INTERNATIONAL MONETARY POLICY SPILLOVER: LINKAGES BETWEEN U.S. AND SOUTH AMERICAN YIELD CURVES

Área 6 - Macroeconomia

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Resumo: Este artigo investiga as interações entre os fatores latentes da estrutura a termo das taxas de juros dos Estados Unidos e de países selecionados da América do Sul. A estrutura a termo da taxa de juros é estimada usando o modelo Nelson-Siegel Dinâmico, extraído por meio do filtro Kalman. Os índices de transbordamento entre países são medidos usando decomposições de variância do erro de previsão em uma estrutura vetorial autoregressiva generalizada. Os resultados encontram um alto grau de transbordamento nos fatores de nível (22,79 %), inclinação (25,53 %) e curvatura (15,18 %), com alta oscilação da intensidade de transmissão ao longo do tempo. Há um aumento substancial no índice de transbordamento durante crises financeiras e outros períodos de alta volatilidade.

Palavras-chaves: Transbordamento de Política Monetária, Estrutura a Termo, Política Monetária, Taxa de Juros.

Abstract: This paper investigates the spillovers between the latent factors of the term structure of the interest rates of the United States and selected South American countries. The term structure of the interest rate is estimated using the Dynamic Nelson-Siegel model, extracted through the Kalman filter. The spillover indices between countries are measured using forecast error variance decompositions in a generalized Vector Autoregressive framework. The results show a high degree of spillover in the level (22.79%), slope (25.53%), and curvature (15.18%) factors, with high oscillation of transmission intensity over time. There is a substantial increase in the spillover index during financial crises and other high-volatility periods.

Key-words: Monetary Policy Spillover, Term Structure, Monetary Policy, Interest Rates.

Classificação JEL: E50, C58, C22

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1 Introduction

Over the past three decades, the term structure of interest rates has been extensively studied by academics and market participants, and has led to the development of a wide literature on its modeling, particularly with regard to the analysis of sovereign debt securities. Much of this literature has a common assumption that the yield curve can be specified by latent factors, such as Litterman e Scheinkman (1991), Dai e Singleton (2000), and Diebold e Li (2006). This approach studies investigate the yield curve of a single country in isolation and relates domestic variables and internal macroeconomic factors to the latent factors, such as by Ang e Piazzesi (2003) and Diebold, Rudebusch e Aruoba (2006). In addition, an extensive literature documents the empirical regularity that the factors of the term structure of interest rates are a reliable predictor of future real economic activity. Stock e Watson (2003) point out that one of the main purposes of studying the slope of the yield curve is forecasting asset prices, including interest rates, stock returns, and exchange rates. Mehl (2009) assesses the predictive ability of the yield curve in emerging market economies (EMEs) and corroborates the past literature, showing that the slope of the yield curve helps forecast inflation and output growth.

Another branch of the literature started with the occurrence of financial, economic, and commercial integration and the recurring financial crises resulting from this. This kind of analysis seeks to evaluate the relationship between the term structures of interest rates of different countries. Sutton (2000) and Engsted e Tanggaard (2007) show that there are comovements in yield rates on long-term government bonds in developed markets, and that these obligations are correlated between countries. The modeling of a yield curve can include, in addition to the "classic" factors of Diebold e Li (2006), factors that may reflect shocks arising from external sectors, that is, global factors (DIEBOLD; LI; YUE, 2008; BYRNE; FAZIO; FIESS, 2012; ABBRITTI *et al.*, 2018). Diebold, Li e Yue (2008) build a dynamic factor model for sets of yield curves, in which the country's interest rates may depend on internal factors or global factors, and find that global yield factors do indeed exist and are economically important. Bae e Kim (2011) examine the influence of global and regional factors on the term structure of interest rates in East Asian economies, and conclude that global and regional factors play an important role in explaining individual yield curves.

There are similar studies with respect to EMEs. Bowman, Londono e Sapriza (2015) explore the impacts of changes in the Federal Reserve (Fed)'s monetary policy on the behavior of interest rates on EMEs' treasury bonds. The authors find that the United States (U.S.)' monetary policy announcements strongly impact the dynamics of these bonds. Jotikasthira, Le e Lundblad (2015) assess why the term structures of interest rates in different countries comove and discover that world inflation and the level factor of the U.S. yield curve, together, explain more than two-thirds of the covariance of yields in other countries across the maturity spectrum. Still in this perspective, Sowmya, Prasanna e Bhaduri (2016) investigate the degrees of integration and transmission of shocks on the factors of the yield curve from one country to another and find a considerable relationship between level, slope and curvature factors among countries. More recently, Stona e Caldeira (2019) assess the improvement in the predictability of the Brazilian yield curve by incorporating factors from the U.S. yield curve and domestic macroeconomic variables into the Dynamic Nelson-Siegel (DNS) Model. The empirical results suggest that the U.S. yield curve and macroeconomic components can explain the latent factors of the Brazilian term structure of interest rates with almost half the variation of the level factor being explained by movements in the U.S. curve.

Shedding light on these discussions, we investigate the degree of integration and transmission of shocks from one country to another, considering different horizons of maturity of interest rates presented in the term structure of the interest rate for selected countries of South America, and their relationship to the U.S. term structure. We follow Sowmya, Prasanna e Bhaduri (2016), in which the factors of the yield curve for individual countries are initially estimated using the DNS model

(DIEBOLD; LI, 2006). The DNS model breaks down the term structure of interest rates into three factors: level, representing long-term interest rates; slope, representing short-term interest rates; and curvature, representing the medium-term interest rates for each country in the sample. These three latent factors in the term structure of the interest rates are extracted using the Kalman filter. Subsequently, we capture the covariation of these factors using the spillover indices proposed by Diebold e Yilmaz (2012). The spillover indices are based on Forecast Error Variance Decomposition (FEVD) from a generalized vector autoregression (VAR) framework, which is invariant to the ordering of the variables. This allows us to compute the total, directional, and net spillovers indices. Lastly, we explore the temporal dynamics of the relationships among the yield curve factors.

Estimations were performed for four countries in South America: Brazil, Chile, Colombia, and Peru, as well as the U.S., with daily observations of interest rates on government bonds, for the period between January 2006 and May 2019. Results indicate a high level of spillover in the slope factor (25.53%), followed by the level factor (22.79%) and the curvature factor (15.18%). There is a higher U.S. effect on the level and curvature factors, and a higher regional effect on the slope factors among emerging economies. The result is consistent with the premise that long-term interest rates are driven by the preferences of international investors, and short-term interest rates are driven by domestic monetary policies and economic fundamentals (DRIESSEN; MELENBERG; NIJMAN, 2003). We also found that connections are higher during periods of crisis and in periods of greater market volatility. The results corroborate the empirical evidence for EMEs (MEHL, 2009; BOWMAN; LONDONO; SAPRIZA, 2015; JOTIKASTHIRA; LE; LUNDBLAD, 2015; STONA; CALDEIRA, 2019), and specifically with Sowmya, Prasanna e Bhaduri (2016), who performed a similar analysis for countries in Asia and Europe.

In addition to this introduction, the article is divided into four more sections. The second section describes the modeling framework used in the empirical analysis. In the third section, the data and estimation of the DNS model are discussed. The fourth section presents the results of the analysis. Finally, the fifth section provides concluding remarks.

2 Modeling framework

We investigate the degree of integration and transmission of shocks from one country to another between the factors of term structure of the interest rate for selected countries of South America and the U.S.. We follow Sowmya, Prasanna e Bhaduri (2016), in which first we extract the yield curve's factors for each individual country by the DNS model (DIEBOLD; LI, 2006). Second, we capture the covariation of these factors using the spillover indices proposed by Diebold e Yilmaz (2012). The DNS model breaks down the term structure of interest rates into three factors: level, representing long-term interest rates; slope, representing short-term interest rates; and curvature, representing the medium-term interest rates for each country in the sample. We use the Kalman filter to extract these three latent factor. In addition, we compute the total, directional, and net spillovers indices, based on FEVD from a generalized VAR, and we explore the temporal dynamics of these relationships by a rolling window.

