dec-14
NOR	Norway	Bloomberg	Jul-95 to Dec-14
SW	Sweden	Bloomberg and IMF	Apr-94 to Dec-14
SZ	Switzerland	Bloomberg	Nov-94 to Dec-14
HK	Hong Kong	Bloomberg	Mar-98 to Dec-14
KOR	Korea	Bloomberg	Apr-01 to Dec-14
TW	Taiwan	Bloomberg	Aug-02 to Dec-14
CHK	Czech Republic	Bloomberg	Apr-97 to Dec-14
Panel C: Developing			
CL	Chile	Bloomberg and Central Bank's website	Jan-03 to Dec-14
THAI	Thailand	Bloomberg	Aug-00 to Dec-14
POL	Poland	Bloomberg	Mar-99 to Dec-14
MX	Mexico	Bloomberg	May-01 to Dec-14
HUN	Hungary	Bloomberg	Oct-97 to Dec-14
SOA	South Africa	Bloomberg	Mar-99 to Dec-14

We consider the country's classification as the IMF does in World Economic Outlook 2014

5.2 Long-term interest rates decomposition

Table 2 shows the affine model error for all countries and specifications. As we mentioned earlier, we consider two version for each model presented in section 3: a model with no macroeconomic factors (considering just the first three principal components of interest rates), and a version which includes CPI and a monthly estimation of GDP as risk factors besides the principal components.

The first two columns of Table 2 show the model error (in basis points) for the standard specification (the column **No Macro** is related to the model with principal components and the column **Macro factors** to the case when the macroeconomic factors are considered). In both cases, the model error is quite similar which is in line with the idea of unspanned macroeconomic factors (the macro factors affect the expected short-term interest rate, but no the model-implied yields). Also, we observe that the error is lower for the G7 countries, and higher for developing countries.

In the ACM methodology, as we mentioned earlier, the model fits the whole yield curve (computed under Nelson-Siegel method) and not directly the observed interest rates. As a result, the model carries with two sources of measurement error: (1) the interpolation step error, and (2) the model-implied yield measurement error. The last four columns in table 2, show the affine model error for the ACM approach. The columns 3 and 4 report the model error (with no macroeconomic factors), understood as the difference between the model-implied yield and the interpolated interest rates under Nelson-Siegel approach and the difference between the model-implied yield and the effective interest rate. The last two columns show the same but considering the decomposition with macroeconomic factors. Thus, even when the affine error in ACM are similar in magnitude to the standard approach, it does not hold when consider the interpolation error, which in most cases increases the error, although the magnitude of these error are in line with the standard approach.

Table 2: Model-implied adjustment errors

	Standard		ACM			
	No Macro	Macro factors	No Macro		Macro factors	
			NS	Effective	NS	Effective
Panel A: G7						
US	13.71	13.71	12.12	16.63	12.12	16.63
CAD	7.81	7.81	6.60	10.19	6.60	10.20
JPN	2.26	2.27	4.47	5.05	4.47	5.05
UK	13.18	13.16	10.37	15.87	10.37	15.87
GER	4.28	4.28	6.06	7.89	6.06	7.89
ITA	5.91	5.91	4.03	7.88	4.03	7.88
FR	4.47	4.47	4.62	6.89	4.62	6.89
Panel B: Others developed						
AUD	8.75	8.73	8.74	11.97	8.74	11.97
NZ	20.77	20.79	30.46	39.91	30.43	39.91
NOR	24.99	24.98	8.91	21.37	8.91	21.37
SW	23.16	23.15	9.23	18.07	9.22	18.07
SZ	12.48	12.48	8.95	13.10	8.95	13.10
HK	15.19	15.19	12.99	18.30	12.99	18.30
KOR	4.23	4.23	6.00	8.20	6.01	8.20
TW	5.18	5.18	2.08	5.03	2.09	5.03
CHK	10.76	10.77	3.45	11.14	3.45	11.14
Panel C: Developing						
CL	7.86	7.86	10.79	13.20	10.79	13.20
THAI	11.63	11.62	4.31	12.07	4.31	12.07
POL	20.34	20.31	9.01	20.14	8.99	20.14
MX	23.30	23.38	10.11	24.03	10.11	24.03
HUN	15.43	15.47	14.59	19.31	14.60	19.32
SOA	41.46	41.52	17.85	36.41	17.87	36.43

This table shows the error in basis points between the DTSM's implied model yield and the effective interest rates. The column **STANDARD** refers to the standard procedure to estimate DTSM models and the **ACM** column is referred to the Adrian et al. (2013) procedure estimation. In **STANDARD** the sub-columns **No Macro** and **Macro factors** shows the error in basis points of the DTSM model when no macro and macro factors are considered respectively. In **ACM** the sub-column **NS** and **Effective** shows the error between the model-implied yield and the Nelson-Siegel interpolation and the model-implied yield and the effective interest rates respectively.

