The influence of global uncertainty and financial shocks and domestic sovereign risk shock on the term structure of interest rate and its components - the case of Brazil

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Resumo

Global shocks and sovereign risk shocks are responsible for a large fraction of the business cycle in emerging markets. Using Brazil as reference, we verify that such influence extends to the nominal term structure of the interest rate (TIR) and two of its components: real TIR and inflation risk premium (*IRP*). We estimate the size and relevance of this impact using a macrofinance SVAR model that includes nominal interest rates maturing in 1, 3 and 4 years, their components, domestic macroeconomic variables, and an exogenous bloc for the world economy. An adverse global uncertainty shock results in steeper nominal and real TIR by reducing shorter maturity rates, while the *IRP* is less responsive. A positive shock to the US 3 years T-Bond ($3yTBond$) moves nominal and real TIR upwards but reduces their slopes because of a smaller rise in longer maturity rates; the *IRP* TIR also moves upwards but becomes steeper. An adverse sovereign risk shock impacts nominal and real TIR, and the IRP TIR similarly, moving them upwards and augment their declivity. Global uncertainty shocks explain around 22% of the forecast error variance (FEV) for 1 year maturity real rate, but not much for longer maturities, nominal rates, and *IRP*. Shocks to $3yTBond$ explain around 25% of the FEV of nominal rates maturing in 1 and 3 years, and real rates maturing in 3 and 4 years, and around 30% of *IRP* at these maturities. Sovereign risk shocks contribute with about 18% of FEV of 3 and 4 years nominal and real rates, and similar magnitude for 4 years *IRP*.

Key words: Term structure of interest rate, inflation risk premium, sovereign risk, uncertainty, SVAR.

1 Introduction

Sovereign risk premium shocks and innovations arising at the world level are responsible for a large fraction of the business cycle in emerging economies. Fernández, González e Rodriguez 2018 estimate in 78% the joint contribution of these shocks for the variance of the unconditional forecast error of the real GDP of Brazil and Chile, and around 55% for Colombia. Estimations by Ferreira e Valério 2023 reach similar figures: 70%-84% the joint contribution of these innovations for the forecast error variance (FEV) of the real GDP of the same countries for 16 quarters ahead forecasts, and proportions above 50% for the CPI, nominal exchange rate, and monetary policy interest rate. With such an influence, one should expect global and sovereign risk shocks to also being important drivers of movements of the term structure of interest rate (TIR) in emerging countries and probably in small open economies in general.

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We conduct a unified analysis about the influence of shocks to sovereign risk, global economic uncertainty, and global finance on the nominal TIR and two of its components - real interest rate and inflation risk premium[1,2]. We study bonds maturing in 1, 3, and 4 years, providing a broader view of the joint impact on the short and middle part of the yield curve and its components at the business cycle frequency. We concentrate our analysis to Brazil, one of the largest emerging economies and with a very liquid and well-functioning primary and secondary markets for government bonds of various maturities.

Despite the intense interest in understanding the relation between TIR and macroeconomic variables, we are not aware of works that conduct a joint analysis about the influence of structural shocks on the macroeconomy, and on the nominal TIR and its components at various maturities. At the same time, very few papers focus on the impact of economically interpretable shocks in the movements of the yield curve, Moench e Soofi-Siavash 2022 being an exception that, differently from us, verify the movements in the US yield curve using factors from principal component analysis instead of evaluating the direct impacts on the yields. Another difference is that they analyze nominal yields and the term premium (which we do not consider), while we focus on the real part of the curve and on inflation risk premium. Evaluating responses and comovements for Brazil provides stylized facts about the importance of such structural shocks for the joint determination of financial and macroeconomic variables in small open economies and emerging countries in particular, shedding light on the channels through which they operate.

Given our interest in evaluating the dynamic responses at the business cycle frequency, we rely on structural vector autorregression (SVAR) to obtain impulse response functions (IRF) and to decompose the forecast error variance (FEV). Estimation is based on the bayesian approach developed by Zha 1999, which, among other things, is designed to accommodate the special case where there is a recursive exogenous block in the system, being very appropriate to model small open economies. In particular, we model the Brazilian economy incorporating a small macro-finance VAR structure for the world economy that can be thought as a small scale *global macro-finance VAR* where the external variables affect each other but are not influenced from any movement arising from the emerging economy. Setting this structure for the world economy is important to properly identify external shocks. As observed by Akinci 2013, innovations in global interest rate only modestly influence the business cycle of emerging economies after controlling for global financial risk factors. Along this line, Ferreira e Valério 2023 show that the contribution of the sovereign risk for the dynamics of macroeconomic and financial variables (Uribe e Yue 2006, Fernández, González e Rodriguez 2018, and Akinci 2013, among several others) needs to be filtered from the influence of global risk and other external shocks for a better measurement of its influence.

Our VAR also includes the following domestic macroeconomic variables commonly present in neokeynesian models of small open economies: sovereign spread, nominal exchange rate, CPI, GDP, and the monetary policy interest rate. From the pure macroeconometric point of view, these variables help filtering long run structural relations. From the macro-finance perspective, their presence allows a better understanding of the dynamic relation between TIR, its components and the macroeconomy, permitting comparisons to canonical no-arbitrage models that use macro variables as factors determining the price of risk.