2.1 Nelson-Siegel (NS) Model

The NS model, proposed by Nelson e Siegel (1987), is a flexible and parsimonious structure with three factors that allow to adjust a smooth yield curve to the interest rates of non-smoothed sovereign bonds. The NS static representation specifies the evolution of the yield curve factors, such as the risk premium dynamics, and exposes a linear combination of three exponential factors that can adjust to the different shapes of the yield curve in any period of time:

$$y(\tau) = \beta_1 + \beta_2 \left(\frac{1 - e^{-\lambda\tau}}{\lambda\tau} \right) + \beta_3 \left(\frac{1 - e^{-\lambda\tau}}{\lambda\tau} - e^{-\lambda\tau} \right), \tag{1}$$

where $y(\tau)$ is the yield curve and τ denotes the maturity. β_1, β_2, β_3 and λ are time-varying parameters. The λ parameter it is an exponential fixed rate of decay, at which the β_3 factor is maximized.

The flexibility of the NS representation in modeling the various shapes of the yield curve can be seen by interpreting the coefficients of the model as measures of the short-, medium-, and long-term components of the curve. According to the way each factor shock affects the curve, Litterman e Scheinkman (1991) named β_1, β_2, β_3 as level, slope, and curvature factors of the term structure of interest rates. They are not observed, and the associated factors are restricted by a functional form that imposes smoothness over the maturities.

2.2 The Dynamic Nelson-Siegel (DNS) Model

We introduce temporal dynamics into the Nelson-Siegel static structure with the incorporation of time-varying parameters:

$$y(\tau) = L_t + S_t \left(\frac{1 - e^{-\lambda\tau}}{\lambda\tau} \right) + C_t \left(\frac{1 - e^{-\lambda\tau}}{\lambda\tau} - e^{-\lambda\tau} \right), \tag{2}$$

where, L_t, S_t, and C_t are the time dynamic coefficients, representative of the parameters β_1, β_2, and β_3 of the NS model, shown in equation (1). The DNS model associates cross-sectional and time series perspectives, representing a spatial and temporal linear projection of $y_t(\tau)$ onto the temporally dynamic variables L_t, S_t, and C_t. These can be interpreted, respectively, as latent factors of the long-, short-, and medium-term.

The interpretation of the yield curve latent factors refers to the inspection of factor loadings $(1, ((1 - e^{-\lambda\tau})/\lambda\tau)$ and $((1 - e^{-\lambda\tau})/\lambda\tau - e^{-\lambda\tau})t)$. The long-term variable, L_t, controls the term structure level from $\lim_{\tau\to\infty} y_t(\tau) = L_t$, whose loading is constant at one for all maturities. An increase in L_t implies a shift in the entire yield curve, as its factor loading is identical across all maturities. The short-term variable loading, S_t, is a function that starts at one, decaying monotonically with maturity. Thus, fluctuations in S_t generate greater deviations in short-term interest rates. The curvature factor loading, C_t, increases at medium maturities, decaying to zero. Thus, an increase in C_t has little effect on short- and long-term yields, but increases yields in the medium-term. In addition, it is important to note that the instantaneous yield depends on the level and slope factors, because $y_t(0) = L_t + S_t$.

The DNS model estimation proposed by Diebold e Li (2006) use a two-stage approach. In the first step, the measurement equation can be estimated by Ordinary Least Squares (OLS) to obtain a three-dimensional time series of estimated factors for each period t, given that λ is a calibrated parameter. In the second step, the time dynamics of the estimated factors can be specified as an AR(1) or a VAR(1) processes, for example. It is noteworthy that the approach ignores and transfers the estimated residuals of the first stage to the estimates of the subsequent stage, distorting the inference of the second step and revealing an inefficient estimation process.

It is possible to interpret the DNS model in the state-space representation, as Diebold, Rudebusch e Aruoba (2006), by assuming that the dynamic latent factors are state-space variables and follow a first order stochastic autoregressive vector. In the state-space system, the model can be described by equations (3) and (4):

$$y_t = \Lambda f_t + \varepsilon_t, \tag{3}$$

$$(f_t - \mu) = A\,(f_{t-1} - \mu) + \eta_t, \tag{4}$$

for $t = 1, ..., T$. For equation (3), y_t is the $N \times 1$ vector of yields for N maturities τ_i at time t. Thus, $y_t = [y_t(\tau_1), y_t(\tau_2), ..., y_t(\tau_N)]'$, with τ_1 being the shortest maturity considered and τ_N the longest. Λ is the sensitivity matrix of the measurement equation, and ε_t is the measurement equation error. For equation (4), f_t is the state vector representing the level, slope, and curvature factors. A is the state transition matrix, μ is the factor mean, and η_t is the state equation factor error.

From the deterministic DNS curve, equation (3) adds a stochastic disturbance term that relates the sets of N yields to unobserved factors: in our case, the level (L_t), slope (S_t), and curvature (C_t) factors. Thus, we can see a implied relationship between the yield curve dynamic and the constructed factors by the factor loadings matrix Λ. The transition equation (equation 4) determines the common factor dynamics as a first-order process or higher-order dynamics. Moreover, the covariance structure of the measurement and transition errors (equation (5)) ensure the orthogonalization of vectors η_t and ε_t. Thus, η_t and ε_t are white noise processes and are mutually orthogonal to the initial state vector:

$$\begin{pmatrix} \eta_t \\ \varepsilon_t \end{pmatrix} \sim \text{WN}\left[\begin{pmatrix} 0 \\ 0 \end{pmatrix}, \begin{pmatrix} Q & 0 \\ 0 & P \end{pmatrix}\right]. \tag{5}$$

The system ensures that the covariance matrix of the measurement error (P) is diagonal. In addition, the transition covariance matrix of error (Q) is not diagonal. This implies that the ε_t errors are not correlated for different maturities, and η_t can be correlated over time, allowing for correlated shocks between state factors. The unobserved factors L_t, S_t, and C_t follow a first-order VAR process in the state-space framework. The measurement equation that relates the set of yields and the three latent factors is formalized as:

$$\begin{pmatrix} y_t(\tau_1) \\ y_t(\tau_2) \\ \vdots \\ y_t(\tau_N) \end{pmatrix} = \begin{pmatrix} 1 & \frac{1-e^{-\lambda\tau_1}}{\lambda\tau_1} & \frac{1-e^{-\lambda\tau_1}}{\lambda\tau_2} - e^{-\lambda\tau_1} \\ 1 & \frac{1-e^{-\lambda\tau_2}}{\lambda\tau_2} & \frac{1-e^{-\lambda\tau_2}}{\lambda\tau_2} - e^{-\lambda\tau_2} \\ \vdots & \vdots & \vdots \\ 1 & \frac{1-e^{-\lambda\tau_N}}{\lambda\tau_N} & \frac{1-e^{-\lambda\tau_N}}{\lambda\tau_N} - e^{-\lambda\tau_N} \end{pmatrix} \begin{pmatrix} L_t \\ S_t \\ C_t \end{pmatrix} + \begin{pmatrix} \varepsilon_t(\tau_1) \\ \varepsilon_t(\tau_2) \\ \vdots \\ \varepsilon_t(\tau_N) \end{pmatrix}. \tag{6}$$

The transition equation that relates the dynamics of latent factors can be written as:

$$\begin{pmatrix} L_t - \mu_L \\ S_t - \mu_S \\ C_t - \mu_C \end{pmatrix} = \begin{pmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{pmatrix} \begin{pmatrix} L_{t-1} - \mu_L \\ S_{t-1} - \mu_S \\ C_{t-1} - \mu_C \end{pmatrix} + \begin{pmatrix} \eta_t(L) \\ \eta_t(S) \\ \eta_t(C) \end{pmatrix}. \tag{7}$$

The unobserved latent factors (L_t, S_t, and C_t) were extracted for each country through the application of the Kalman filter. The use of the Kalman filter, in turn, allows for estimating λ and obtaining the conditional distribution of the vector f_t, given the set of past information in the vector of observed variables $Y_t = y_1, ..., y_t$. This generates the likelihood function to be maximized.

2.3 Measuring spillover effects

Our analysis is performed with the spillover indices introduced by Diebold e Yilmaz (2012), and based on the framework of a generalized FEVD proposed by Pesaran e Shin (1998), and Koop, Pesaran e Potter (1996). The indices are defined as follows:

Consider the N-variable covariance stationary VAR(p):

$$x_t = \sum_{n=1}^{p} \Phi x_{t-n} + \varepsilon_t, \tag{8}$$

such that $\varepsilon_t \sim (0, \Sigma)$ is a vector of independent and identically distributed random disturbances. The representation of the moving average is written as:

$$x_t = \sum_{n=0}^{\infty} A_n \varepsilon_{t-n}, \tag{9}$$

so that the $N \times N$ matrices of A_i coefficients obey the recursion:

$$A_i = \Phi_1 A_{i-1} + \Phi_2 A_{i-2} + \cdots + \Phi_p A_{i-p}, \tag{10}$$

where A_0 is a $N \times N$ identity matrix and $A_i = 0$ for $i < 0$.