5.3 Explaining historical movements

As we pointed out, the current values of long-term interest rates reached its minimal historical levels in many countries. However, the decrease in these yields may be influenced by different factors such as conventional and unconventional monetary policies faced by the economy. In order to decompose the movements of interest rates we considered different samples accounting for different monetary policy regimes. In what follows we use the interest rates decomposition considering macroeconomic factors under the standard methodology presented in section 3.2.

First, we consider the sample from January 2003 to May 2007, which we denote as a normal period before the onset of the financial crisis. Second, the sample starting from June 2007 to November 2008 is related to the onset of the sub-prime crisis in the US which was characterized by coordinated measures of the most relevant central banks in order to maintain the counterpart confidence in the financial system, such as aggressive interest rates cut in order to restore financial stability, where in most developed countries the conventional monetary policy reached the zero-lower bound (henceforth ZLB). Third, the period covering from December 2008 to May 2013 is mainly related to the period where the unconventional monetary policies were applied. Such policies were mainly implemented by the US Federal Reserve in the US, the Bank of England, the European Central Bank and the Bank of Japan as a way to stimulate the economy after the nominal short-term interest rate was close to zero. Also, the end of this period coincides with the tapering talk event, which was the date where the US Federal Reserve began to talk about the possibility of tapering their bond purchases. Finally, the last period covers from April 2013 to December 2014, which is characterized by the normalization in most countries of their monetary policy.

Figure 3 presents the changes in both long-term interest rates and the term premium for each period. Panel (a) shows changes in basis points of the average level of interest rates in the crisis period over the pre-crisis sample, panel (b) changes of interest rates during the UMP period respect to the crisis period and panel (c) the normalization period over the UMP episode[17]. The figure shows changes in basis points of the model-implied yield in the X-axis and changes in the term premium in the Y-axis.

During the crisis period, in general, long-term interest rate showed an increase in most

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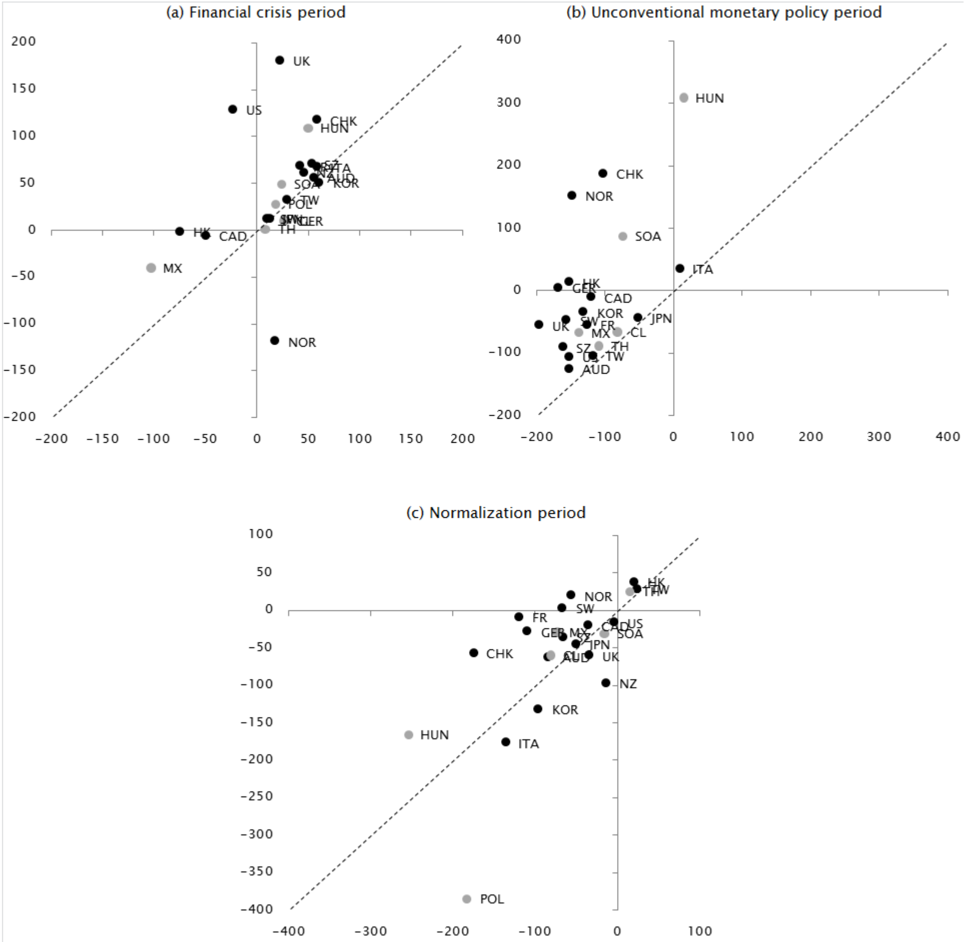
[17] In Appendix B we show the descriptive statistics of long-term interest rates.

countries (except in some G7 countries and Mexico). The increase on yield during this period can be explained mainly by an increase in the term premium component, and also by a reduction in the risk neutral rates. Thus, in the crisis period there was a higher term premium as panel (a) in Figure 3 shows. Also, in the UMP period the common pattern was a decrease in long-term yields explained by reductions in both components (risk neutral and term premium) which is in line with the ZLB reached by many countries which affected the risk-neutral channel as well as the unconventional monetary policies which in turn affected the long-term interest rates via term premium channel. However, some countries such as Norway, Czech Republic, South Africa and Hungary registered significant increases in term premiums. Finally, the normalization sample was characterized by a heterogeneous behavior in countries considered. For instance, in G7 countries and most of developing countries, both risk-neutral and term premium components exhibited reductions in the period, but other developed countries such as Hong Kong, Norway and Taiwan registered a slightly increase in the term premium component.

FIGURE 3: Changes in yields and term premium on different samples



The figure shows changes in basis points of model-implied yields (in X-axis) and term premium (Y-axis) for crisis sample, the unconventional monetary policy implementation period and the normalization period. Black dot denotes developed countries and gray dots developing economies. Source: author's calculations.

5.4 Spillovers

At this point, we have shed some lights regarding the co-movement of long-term interest rates, considering different samples and components in which may affect interest rates. However, the role that the US monetary policy has over other economies has been notorious and we will try to characterize such contribution of the US monetary policy throughout a spillover framework[18].

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[18] Unreported results considering decomposed interest rates without macroeconomic factors show similar results and the empirical findings holds.

Table 3 presents the contribution of risk neutral and term premium US shocks affecting the decomposed interest rates in others economies, controlling by macroeconomic factors (inflation and GDP). The table report the relative contribution of the US components in percentages for different horizons (3, 6, 9 and 12 months ahead). Also, as we have discussed earlier, we split the sample in two: (i) the pre-crisis period covering from January 2003 to June 2007 and (ii) the sample where the crisis started as well as the ZLB were reached and the UMP were applied starting from July 2007 to December 2014.

For G7 countries (excluding the US), the empirical evidence for the pre-crisis sample suggests a strong spillover effect from US risk neutral and term premium to these countries. Furthermore, the results show that the US risk-neutral interest rate had a great impact in both risk-neutral and term premium components and a lower effect of the term premium channel when the forecasting horizon is increased. After the ongoing of the subprime and financial crisis in US, the results are unchanged and the US risk neutral channel is the relevant spillover source in these countries.

For other developed economies, the empirical results suggest that spillovers from the US are lower than G7 countries, but mixed results about the channels. For instance, Australia is affected in both channels (risk-neutral and term premium), but Korea have no relevant spillover from the US. Also, meanwhile in Czech Republic and Hong Kong are affected via risk-neutral rates, the opposite is observed in Taiwan, where the term premium is the driver in which the spillover from the US affect the long-term interest rates. However, in the second sample the US spillovers are lower than the pre-crisis period, moreover in Czech Republic, Korea, New Zealand and Taiwan there are no relevant effect.

Finally, for most developing countries, but Mexico and Thailand, the US term premium is the relevant sources in which the spillovers is transmitted. In Mexico, long-term interest rate is affected through the term premium component where the US risk neutral rate is the relevant source of transmission. The same occurs for Thailand, but affects both risk-neutral and term premium components. Interestingly, in the second sample the relevant channel of spillovers is the US term premium. For Chile, South Africa and Thailand the long yield are affected via the term premium component, in South Africa the yields were affected through the risk-neutral channel, while in Mexico the risk-neutral rate and the term premium are affected.