The moving average coefficients (or transformations as impulse-response functions or variance decompositions) are the key to understanding the dynamics of the system. We use the variance decompositions to indicate the amount of information each variable contributes to the other variables in the autoregression framework. The calculation of variance decompositions requires orthogonal innovations, but the VAR innovations are generally correlated contemporaneously. Identification schemes such as the one based on Cholesky factorization achieve orthogonality, but the variance decompositions depend on the ordering of the variables. We overcome this problem using the generalized VAR structure of Koop, Pesaran e Potter (1996) and Pesaran e Shin (1998), which produces variance decompositions that are invariant to the ordering of the variables. Instead of trying to orthogonalize shocks, the generalized approach allows shocks to be correlated through the historical distribution of errors. The sum of the contributions to the variance of the forecast error may not necessarily sum to one the shocks for each variable are not orthogonal.

The variance decompositions allow us to compute the fraction of the H-step-ahead error variance in forecasting x_i that is due to shocks to x_j, $\forall i \neq j$, which we call cross variance shares (or spillovers), and the own variance portions is defined as the fractions of the variations of the H-step-ahead error variance in forecasting x_i that are due to shocks to x_i, for $i = 1, 2, \ldots, N$, which we call own variance shares. Thus, in the generalized VAR framework, the H-step-ahead forecast error variance contribution is:

$$\theta_{ij}^{g}(H) = \frac{\sigma_{jj}^{-1} \sum_{h=0}^{H-1} \left(e_i' A_h \Sigma e_j\right)^2}{\sum_{h=0}^{H-1} \left(e_i' A_h \Sigma A_h' e_i\right)}, \tag{11}$$

where Σ is the estimated variance matrix for the error vector ε, σ_{jj} is the estimated standard deviation of the error term for variable j, e_i is the selection vector where the unit is the ith element and zeros otherwise. So, the main diagonal elements contains the own contributions of shocks to variable i, to its own forecast error variance, and the off-diagonal elements represent cross-variance spillover, defined here as contributions of the variable j to the forecast error variance of i.

From equation (11) and the generalized VAR structure, we have determined that the sum of the elements in each line of the variance decomposition table is not equal to 1: $\sum_{j=1}^{N} \theta_{ij}^{g}(H) \neq 1$. So, to calculate the spillover indices, we normalize each entry of the variance decomposition matrix by its row sum, such that:

$$\tilde{\theta}_{ij}^{g}(H) = \frac{\theta_{ij}^{g}(H)}{\sum_{j=1}^{N} \theta_{ij}^{g}(H)}. \tag{12}$$

We build the total spillovers index using the shares of contributions of each country from the variance decomposition proposed by Koop, Pesaran e Potter (1996). The Total Spillover Index (TSI) measures, on average, the contribution of spillovers shocks across all countries considered to the total forecast error variance as:

$$S^g(H) = \frac{\sum_{\substack{i,j=1 \\ i \neq j}}^{N} \tilde{\theta}_{ij}^g(H)}{N} \times 100. \tag{13}$$

The generalized VAR approach allows us to identify the direction of spillovers among the factors of the term structure for each country. As the generalized impulse response functions and the variance decompositions are invariant to the ordering of the variables, we calculate the directional spillover indices using the normalized elements of the generalized variance decomposition matrix. The directional spillovers received and transmitted by country i from all other countries j are measured as:

$$S_i^g(H) = \frac{\sum_{\substack{j=1 \\ j \neq i}}^{N} \tilde{\theta}_{ij}^g(H)}{N} \times 100. \tag{14}$$

The net spillover index is simply the difference between shocks transmitted to all other countries and shocks received from all other countries. We obtain the net spillover indices from market i to all other markets j as the difference:

$$S_i^g(H) = S_{\cdot i}^g(H) - S_{i \cdot}^g(H). \tag{15}$$

Lastly, we examine the net spillover indices in pairs. This index provides the information on whether a country is a receiver or transmitter of shocks in net terms. The index that measures the spillovers between two countries is defined as:

$$S_{ij}^g(H) = \left(\frac{\tilde{\theta}_{ji}^g(H) - \tilde{\theta}_{ij}^g(H)}{N} \right) \times 100. \tag{16}$$

2.3.1 Vector Error Correction Model (VECM)

The VAR model is appropriate to analyze the dynamics between a set of variables treated as endogenous. However, in cases where the series used are non-stationary, as ours, using the VAR methodology omits relevant information. In the presence of heteroscedasticity and autocorrelation, the estimators continue to be unbiased and consistent, but they are no longer efficient. However, when the series have some cointegrating relationship, this problem can be solved with an error correction vector. According to Engle e Granger (1987), a VECM has consistent and efficient estimators maintaining information regarding level variables. We obtain our VECM as follows:

$$\begin{aligned} \Delta x_t &= \sum_{i=1}^{p-1} \Gamma_i \Delta x_{t-i} + \Pi x_{t-1} + \varepsilon_t, \\ \Gamma_i &= -\left(I - \Pi_{i+1} + \ldots + \Pi_p\right), \quad i = 1, \ldots, p-1 \\ \Pi &= -\left(I - \Pi_1 - \ldots - \Pi_p\right). \end{aligned} \tag{17}$$

where I is a $(k \times k)$ identity matrix and Γ_i is the matrix that captures the long-term impact.

For Δx_t to be stationary, the rank of the matrix Π must be higher than one. Thus, there will be cointegrating vectors that represent the long-term relationships between the series of x_t. The Johansen test is used to verify the existence of cointegration, which evaluates the rank of the Π matrix. Finally, the VECM is re-transformed to a VAR structure allowing to obtain the equations (8) and (9) and, consequently, the spillover indices.

3 Data

To obtain the latent factors of the term structure of interest rates for each country, we use the interest rates of government bonds with maturities between 3 and 120 months for four South American economies: Brazil, Chile, Colombia, and Peru, as well as the U.S. as a representative of global monetary policy. This follows the approach of Rey (2015). We use 2944 daily observations for the period from January 2006 to May 2019, on days when operations occurred in all markets. The maturities we use, and the data source, are shown in Table 1. We emphasize that, in some cases, we decided to use inter-bank interest rates as proxies for government bond rates due to their liquidity, as in Brazil and Chile.

Tabela 1 – Maturities (Months) and Source of Data

Country	Maturities	Source
Brazil	3, 6, 12, 24, 36, 48, 60, 72, 96, 108, 120	B3
Chile	3, 6, 12, 24, 36, 48, 60, 120	CBCh
Colombia	3, 6, 12, 60, 120	CBCo
U.S.	3, 6, 12, 24, 36, 60, 84, 120	FRED
Peru	3, 6, 12, 24, 36, 48, 60, 72, 96, 108, 120	SBS

Note: B3 is the Brazilian Stock Exchange. CBCh is the Central Bank of Chile. CBCo is the Central Bank of Colombia. FRED is the Federal Reserve Bank of St. Louis Data Service. SBS is the Superintendence of Bank and Insurance of Peru.

The yields on sovereign bonds in the South American and U.S. markets are denominated in local currency. We use this approach for two reasons. First, because the emerging markets considered in the study are in different stages of economic and financial development. This allows us to better capture the effects by valuing bonds denominated in domestic currency, rather than in U.S. dollars. Second, the debt denominated in local currency has higher liquidity and better credit quality compared to debt denominated in dollars Sowmya, Prasanna e Bhaduri (2016). In addition, local currency bonds also reflect the monetary policy orientation of the local economy, which makes it possible to assess the comovement of yields on local currency bonds and to make inferences about the convergence hypothesis of monetary policy and the business cycle.

The data used to obtain the spillover indices are the latent factors extracted from each country using its zero coupon yield curve, which represents its term structure of interest rates in domestic currency.