Table 3: US Spillovers to other economies

		January 2003 to June 2007								July 2007 to December 2014							
		$h = 3$		$h = 6$		$h = 9$		$h = 12$		$h = 3$		$h = 6$		$h = 9$		$h = 12$	
		rn	tp	rn	tp	rn	tp	rn	tp	rn	tp	rn	tp	rn	tp	rn	tp
G7 (ex. US)																	
CAD	rn	41.5	8.7	33.6	14.5	30.0	15.8	27.8	16.1	30.7	11.9	32.3	10.5	34.0	9.3	35.1	8.5
	tp	9.1	34.1	11.8	27.2	11.9	24.0	11.8	22.1	4.9	13.2	4.3	10.6	4.1	9.4	4.4	8.8
FR	rn	44.7	7.8	34.0	9.2	28.6	9.5	25.6	9.5	14.9	21.5	17.9	17.6	19.4	14.9	20.2	13.1
	tp	39.5	0.7	32.3	2.1	28.5	2.8	26.2	3.0	19.3	0.3	20.8	0.3	20.0	0.4	18.7	0.5
GER	rn	42.8	18.6	34.2	19.5	29.4	19.0	26.3	18.1	17.9	33.4	21.5	28.5	25.2	24.8	28.3	22.1
	tp	1.3	5.8	1.1	4.4	1.1	3.8	1.4	3.8	4.7	5.3	4.2	6.2	3.7	6.1	3.5	5.8
ITA	rn	17.0	0.6	18.0	1.0	17.2	1.7	16.4	2.1	6.5	0.8	8.4	1.7	10.3	1.9	11.6	2.0
	tp	11.8	19.7	9.2	18.8	7.9	17.2	7.3	16.1	7.6	8.4	11.3	5.6	12.2	4.3	11.7	3.6
JPN	rn	14.5	24.1	12.4	21.0	10.9	18.6	9.9	17.1	15.0	5.1	18.7	3.8	20.3	3.3	20.9	3.2
	tp	10.4	27.4	8.6	21.4	7.5	18.2	6.9	16.4	9.5	25.4	10.8	20.2	12.7	17.2	14.4	15.2
UK	rn	27.3	7.1	20.4	8.3	16.7	8.8	14.5	8.8	16.9	0.8	22.0	1.1	21.7	1.1	20.3	1.0
	tp	10.4	1.4	7.9	4.7	6.4	6.1	5.6	6.6	7.0	18.7	9.8	18.8	9.5	16.8	10.0	15.0
Others developed																	
AUD	rn	23.6	35.3	19.0	30.1	16.6	26.9	15.2	24.8	15.2	19.2	12.3	13.9	11.6	11.1	11.2	9.5
	tp	33.2	23.7	28.8	18.6	26.3	16.0	24.4	14.5	1.4	12.7	0.9	8.1	0.8	6.0	0.7	4.8
CHK	rn	18.9	12.8	15.6	15.5	14.0	16.1	12.9	16.1	8.4	3.7	9.2	4.7	9.2	4.7	9.0	4.5
	tp	11.3	3.6	9.9	6.6	8.9	8.3	8.3	9.0	4.2	0.8	4.8	1.8	4.8	2.4	4.8	2.7
HK	rn	23.3	19.4	18.3	17.4	15.2	15.7	13.3	14.3	22.3	10.3	24.3	8.4	22.8	7.1	21.2	6.5
	tp	2.5	6.9	2.4	6.1	2.4	5.7	2.5	5.4	1.9	24.8	1.8	20.4	2.1	17.6	2.5	15.8
KOR	rn	3.6	5.5	2.8	5.1	2.8	5.0	2.7	4.8	0.3	4.9	0.7	4.0	0.9	3.4	1.0	3.0
	tp	7.9	0.6	6.5	4.6	5.8	8.7	5.4	10.7	2.4	8.9	2.7	7.0	2.6	5.8	2.6	5.0
NOR	rn	6.1	31.9	9.1	29.9	12.3	28.0	14.5	26.8	15.1	0.7	10.5	0.8	8.0	0.9	6.5	0.9
	tp	3.9	3.6	9.4	9.4	14.3	10.8	17.8	11.0	0.6	24.4	2.0	17.6	2.7	13.8	2.9	11.3
NZ	rn	14.5	2.8	12.5	3.9	11.8	3.9	11.2	4.2	0.1	2.0	0.1	2.6	0.1	2.8	0.2	2.9
	tp	6.1	40.4	6.9	38.0	7.2	34.6	7.5	32.2	0.7	9.4	1.1	6.9	1.6	5.6	2.0	4.7
SW	rn	25.4	15.9	18.3	12.4	14.6	10.7	12.4	9.5	6.8	34.2	8.5	23.1	9.3	18.0	9.6	15.1
	tp	5.3	15.5	8.1	18.7	9.5	19.2	10.0	18.9	16.2	8.0	10.9	6.2	8.4	5.2	6.9	4.4
SZ	rn	30.2	11.6	23.8	10.2	19.9	10.1	17.7	10.0	30.7	0.5	26.5	0.6	24.1	0.6	22.4	0.6
	tp	13.8	1.1	14.4	1.5	13.4	2.2	12.8	3.6	3.6	29.3	3.3	22.8	3.2	18.9	3.0	16.4
TW	rn	1.6	9.5	3.1	7.1	4.3	6.0	4.9	5.5	4.4	1.0	3.8	1.7	3.4	2.0	3.1	2.2
	tp	18.3	7.2	15.2	7.2	13.0	7.9	12.1	8.0	2.3	2.9	1.7	2.3	1.4	2.1	1.3	1.9
Developing																	
CL	rn	7.9	14.3	10.3	11.9	10.2	10.2	9.6	9.0	4.2	1.8	6.4	3.3	6.8	4.0	6.8	4.3
	tp	3.0	27.5	8.5	23.4	11.7	20.0	13.8	17.6	3.6	28.0	3.8	30.8	3.7	31.9	3.5	32.4
HUN	rn	20.7	2.7	26.1	2.2	25.7	2.0	24.1	1.8	2.4	5.9	1.9	7.1	2.1	7.0	2.6	6.6
	tp	6.9	12.5	12.4	11.7	13.4	10.6	13.2	9.7	3.7	4.8	4.8	3.4	5.5	2.8	6.1	2.8
MX	rn	1.0	6.2	1.4	6.1	1.4	6.5	1.4	6.6	1.7	40.0	1.2	41.9	0.9	42.7	0.8	43.3
	tp	10.7	3.7	11.0	2.8	12.3	2.5	13.0	2.5	1.1	33.6	2.6	37.8	3.7	39.8	4.2	40.8
POL	rn	0.5	13.8	0.4	12.8	0.3	12.3	0.3	12.4	0.7	3.1	1.1	6.8	2.1	8.2	3.4	8.5
	tp	4.2	21.7	3.2	21.6	2.7	20.9	2.5	20.4	0.3	3.1	0.6	2.6	1.1	2.3	1.7	2.2
SOA	rn	4.7	8.4	4.0	10.8	3.8	11.0	3.7	10.7	5.0	11.4	9.2	17.9	10.7	22.2	11.2	24.9
	tp	0.8	1.2	1.2	1.0	2.2	0.9	3.5	0.8	2.1	9.2	4.7	7.7	6.1	6.9	6.7	6.3
THAI	rn	16.5	1.2	17.2	1.7	16.2	2.4	15.0	2.7	0.5	2.6	1.2	2.2	1.7	1.9	2.0	1.8
	tp	21.2	6.5	19.4	6.1	18.4	5.9	17.8	5.9	1.0	31.4	1.1	31.5	1.3	31.4	1.4	31.3