3.1 Dynamic Nelson-Siegel and Yield Curve Factors

We use the DNS framework in the state-space model (SSM) to extract the latent factors (level, slope, and curvature) for each country separately, following Diebold, Rudebusch e Aruoba (2006). However, due to the sensitivity of the Kalman filter to the initial parameters in estimating the maximum likelihood (CALDEIRA; MOURA; PORTUGAL, 2009), we decided to use the estimates obtained by the model presented in two stages, as the vector of initialization for the Kalman filter.

Initially, we estimate the model parameter using a two-stage approach. First, with λ constant, we estimate the level, slope, and curvature parameters for each daily yield curve. We repeat the process for all observed yield curves, which provides a three-dimensional time series of the unobserved level, slope, and curvature estimated factors. Subsequently, we adjust a first-order autoregressive model, or VAR (1), to the time series of factors derived in the first step, which allows us to extract the final estimates for the latent factors. Following Diebold e Li (2006), we set $\lambda = 0.0609$ in the first step, transforming what would otherwise be a nonlinear least squares estimation into a relatively simple

OLS estimator. To extract latent factors using the SSM we follow Diebold, Rudebusch e Aruoba (2006) and Caldeira, Moura e Portugal (2009). It is an implicit approach in which we specify a parameter map function. This function maps a vector of coefficients to the parameters of the SSM model, deflates the observations considering the averages of each factor and imposes restrictions on the covariance matrices. Thus, the Kalman filter procedure starts with initial values for states (f_0), for the coefficients of the state transition matrix (A_0), for the initial state disturbance loading matrix (B_0), for the observation innovation matrix (D_0), and for the parameter λ_0, forming the initial set of parameters (θ_0).

Finally, we use the Kalman filter with an optimization algorithm to extract the latent factors in each country. In our case, we assumed that the vectors of the error term η_t and ε_t are equal to $\eta_t = Bu_t$ and $\varepsilon_t = D\epsilon_t$, respectively. B is the state disturbance loading matrix, and D is the observation innovation matrix. The vectors η_t and ε_t of disturbances are defined as an uncorrelated unit-variance white noise processes, and their covariance matrices are identity matrices. In addition, it is possible to note that the covariance of η_t and ε_t must be equal to the covariance of the white noise process, such that $Q = BB'$ and $H = DD'$.

Tabela 2 – Exponential Decay Rate and Maximized Maturity

	Brazil	Chile	Colombia	U.S.	Peru
λ_i	0.1110	0.0644	0.0508	0.0397	0.0369
Maturity	16.16	27.85	35.30	45.17	48.60

The λ parameter represents the exponential decay rate of the equation. They are the values in which the curvature of the term structure of the interest rates is maximized. According to Diebold e Li (2006), a slow decay, represented by a low λ, better adjusts the curve at long maturities, while large values produce faster decay and can better adjust the curve at short maturities. Table 2 shows the λ found in the estimation by the Kalman filter. All the estimated λ_i, differ from the initialization λ_0, which had a value set at 0.0609. There is a great difference between the countries analyzed, with Brazil having the maximization of its yield curve with the lowest maturity and Peru its largest, respectively, 16 and 49 months. The maturity at which the curve is maximized provides information on the political and economic instability of the countries evaluated, making it possible to assess the market's expectations regarding the development of future monetary policy.

Table 3 shows descriptive statistics for the three estimated latent factors considering all countries in the sample. The average level factor is positive for all countries, highest for Brazil (12.34) and lowest for the U.S. (4.16). The average slope factor is negative for all countries, indicating that long-term rates are higher than short-term rates. The average slope is lowest in Peru (-4.23) and highest in Chile (-1.16); however, there are moments when the inclination was positive, which indicates periods when restrictive monetary policies occurred (SOWMYA; PRASANNA; BHADURI, 2016). The average curvature factor is lowest in Peru (-2.90) and highest in Brazil (-1.27), and is negative for all the countries in the sample.

As we are going to evaluate the spillover indices among the factors of the yield curve with a generalized FEVD, which requires stationarity, we tested the presence of unit roots using the Kwiatkowski-Phillips-Schmidt-Shin (KPSS) test. The level, slope, and curvature coefficients are non-stationary for all countries in the sample. We choose to use all series in levels adopting a methodology with a VECM. Taylor (2013) justifies this choice by assuming that there is coordination between monetary policies and, consequently, a common time path between the factors of the term structure of interest rates for the countries evaluated.

Tabela 3 – Descriptive Statistics for DNS Latent Factors

Maturity	Mean	Std. Dev.	Min	Max	Skew.	Kurt.	JB	KPSS
Brazil								
Level	12.34	1.52	9.55	18.33	0.70	0.56	**278.62**	**3.30**
Slope	-1.73	2.43	-7.31	4.05	0.18	-0.33	**30.05**	**1.40**
Curvature	-1.27	3.57	-11.99	8.33	0.05	-0.84	**87.60**	**8.78**
Chile								
Level	5.91	0.86	4.27	8.08	0.27	-0.92	**138.21**	**23.52**
Slope	-1.16	2.06	-7.36	5.95	-1.01	2.20	**1098.80**	**0.98**
Curvature	-2.89	1.66	-7.03	1.83	0.06	-0.51	**32.99**	**6.61**
Colombia								
Level	9.01	1.36	5.76	15.11	0.59	0.88	**265.83**	**11.38**
Slope	-3.64	1.74	-7.92	-0.04	-0.26	-0.53	**66.55**	**3.12**
Curvature	-1.40	3.38	-8.35	9.07	0.71	-0.35	**260.31**	**17.30**
U.S.								
Level	4.16	1.15	2.07	6.50	0.16	-1.34	**231.56**	**16.58**
Slope	-2.95	1.89	-6.45	0.59	0.11	-0.90	**105.91**	**4.97**
Curvature	-2.88	2.12	-7.52	1.42	-0.14	-0.99	**128.61**	**7.54**
Peru								
Level	7.76	1.06	5.27	10.64	0.14	-0.68	**65.20**	**3.18**
Slope	-4.23	1.76	-8.99	-0.56	-0.55	0.38	**166.03**	**1.63**
Curvature	-2.90	2.54	-10.65	4.18	-0.09	-0.10	**4.89**	**2.54**

Note: Table 3 reports summary statistics, KPSS Test for stationatiry and Jarque-Bera (JB) test for normality. Jarque-Bera (JB) alternative hypothesis is non-normality. KPSS alternative hypothesis is different from ADF test, H1 is Non-Stationarity. Results in bold are statistically significant at 5% level.

4 Empirical Evaluation

We extract the latent factors through the DNS model and use them to assess the effects of spillovers among countries. As the factors proved to be non-stationary, we chose to use a VECM structure in the evaluation, which will be transformed into a generalized VAR to estimate the FEVD and, consequently, estimate the indices proposed by Diebold e Yilmaz (2012). The VECM consists of five endogenous variables with two lags selected using the Schwarz Bayesian Criteria (SBC). As the data present daily frequency, we chose a forecast horizon of 210 steps - this represents the average number of business days, among all markets, during a year - to perform the FEVD. To choose the forecast window, we follow Sowmya, Prasanna e Bhaduri (2016), who say that one year is the time necessary to observe changes in economies as a result of monetary policy decisions.

4.1 Spillovers in the Level Factor

We interpret the level factor as the long-term factor of the yield curve, indicating the expectations of the bond market regarding long-term interest rates and inflation (DIEBOLD; RUDEBUSCH; ARUOBA, 2006). Driessen, Melenberg e Nijman (2003) explain that changes in levels are positively correlated between countries, and their changes in slope are country-specific. Abbritti *et al.* (2018) found that global factors impact the level factor in the term structure of the interest rates. According to Sowmya, Prasanna e Bhaduri (2016), the level factor is mainly related to foreign investor preferences, global savings, and foreign capital flows. Thus, we expect a greater degree of integration in the evaluation of the level factor spillover among all other factors.

In Table 4 we present the spillover indices for the level factor. The diagonal elements represent

Tabela 4 – Spillover Index for Level Factors

	Brazil	Chile	Colombia	U.S.	Peru	Others
Brazil	80.67	3.27	5.5	0.26	10.29	31.49
Chile	1.42	92.48	0.77	5.22	0.11	24.60
Colombia	13.23	2.13	79.82	4.16	0.66	35.15
U.S.	0.53	5.03	2.20	81.78	10.46	27.88
Peru	29.88	0.05	1.06	17.73	51.29	42.42
Spillover to Others	45.06	10.48	9.53	27.37	21.52	161.54
Total Spillover	125.73	102.96	89.35	109.15	72.81	**TSI:**
Net Spillover	25.73	2.96	-10.65	9.15	-27.19	**22.79**

Note: The diagonal values are the own country influences on the level factor. The values in each row represent the influence of the other countries upon the domestic level factor. The values in each column represent the influences of the respective countries upon the level factor of other countries. The Total Spillover Index is calculated as the total contribution to others divided by the total contribution including it self. The net spillover index is the difference between the total spillovers and the total forecast error variance for each country.

the shock of the country's own factor on itself. The elements outside the diagonal represent the spillovers of shocks between countries. The values in each row represent the spillovers from other countries in the internal level factor, while the values in each column represent the impacts from the country over the others. The Total Spillover Index (TSI) describes the average spillovers between countries in a single spillover index. The TSI index for the level factor accounts for 22.79% of the forecast error variance, indicating the average percentage of the total forecast error variance is due to the interaction, and consequently, the spillover between countries. The remaining 77.21% of the average total variance is explained by own-country shocks.

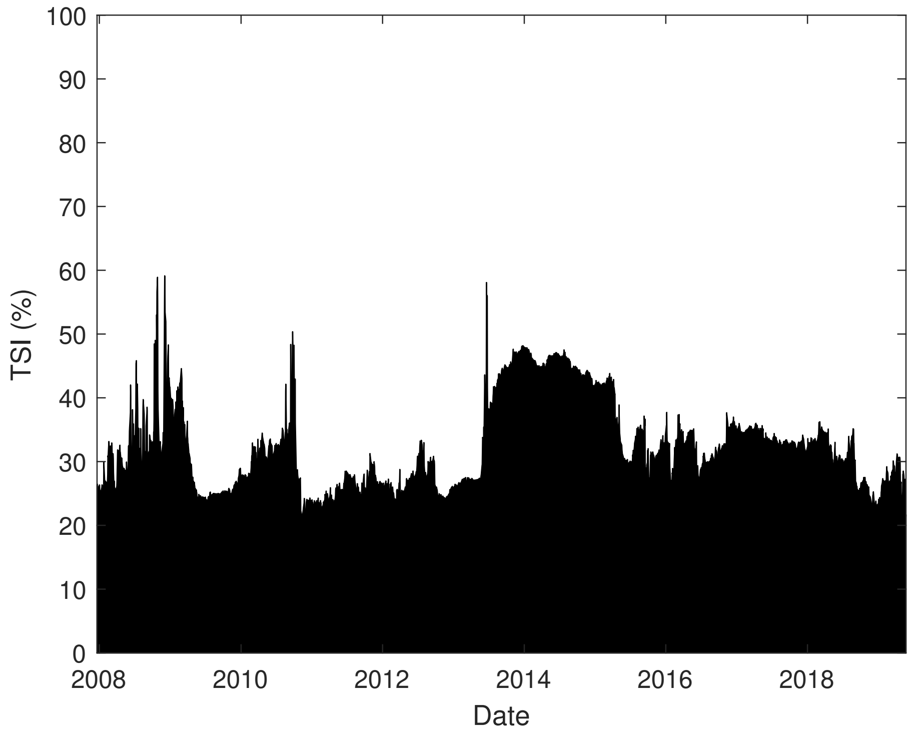
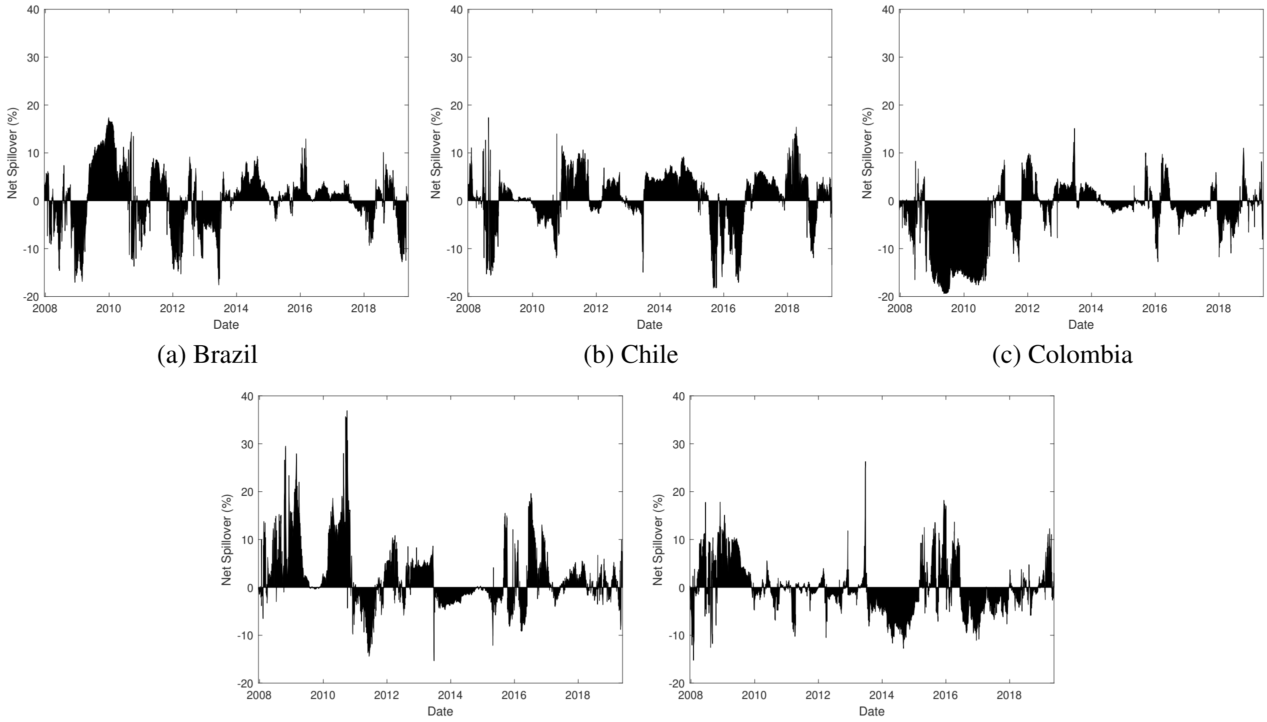


Figura 1 – Rolling Window Total Spillover Index for the Level Factor

As we can see, the impact of the country shocks on its own level factor is higher in the markets of Chile and the U.S., which indicates that they are less impacted by the other countries in the sample. The countries that had the biggest directional spillovers index, which compute shocks on the level factor of one country to others, were Brazil and the U.S., accounting for 45.06% and 27.37% of the system variance shocks, respectively. In contrast, the largest receiving countries are Colombia and Peru, with 42.42% and 35.15% of forecast error variance in their level factor coming from external sources. These results are consistent with the empirical evidence of Canova (2005) and Maćkowiak (2007) who noted that the U.S. economy is less influenced by emerging ones, having a high potential to transmit shocks from their economy to South American markets. These results support the hypothesis that financial integration plays an important role in transmitting shocks from one economy to another, showing the great importance of analyzing the impact of external monetary policies on internal macroeconomic variables.



(a) Brazil (b) Chile (c) Colombia

(d) United States (e) Peru

Figura 2 – Rolling Window Net Spillover Index for Level Factor

The calculation of the spillover index for the entire sample may not capture cyclical and structural changes, so we decided to evaluate this relationship over time. We investigate the temporal dynamics of the TSI in the level factor using a 420-working-day (24 month) rolling window, which captures variation in the spillover over time, as shown in Figure 1. We found that the shocks transmission and spillovers are greater during crisis periods; the TSI for the level factor ranges between 25% and 60%. In addition, we link peaks and valleys in the spillover index to financial events. A substantial increase in the TSI measure can be seen in the 2008 global financial crisis; subsequently, with the expansive monetary policy actions in 2009-2010, including the quantitative easing (QE) program (BLINDER, 2010); and an increase in the period of strong volatility between 2012 and 2014 due to instabilities in the Eurozone. The stronger linkages during crisis periods reinforce the importance of assessing the contagion effect. Following the crisis, several countries around the world, mainly the U.S., initiated an expansionary monetary policy. Specifically in March 2009, the Fed initiated the QE, an unconventional monetary policy. This type of monetary policy involves the massive expansion of central bank balance sheets, as well as attempts to influence interest rates other than the usual official short-term rates (JOYCE *et al.*, 2012), which were already close to zero.