This table shows the US long-term interest rate spillover transmission to other economies. The table reports two subsamples January 2003 to June 2007 and July 2007 to December 2014. In each subsample the spillovers from the US risk neutral and term premia component are reported considering different horizons to compute the Forecast Error Variance Decomposition (FEVD) as proposed by Diebold & Yilmaz (2009). Each value corresponds to the contribution in percentage of each component of the US interest rate explaining both component in yield in all economies.

6 Conclusions

In this paper we present a revision of the most used approaches to compute affine models. With this, we decompose long-term interest rates into the risk neutral and term premium components for several developed and developing economies. Thus, we are able to analyze and explain interest rates movement in those economies in different periods and monetary policy regimes, and quantify the transmission channel of the US long-term interest rates.

Our results suggest that during the financial crisis period (June 2007 to November 2008) long-term interest rates showed an increase in most countries explained mainly by an increase in the term premium components and a reduction in the risk-neutral rates. In the period where unconventional monetary policies were applied (December 2008 to May 2013) was observed a reduction in both risk-neutral rates and term premium. Finally, in the normalization period (after May 2013), a heterogeneous behavior has been reported.

Finally, we analyzed the transmission of US interest rate movements to other economies through the spillover index methodology proposed by Diebold & Yilmaz (2009). Our empirical evidence suggest that in G7 countries, the US transmission to these economies had a significant impact in both channels (risk-neutral and term premium) mainly by the US risk-neutral rates channel, which was a observed in the pre-crisis sample (before January 2003 to June 2007) and after the ongoing of the subprime and financial crisis period. In other developed economies, the evidence suggest a lower transmission of US interest rates with mixed results. For developing countries, the US term premium channel is the relevant affecting those economies through the term premium channel.