One of the consequences of the so-called QE is the depreciation of the currency of the country in which the stimulus is implemented (KRISHNAMURTHY; VISSING-JORGENSEN, 2011). For example, for the cases of the U.S.' QE1 and QE2, the dollar depreciated against a basket of other major currencies. However, the money created by the Fed has also spilled over into other economies of the world. It was as if the cash flow generated in the U.S. was being exported to other countries, mainly to developing countries, which had higher interest rates and, consequently, more advantageous investment options. This led to a strong appreciation of the currencies of the countries analyzed, with spillovers to their monetary policy and interest rates. In Figure 2 we show the net spillovers for the level factors in a temporal distribution, that is, the difference between the influence transmitted and influence received by the factors of each country over time. We see that the influence on the level factor for external shocks is temporally heterogeneous for the analyzed countries. However, we note that the U.S. is the country that, for the most part, has impacted other countries and can be considered a dominant transmitter. Following the U.S. is Chile, which has periods of strong influence over other countries as in the periods between 2008 and 2010, and 2012 and 2014. Brazil and Colombia sometimes acted as net receivers, and sometimes as net transmitters, of monetary policy shocks. Finally, Peru was the country that received the most influence from others, albeit heterogeneously over time.

4.2 Spillovers in the Slope Factor

The slope factors changes are usually country-specific, influenced by the internal monetary policy carried out by each central bank. This is because the slope factors can be interpreted as a proxy for short-term rates, rates which the monetary authorities use as an instrument (DIEBOLD; RUDEBUSCH; ARUOBA, 2006). According to Driessen, Melenberg e Nijman (2003), the slope factor reflects the internal monetary policy and the economic and financial conditions of the internal market. Moreover, due to the fact that monetary authorities seek to affect long-term interest-sensitive sectors of the economy such as housing, consumer durables, and fixed investment, they must initially operate on short-term rates. The past empirical evidence is that the correlation of long-term rates between economies is higher than that of short-term rates. However, synchronicity in the business cycles between countries also leads to some synchronicity in monetary policy, which leads the slope factor to be correlated with other countries (BYRNE; FAZIO; FIESS, 2012; SOWMYA; PRASANNA; BHADURI, 2016).

Tabela 5 – Spillover Index for the Slope Factor

	Brazil	Chile	Colombia	U.S.	Peru	Others
Brazil	91.96	4.11	2.06	1.79	0.08	8.04
Chile	0.43	90.98	1.00	3.34	4.25	9.02
Colombia	13.32	10.84	58.57	6.49	10.78	41.43
U.S.	1.76	0.75	0.62	96.08	0.79	3.92
Peru	15.29	24.96	7.66	17.31	34.77	65.23
Spillover to Others	30.80	40.66	11.34	28.93	15.90	127.64
Total Spillover	122.76	131.64	69.91	125.01	50.67	**TSI:**
Net Spillover	22.76	31.64	-30.09	25.01	-49.33	**25.53**

Note: The diagonal values are the own country influences on the slope factor. The values in each row represent the influence of the other countries upon the domestic slope factor. The values in each column represent the influences of the respective countries upon the slope factor of other countries. The Total Spillover Index is calculated as the total contribution to others divided by the total contribution including it self. The net spillover index is the difference between the total spillovers and the total forecast error variance for each country.

We show the spillover index coefficients for the slope factor in Table 5. We can note that the slope factor is more influenced by a country's own past shocks than the shocks coming from other countries, represented by the diagonal elements in the table. However, when there is a spillover, as in the cases of Colombia and Peru, the dominant shock transmitters are also countries in the same region, such as Chile and Brazil, which transmit 40.66% and 30.80%, respectively. It is also interesting to observe the behavior of the spillover index for Colombia and Peru. In the case of Colombia, 41.43% of the variation in its slope factor is due to actions of monetary policy carried out by the other countries analyzed. This spillover is even greater for the case of Peru, where 65.23% of the variation is due to external shocks. The result we found is consistent with the past literature (DRIESSEN; MELENBERG; NIJMAN, 2003; DIEBOLD; RUDEBUSCH; ARUOBA, 2006; BYRNE; FAZIO; FIESS, 2012; SOWMYA; PRASANNA; BHADURI, 2016) which points out that the slope factor represents more internal and regional aspects. In our case, Brazil and Chile are the countries responsible for the biggest spillover in the slope factors. Moreover, we note that the influence of South American countries on the U.S. is almost zero, with the U.S.'s past shocks influencing 96.08% of its slope factor. This result is one more piece of evidence for the low influence of external monetary policy on the U.S. (EDWARDS, 2015; REY, 2016).

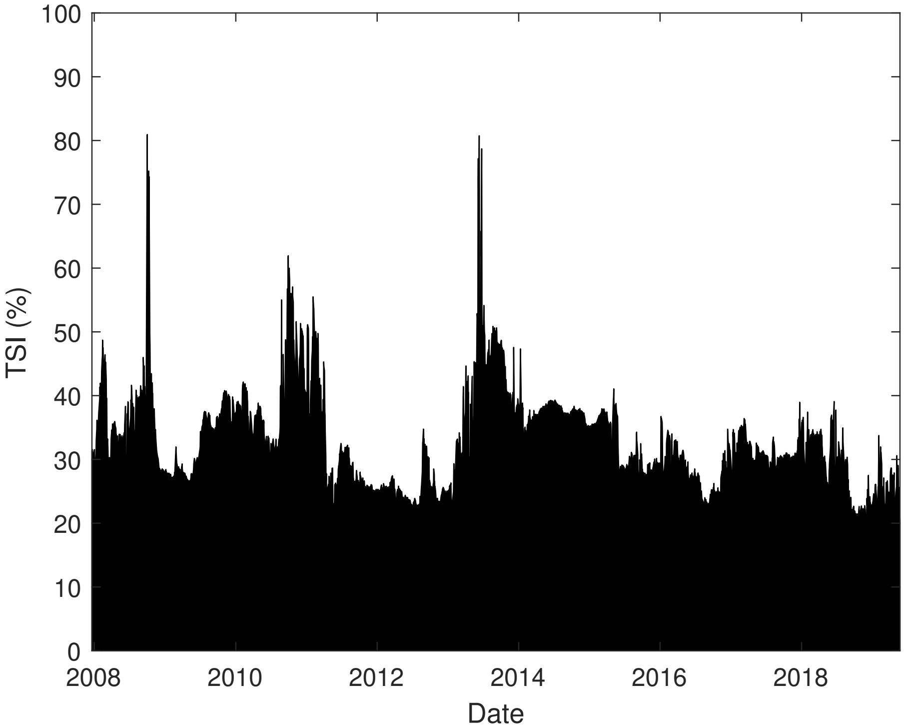
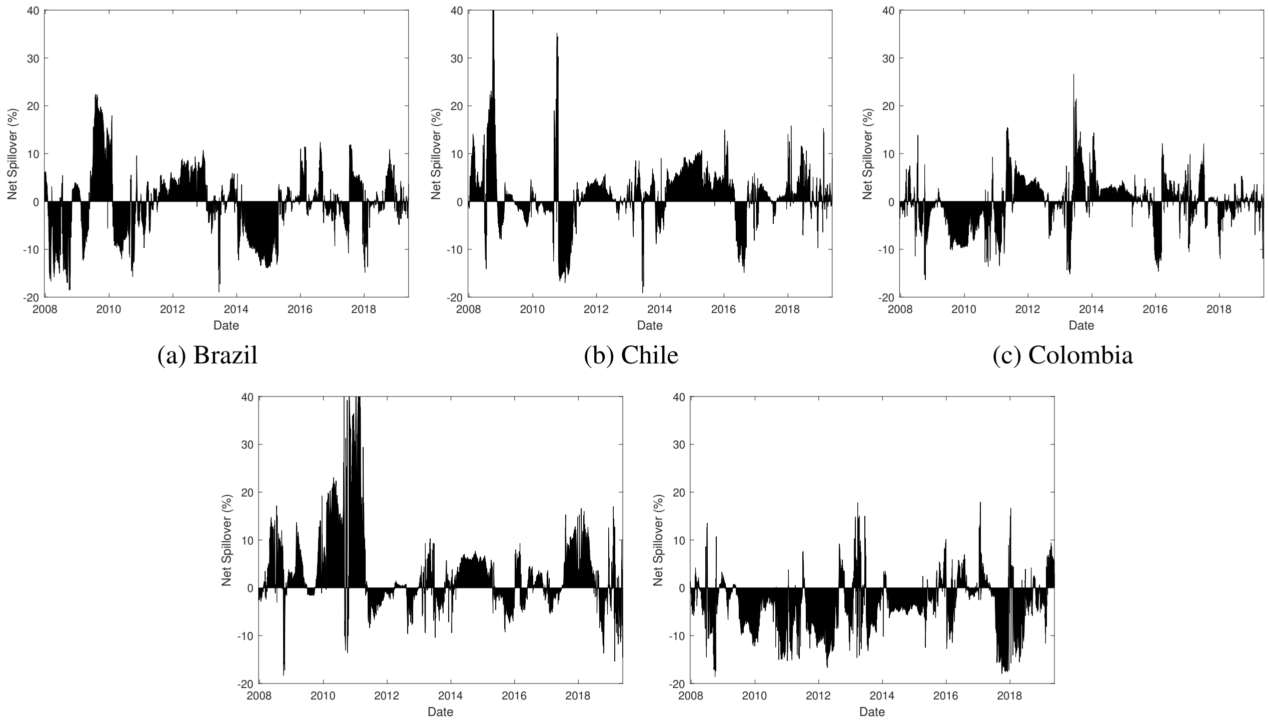


Figura 3 – Rolling Window Total Spillover Index for the Slope Factor

The TSI index between countries is 25.53%, which is the amount of the shocks, on average, that are transmitted between countries. The remaining variation of 74.47% is explained by the characteristics of the domestic market. We introduce time dynamics in the TSI for the slope factor using a 420-working-day rolling window and a forecast horizon of 210 steps (12 months) ahead to compute the FEVD. Figure 3 shows the index dynamics between 2008 and 2019. As we saw in the analysis of the level factor, the TSI for the slope factor peaked in 2008-2009 and 2013, moments of crises and worldwide instability. It was during this period that the South American countries also began to follow expansionary monetary policies. This occurred due to the strong inflows of foreign capital into the South American economies inducing a strong appreciation of the local currency and a lower interest rate for financing countries debts. This caused interest rates to plummet for Chile, Brazil, and Peru. Specifically, Chile went from an interest rate of 8.25% to 0.50% in less than a year. The same type of monetary policy was carried out in Brazil, with the interest rate reaching 8.75% in early 2009, and Peru, reducing the basic interest rate from 6.25% to 0.90% (CARRERA; RAMÍREZ-RONDÁN, 2019). This concomitant monetary policy implementation explains the strong increase in the TSI in that period, especially among the South American economies.

Figure 4 shows the net spillover in a temporal distribution for the slope factors; that is, the difference between the influence transmitted and the influence received by countries over time. As we



(a) Brazil (b) Chile (c) Colombia

(d) United States (e) Peru

Figura 4 – Rolling Window Net Spillover Index for the Slope Factor

can see, the influence on the slope factor from external shocks is temporally heterogeneous for all the countries analyzed. We observe that Chile, Brazil, and the U.S. are the countries that most transmitted influences to other interest rates (observe the values of the y-axis), which leads us to consider them as dominant transmitters. In contrast, Colombia and Peru are the countries that received more influence than they transmitted, which leads us to consider them as dominant receivers (EDWARDS, 2015; TAYLOR, 2013). This evidence corroborates the hypothesis that the slope factor reflects monetary policy and internal economic conditions, which causes the factor to be more impacted by regional shocks, and implies that synchronicity in the business cycle between countries can also lead to some similarity in the execution of their internal monetary policies, given the high level of spillovers in one-off events.

In comparing Figures 2 and 4, we can observe two facts. The first is that the spillovers are more concentrated in specific periods, as in the case of Chile and the U.S. The second fact is that there is higher volatility in the TSI index; there are clear bursts of increases and reductions in effects. This, once again, reinforces the idea that the slope factor reflects the internal monetary policy and the economic and financial conditions of the market, with moments of external shocks being transmitted and absorbed more quickly (DRIESSEN; MELENBERG; NIJMAN, 2003).

4.3 Spillovers in the Curvature Factor

According to Sowmya, Prasanna e Bhaduri (2016), the curvature factor explains the variation in interest rates over maturities and represents the risk premium associated with the government bonds of each country and their solvency. So, the curvature factor can be affected by external sources when there is a change in the level of risk worldwide. Diebold, Rudebusch e Aruoba (2006) corroborate this evidence, identifying that the curvature has low links with the macroeconomic fundamentals. Therefore, we expect that in comparison to the level and slope factors, the spillover effect on the curvature to be smaller.

In Table 6 we show the relationships of the curvature factor between countries. We find that the

Tabela 6 – Spillover Index for Curvature Factor

	Brazil	Chile	Colombia	U.S.	Peru	Others
Brazil	95.10	1.89	0.00	0.47	2.53	19.33
Chile	0.83	97.29	0.92	0.21	0.76	17.97
Colombia	0.54	0.79	93.74	0.70	4.24	33.77
U.S.	0.04	0.76	0.77	95.80	2.63	6.23
Peru	0.61	19.9	2.09	35.22	42.18	32.27
Spillover to Others	2.02	23.34	3.78	36.60	10.16	109.57
Total Spillover	97.12	120.63	97.52	132.40	52.34	**TSI:**
Net Spillover	-2.88	20.63	-2.48	32.40	-47.66	**15.18**

Note: The diagonal values are the own country influences on the curvature factor. The values in each row represent the influence of the other countries upon the domestic curvature factor. The values in each column represent the influences of the respective countries upon the curvature factor of other countries. The Total Spillover Index is calculated as the total contribution to others divided by the total contribution including it self. The net spillover index is the difference between the total spillovers and the total forecast error variance for each country.

country's own variance spillovers were relatively higher compared to the level and slope factors, which implies that most of the variation in curvature was explained by domestic aspects. The spillovers of the own country to their predicted curvature factor was lower for Colombia and Peru. The U.S. was the dominant transmitter, a result consistent with Rey (2016). This behavior highlights the importance of the U.S. economy in determining the risk premiums of South American economies and how this economy has the power to affect interest rates in emerging countries in the medium term.