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Appendix A Linear regression

Table 4: Linear regression coefficients

	January 1990 to June 2007			July 2007 to December 2014		
Countries	**Alpha**	**Beta**	**Adj R2**	**Alpha**	**Beta**	**Adj R2**
CAD	-0.01	0.71	0.76	-0.01	0.63	0.85
	(0.01)	(0.04)		(0.01)	(0.03)	
JPN	-0.02	0.26	0.11	-0.01	0.24	0.44
	(0.01)	(0.05)		(0.01)	(0.03)	
MX	-0.10	0.28	0.01	0.00	0.80	0.38
	(0.05)	(0.24)		(0.02)	(0.11)	
GER	-0.01	0.54	0.53	-0.02	0.61	0.69
	(0.01)	(0.04)		(0.01)	(0.04)	
UK	-0.02	0.52	0.32	-0.01	0.76	0.79
	(0.01)	(0.06)		(0.01)	(0.04)	
NZ	-0.01	0.76	0.46	0.00	0.75	0.58
	(0.01)	(0.06)		(0.02)	(0.07)	
AUD	-0.01	0.89	0.59	-0.01	0.76	0.62
	(0.01)	(0.05)		(0.01)	(0.06)	
HK	-0.03	0.67	0.19	0.00	0.83	0.57
	(0.03)	(0.13)		(0.02)	(0.08)	
NOR	-0.02	0.54	0.38	-0.02	0.57	0.53
	(0.01)	(0.06)		(0.01)	(0.06)	
POL	-0.06	0.32	0.01	-0.02	0.39	0.17
	(0.05)	(0.24)		(0.02)	(0.09)	
SoA	-0.07	0.54	0.10	0.02	0.66	0.23
	(0.03)	(0.16)		(0.03)	(0.12)	
KOR	-0.03	0.59	0.17	-0.01	0.52	0.32
	(0.03)	(0.14)		(0.02)	(0.08)	
SW	-0.03	0.58	0.24	-0.01	0.67	0.68
	(0.02)	(0.08)		(0.01)	(0.05)	
SZ	-0.01	0.35	0.30	-0.02	0.42	0.54
	(0.01)	(0.04)		(0.01)	(0.04)	
TW	-0.03	0.48	0.26	0.00	0.22	0.29
	(0.02)	(0.11)		(0.01)	(0.04)	
THAI	-0.01	0.54	0.08	0.00	0.65	0.30
	(0.04)	(0.19)		(0.02)	(0.10)	
CHK	-0.05	0.23	0.01	-0.03	0.37	0.14
	(0.04)	(0.17)		(0.02)	(0.09)	
FR	-0.02	0.50	0.33	-0.02	0.52	0.48
	(0.01)	(0.05)		(0.01)	(0.06)	
ITA	-0.04	0.50	0.20	-0.02	0.20	0.02
	(0.02)	(0.08)		(0.03)	(0.12)	
HUN	-0.10	-0.24	0.00	-0.02	0.49	0.04
	(0.05)	(0.24)		(0.05)	(0.23)	
CL	-0.04	0.50	0.10	0.00	0.46	0.17
	(0.04)	(0.20)		(0.02)	(0.10)	

This table shows the coefficients, standard errors (in parenthesis) and the adjusted R^2 the following regression: $\triangle y_{t,j} = \alpha_j + \beta_j \triangle y_{t,US} + \epsilon_{t,j}$, where $\triangle y'_{t,j}$ denotes the monthly change of the long-term yield in country j and $\triangle y_{t,US}$ correspond the monthly change in the US long-term yield.

Appendix B Descriptive statistics

Table 5: Descriptive statistics: G7

		US	CAD	JPN	UK	GER	ITA	FR
Panel A: No macroeconomic factors								
RN-ACM	Mean	3,32	2,52	0,20	4,29	2,48	2,47	3,44
	SD	1,86	1,29	0,04	1,45	1,38	1,07	2,39
	Min	-0,09	0,74	0,15	1,24	0,02	-0,08	-0,52
	Max	7,07	5,28	0,34	8,09	5,62	4,40	9,57
RN-B	Mean	3,54	2,62	0,20	4,50	2,57	2,47	3,44
	SD	1,85	1,35	0,04	1,47	1,39	1,07	2,39
	Min	0,11	0,71	0,15	1,18	0,10	-0,08	-0,52
	Max	7,34	5,40	0,34	8,26	5,72	4,40	9,57
TP-ACM	Mean	1,55	1,45	1,36	0,84	1,67	2,16	1,58
	SD	0,63	0,59	0,65	0,92	0,69	1,43	0,73
	Min	0,26	0,54	0,22	-0,62	0,36	-1,29	0,14
	Max	3,97	2,68	3,27	3,51	3,57	6,55	3,57
TP-B	Mean	1,41	1,43	1,32	0,63	1,60	2,02	1,37
	SD	0,53	0,48	0,63	0,90	0,62	1,41	0,71
	Min	0,31	0,69	0,22	-0,79	0,46	-1,44	-0,11
	Max	3,65	2,50	3,17	3,65	3,32	6,36	3,46
Panel B: Including inflation and growth								
RN-ACM	Mean	3,31	2,53	0,20	4,20	2,50	2,51	3,45
	SD	1,94	1,25	0,06	2,21	1,49	0,64	2,21
	Min	-0,78	0,55	0,11	-0,73	-0,48	0,94	-0,58
	Max	7,28	5,31	0,38	9,10	5,83	4,23	8,32
RN-B	Mean	3,54	2,62	0,20	4,50	2,57	2,62	3,67
	SD	1,95	1,27	0,06	2,26	1,50	0,69	2,21
	Min	-0,55	0,60	0,12	-0,57	-0,43	1,01	-0,34
	Max	7,55	5,41	0,38	9,24	5,90	4,53	8,52
TP-ACM	Mean	1,56	1,45	1,36	0,93	1,66	2,11	1,56
	SD	0,86	0,52	0,64	1,11	0,43	0,87	0,74
	Min	0,02	0,51	0,26	-1,36	0,67	-0,64	-0,05
	Max	4,24	2,84	3,26	4,31	2,88	4,58	4,11
TP-B	Mean	1,42	1,43	1,32	0,63	1,60	2,02	1,37
	SD	0,79	0,45	0,61	1,12	0,37	0,84	0,73
	Min	-0,03	0,62	0,27	-1,75	0,73	-0,49	-0,23
	Max	3,91	2,66	3,16	4,32	2,71	4,39	3,82
Obs		300	204	237	276	260	215	300