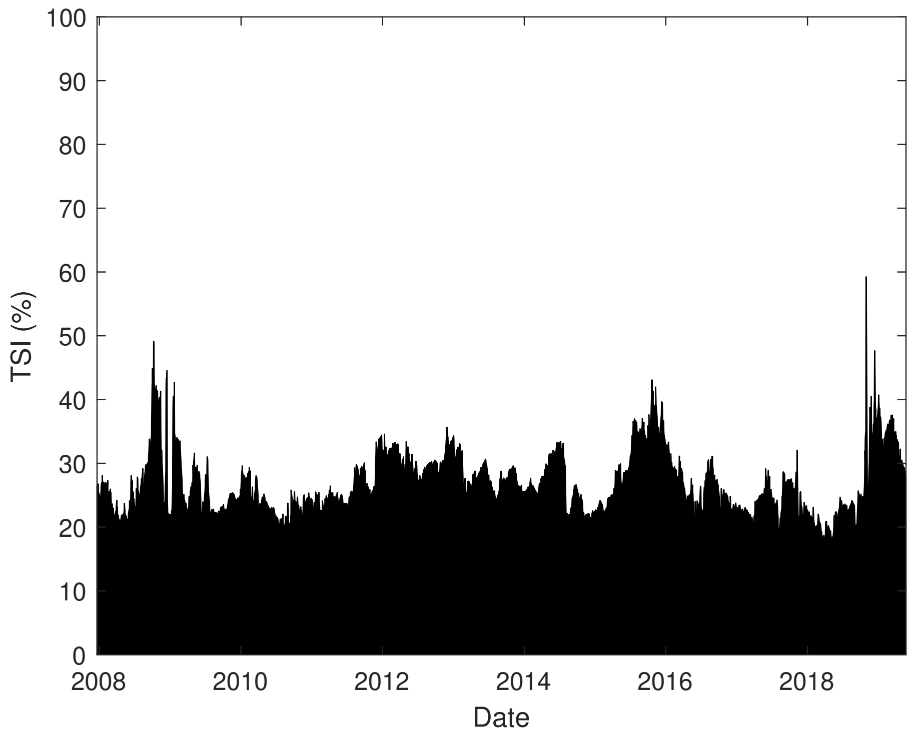
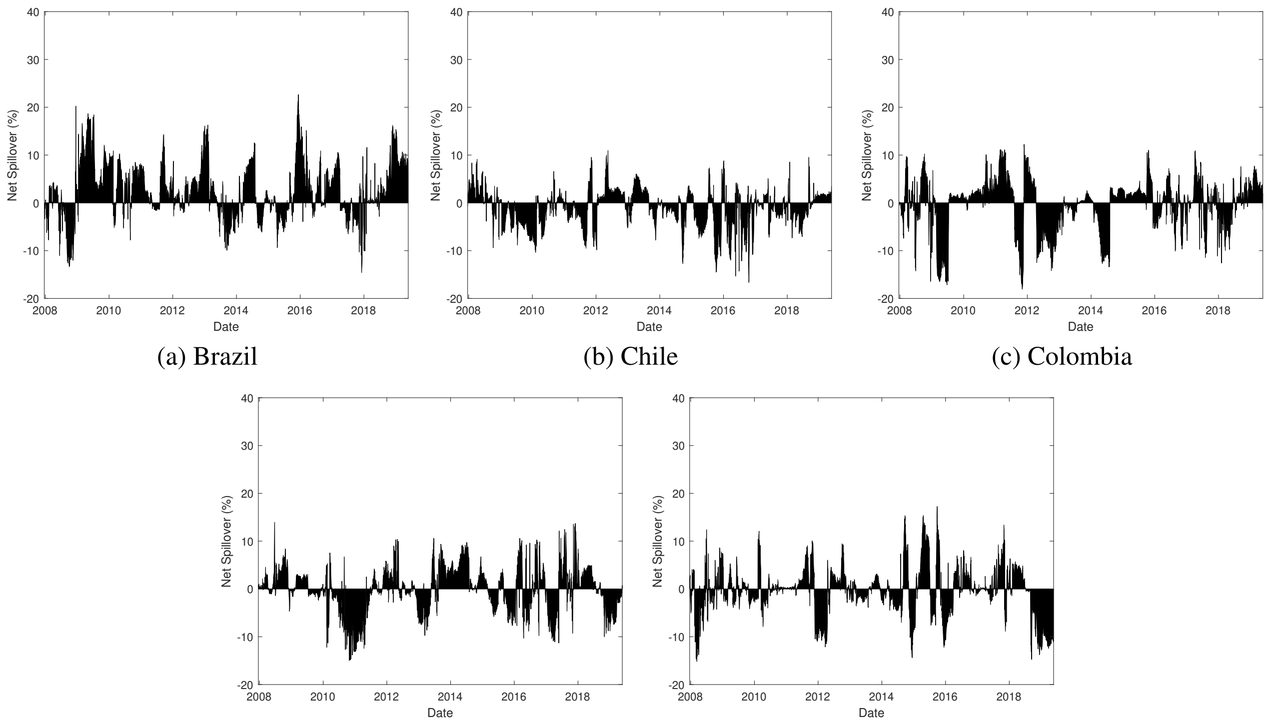


Figura 5 – Rolling Window Total Spillover Index for the Curvature Factor

The TSI for curvature between countries was 15.18%. The remaining 84.82% of the forecast error variance for the curvature factor was explained by the own countries' shocks. As we expected, the results show a lower TSI index for curvature compared to the level and slope factors. We analyze the temporal dynamics for the TSI using a rolling window of 420 working days. The curvature spillover index reached values between 20% and 60% in the period, with less volatility in the index when compared to the TSI for the level and slope factors. Unlike the results found by Sowmya, Prasanna e Bhaduri (2016) for Asian countries, the spillover of the curvature factor, although less than the spillover for the level and slope factors, shows a higher importance of medium-term rates in the term structures of interest rates in the countries of South America, which can be justified by the lower level of development of these countries compared to the Asian countries analyzed.

In Figure 5 we present the TSI temporal dynamics for the curvature factor. We can see two periods of strong expansion of the TSI, the first occurring in the period of 2008-2009, and the second occurring in mid-2018 onwards. These increases are strongly associated with the risk level of the assessed economies. In the period from 2008 to 2009 we had the financial crisis that generated an increase in the level of risk worldwide, starting in the U.S. and overflowing to the other economies under analysis. In the middle of 2018, we observed a return of the growth potential of the U.S. which led to an outflow of foreign capital and the consequent devaluation of the currencies of the South American countries. This scenario, associated with other types of political instability, generated economic uncertainty, which led to the concomitant increase in interest rates in the medium term and an increase in the TSI in this period.



(a) Brazil (b) Chile (c) Colombia

(d) United States (e) Peru

Figura 6 – Rolling Window Net Spillover Index for the Curvature Factor

In Figure 6 we show the net spillover index in a temporal distribution for the curvature factor. In the results for the level and slope factors (Figures 2 and 4) we found that the country that has the highest influence on the spillover index is the U.S., which is consistent with the literature (CANOVA, 2005; MAĆKOWIAK, 2007; TAYLOR, 2013; EDWARDS, 2015). Moreover, the net spillover index for the curvature factor show more stable results when compared to the slope factor, that is, the turbulent periods are better defined. However, as in the previous cases, these periods are heterogeneous throughout the sample. One interesting point is the cases of Chile and Peru. Unlike what is shown in Figure 2 and 4, they had an inversion in the behavior of their coefficients. While Chile had been a transmitter country, it then became a receiver. Peru, on the other hand, went from being a receiver of external influence to being a country with a higher potential to transmit shocks to other countries' curvature factors. These results are interesting because they emphasize the importance of considering λ when estimating the term structure of the interest rates. Reinforcing that, although the factors are composed of interest rates, they present different information regarding the economies analyzed (DRIESSEN; MELENBERG; NIJMAN, 2003; SOWMYA; PRASANNA; BHADURI, 2016).

5 Concluding Remarks

The purpose of this article was to evaluate the spillovers between the latent factors of the term structure of interest rates, calculating the magnitude and direction of the connection in the entire maturity spectrum for selected countries in South America and their relationship with the U.S.. We chose to adopt the approach proposed by Sowmya, Prasanna e Bhaduri (2016). Initially, we modeled the term structure of interest rates for several countries using the DNS model as Diebold e Li (2006). We extracted the latent factors of the DNS model (level, slope, and curvature) representing long-, short-, and medium-term interest rates using the Kalman filter. The spillover effects on latent factors were measured using the FEVD from a generalized VAR model as Diebold e Yilmaz (2012), which is invariant to country ordering.

The results we found indicate that the slope factor has a higher spillover index between countries, followed by the level and curvature factors. This result is consistent with the premise that long-term rates are influenced by global investors' preferences and global financial conditions; therefore, the impact should be higher on long-term rates. The dominant transmitters in the level factor were the economies of the U.S. and Chile. Regional influences are high on slope factors, with greater integration between South American countries, and Chile and Brazil dominating shock transmissions. Regarding the curvature factors, it was observed that the U.S. is a dominant transmitter, which shows that the U.S. still has a higher influence on the medium-term rates of South American countries yield curves, mainly impacting the risk premium associated with government bonds of countries in that region.

The indices' temporal dynamics were captured using a rolling window of 420 working days and a forecast horizon of 210 steps, considering the period between 2008 and 2019, periods with crises, and high market volatility. The results we found show a heterogeneity of the TSI in all the factors analyzed. The behavior of the dynamics of the level factors showed the highest TSI values throughout the period. Greater stability of the TSI coefficient was observed in the curvature factors, with three events increasing its magnitude but quickly reversing to the mean. The temporal dynamics of the TSI for the curvature factors proved to be the most volatile, with frequent episodes of sudden growth in the TSI.

The results are useful to help understand how the term structure of interest rates in other countries can affect internal economic variables, corroborating the evidence found by Canova (2005), Taylor (2013), Edwards (2015), and Rey (2016), using a different technique and object of study. The comovements of these factors are crucial for understanding the impact of changes in short-, medium-, and long-term rates, given the transmission process necessary to affect sectors of the economy sensitive to long-term interest rates, such as housing, durable goods consumption and fixed investment. It also helps global investors to understand the interaction of sovereign bond markets.

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