This table shows the descriptive statistics for several developed countries. Panel A reports the statistics for DTSM model with no macroeconomics factors. Panel B refers the DTSM estimation which includes CPI and GDP growth as a risk factors. The RN-ACM and RN-B refers to the risk neutral estimation under the methodology proposed by Adrian et al. (2013) and the standard MLE approach respectively. The TP-ACM and TP-B refers to the term premium estimation under the methodology proposed by Adrian et al. (2013) and the standard MLE approach respectively. All variables are expressed in percentages.

Table 6: Descriptive statistics: Other developed economies

		AUD	NZ	NOR	SW	SZ	HK	KOR	TW	CHK
Panel A: No macroeconomic factors										
RN-ACM	Mean	5,32	5,49	3,76	3,05	1,27	1,84	3,58	1,06	3,44
	SD	0,71	1,15	1,99	2,10	0,64	1,87	0,87	0,72	3,76
	Min	4,02	3,07	0,78	-0,42	0,35	-0,50	1,91	0,11	-1,03
	Max	7,12	9,26	7,33	9,17	3,03	7,48	5,77	2,67	15,50
RN-B	Mean	5,35	5,57	3,84	3,15	1,32	2,05	3,64	1,09	3,68
	SD	0,72	1,35	2,02	2,30	0,65	1,86	0,86	0,68	3,66
	Min	4,05	2,73	0,50	-0,72	0,42	-0,40	1,98	0,23	-1,02
	Max	7,16	9,70	7,28	10,28	3,07	7,52	5,81	2,63	15,59
TP-ACM	Mean	0,86	0,65	0,93	1,61	1,25	2,30	1,20	0,84	1,79
	SD	1,18	0,48	0,95	0,33	0,83	0,96	0,47	0,37	0,85
	Min	-1,31	-0,40	-0,99	0,92	-0,59	1,01	0,53	-0,11	-0,36
	Max	4,54	2,07	2,65	2,41	3,30	6,36	2,36	1,49	3,25
TP-B	Mean	0,85	0,78	0,82	1,47	1,30	2,13	1,21	0,80	1,55
	SD	1,17	0,19	0,91	0,77	0,75	1,00	0,47	0,32	0,73
	Min	-1,30	0,24	-1,35	-0,47	-0,39	0,74	0,53	-0,10	-0,75
	Max	4,51	1,14	2,25	3,55	3,34	6,65	2,31	1,33	2,48
Panel B: Including inflation and growth										
RN-ACM	Mean	5,31	5,43	3,72	3,05	1,28	1,91	3,55	1,08	3,20
	SD	0,78	1,10	2,01	1,95	0,70	2,02	0,64	0,15	4,29
	Min	3,77	2,42	0,05	-0,24	-0,17	-0,77	2,27	0,68	-3,85
	Max	7,47	7,45	7,17	8,77	3,01	6,58	5,01	1,42	16,10
RN-B	Mean	5,35	5,57	3,84	3,15	1,32	2,05	3,64	1,09	3,68
	SD	0,80	1,20	2,05	1,93	0,68	2,14	0,63	0,16	4,39
	Min	3,79	2,18	-0,09	-0,29	-0,08	-0,79	2,36	0,66	-3,21
	Max	7,53	7,91	7,28	9,18	3,03	7,08	5,07	1,46	17,34
TP-ACM	Mean	0,87	0,71	0,96	1,60	1,24	2,23	1,24	0,82	2,03
	SD	1,11	0,96	0,82	0,42	0,55	0,73	0,84	0,53	1,80
	Min	-1,21	-1,29	-0,80	0,98	0,08	1,15	-0,50	0,04	-1,16
	Max	3,95	4,40	3,25	2,68	2,50	5,34	3,23	2,24	6,24
TP-B	Mean	0,85	0,78	0,82	1,43	1,30	2,13	1,21	0,80	1,55
	SD	1,09	0,88	0,85	0,53	0,52	0,77	0,85	0,50	1,75
	Min	-1,20	-0,90	-0,93	0,25	0,22	1,15	-0,56	0,06	-2,34
	Max	3,89	3,94	2,86	2,78	2,86	5,73	3,25	2,08	5,37
Obs		286	286	234	249	242	202	165	149	213

This table shows the descriptive statistics for several developed countries (excluding G7 economies). Panel A reports the statistics for DTSM model with no macroeconomics factors. Panel B refers the DTSM estimation which includes CPI and GDP growth as a risk factors. The RN-ACM and RN-B refers to the risk neutral estimation under the methodology proposed by Adrian et al. (2013) and the standard MLE approach respectively. The TP-ACM and TP-B refers to the term premium estimation under the methodology proposed by Adrian et al. (2013) and the standard MLE approach respectively. All variables are expressed in percentages.

Table 7: Descriptive statistics: Developing economies

		CL	THAI	POL	MX	HUN	SOA
Panel A: No macroeconomic factors							
RN-ACM	Mean	3,98	2,52	6,32	6,12	8,14	8,45
	SD	0,20	0,73	4,64	1,06	3,42	0,91
	Min	3,46	1,18	2,03	4,03	1,68	6,47
	Max	4,39	4,36	19,22	9,08	16,61	10,90
RN-B	Mean	3,95	2,63	6,94	6,25	8,69	8,58
	SD	0,19	0,76	4,70	0,67	3,42	1,36
	Min	3,44	1,22	2,72	5,06	2,24	6,54
	Max	4,36	4,56	19,76	8,16	17,17	12,66
TP-ACM	Mean	2,11	1,81	0,36	1,86	0,00	1,00
	SD	0,77	0,73	2,83	0,70	1,83	1,76
	Min	0,89	0,63	-8,68	0,57	-5,07	-2,11
	Max	4,10	3,61	6,20	3,83	3,08	5,59
TP-B	Mean	2,16	1,68	-0,29	1,83	-0,53	1,02
	SD	0,73	0,70	2,82	1,08	1,79	1,64
	Min	0,96	0,56	-9,02	-0,29	-5,48	-2,61
	Max	3,99	3,34	5,04	4,64	2,43	5,03
Panel B: Including inflation and growth							
RN-ACM	Mean	3,99	2,61	5,89	6,09	8,36	8,43
	SD	0,16	0,21	4,04	1,05	3,39	1,68
	Min	3,59	1,96	-2,03	4,10	2,12	5,43
	Max	4,36	3,11	14,99	9,22	17,00	13,14
RN-B	Mean	3,95	2,63	6,94	6,25	8,69	8,58
	SD	0,14	0,22	4,06	0,74	3,37	1,98
	Min	3,60	1,98	-1,04	4,95	2,58	5,58
	Max	4,25	3,13	16,09	8,35	17,30	14,22
TP-ACM	Mean	2,10	1,72	0,80	1,89	-0,22	1,02
	SD	0,68	0,80	3,03	0,75	2,58	1,20
	Min	0,95	0,22	-4,63	0,44	-4,88	-1,58
	Max	3,84	3,74	8,25	3,82	9,22	3,66
TP-B	Mean	2,16	1,68	-0,29	1,83	-0,55	1,03
	SD	0,70	0,78	3,05	0,98	2,54	0,92
	Min	0,94	0,18	-5,81	-0,15	-5,10	-1,10
	Max	3,87	3,70	7,20	4,37	8,85	2,97
Obs		144	173	190	164	207	191

This table shows the descriptive statistics for several developing countries. Panel A reports the statistics for DTSM model with no macroeconomics factors. Panel B refers the DTSM estimation which includes CPI and GDP growth as a risk factors. The RN-ACM and RN-B refers to the risk neutral estimation under the methodology proposed by Adrian et al. (2013) and the standard MLE approach respectively. The TP-ACM and TP-B refers to the term premium estimation under the methodology proposed by Adrian et al. (2013) and the standard MLE approach respectively. All variables are expressed in percentages.

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