Our structure is closer in spirit to the canonical no-arbitrage macro-finance models of Haubrich, Pennacchi e Ritchken 2012 and Hördahl, Tristani e Vestin 2006 in the sense that there is feedback between TIR and macroeconomic variables, including the monetary policy interest rate. This class of model is

[1] The difference between nominal and real term structure of the interest, known as break even inflation (*brei*), is normally decomposed in two parts: inflation risk premium and expected inflation. However, a more rigorous decomposition also allows the presence of another two components: liquidity risk premium and a convexity term due to Jensen's inequality. Vicente e Graminho 2015 show that these last two terms have a negligible contribution for the BREI of the Brazilian Federal Treasuries bonds. Joyce, Lildholdt e Sorensen 2010 reach similar conclusion for the UK.

[2] Since the nominal TIR is formed by three components - real interest rate, expected inflation, and the inflation risk premium - to avoid perfect multicolinearity the econometric model can only be estimated using the nominal TIR with two of its components.

extremely useful to characterize and explain long run relation between different moments of macro and financial variables. They also constitute an excellent framework to analyze the dynamic properties of jointly determined variables, with the important advantage that they allow for a more precise interpretation of the structural nature of the shocks. Hördahl, Tristani e Vestin 2006, for instance, analyze the impulse response of German macroeconomic variables and nominal yields of several maturities to macroeconomic shocks, which are mapped into yields through prices of risk. In their work for the USA, Haubrich, Pennacchi e Ritchken 2012 stablish stylized facts about the long run relation between nominal TIR and its components with volatility and macroeconomic factors (short run real interest rate, expected inflation and inflation's central tendency), without worrying about the dynamic responses to structural shocks. We focus on stablishing stylized facts about the dynamic relation between the term structure and its components with macroeconomic variables following global shocks and an innovation to the sovereign risk. We also care about measuring the importance of these perturbations for the forecast error variance.

The variables we extract these shocks from are easily qualified as exogenous to the TIR and to the macroeconomic variables of the model, especially at the business cycle frequency, minimizing the need to rely on factors. This exogenous nature also allows for a simpler and more direct structure for studying the variables of our interest if compared to other empirical models in which this exogeneity is harder to stablish. For instance, Moench e Soofi-Siavash 2022 develop a denser dynamic factor model to study shocks directly applied to the yield curve, which they operate through innovations in the factors and in the part of the yields not explained by the first two principal components of the nominal yield curve. Perturbating these factors minimize the potential problem of having to stablish precedence between various forward looking financial variables that tends to simultaneously react to news. But even in this case, it is not so trivial to stablish precedence between factors, and less so to economically interpret the innovations.

In our case, the VAR structure using variables normally incorporated in canonical macro-finance models and in DSGE models of small open economies suffices to our goals, and the shocks we identify can still be interpreted as structural innovations to prices of risk that affect yields.

Our work also dialogues with the literature aimed at differentiating between economic uncertainty and financial shocks, which is not a trivial task since these innovations tend to be extracted from high frequency forward looking financial series, making difficult to stablish precedence especially when working with monthly or quarterly averages of daily observations. In the context of SVAR, Popescu e Smets 2010 and Caldara et al. 2016 are important references, with the identification strategy of the first being closer to ours as they also rely on traditional zero restriction and place the proxy for uncertainty preceding a measure of financial tightening in a model that also contains other macroeconomic variables. Caldara et al. 2016 disentangle uncertainty and financial shocks in a SVAR using a different identification approach that allows both shocks to produce a contemporaneous impact on each other[3]. Apart from methodology, and strictly concerning the differentiation between uncertainty and financial shocks, an important difference with our work is related to the variable from which we identify financial shock. Popescu e Smets 2010 use a measure of financial risk premia in their study for the business cycle in Germany, while Caldara et al. 2016 use US corporate bond credit spreads[4]. We rely on the 3 years US T-Bond ($3yTBond$), which is not a direct measure of financial squeeze, but impacts on the tightening condition of the financial and credit market. We see $3yTBond$ being able to identify shocks of broader economic meaning that ultimately represents innovations to financial conditions through its direct impact on the term structure of interest rate in the US. As an example, a shock characterized by an adverse news about the inflation can be captured by a sudden augment of $3yTBond$[5], which tends to provoke a rise in

3 The identification strategy of Caldara et al. 2016 rely on the penalty function approach (see Faust 1998 and Uhlig 2005). The identification of uncertainty and financial shocks uses the criterion that each shock should maximize the impulse response of its respective target variable over a pre-specified horizon.

4 Specifically, they use the excess bond premium (EBP) of Gilchrist and Zakrajˇsek (2012), which is an estimate of premium beyond the compensation for expected losses demanded by bond investors for bearing exposure to U.S. nonfinancial corporate credit risk.

5 This highten could arise not only because of the rise in the expected inflation component of the $3yTBond$, but also because

the rates charged at the credit market and in the discounting rate of cash flows. In the context of our study, aimed at verifying the impact of global shocks in an emerging economy, $3yTBond$ also allows a direct communication with the literature about the influence of changes in global interest rates in the business cycle and financial conditions of emerging economies, where interest parity play a central role.

Despite some differences, we are still able to extend comparisons to some results reported by Popescu e Smets 2010 and Caldara et al. 2016. A positive (in terms of sign) shock applied to $3yTBond$ leads to higher volatility, which is a similar response following an adverse shock to their measure of financial condition. Comparing the responses following an adverse uncertainty shock is less straightforward but still possible. They observe a rise in their measures of premium and spread, while we verify a drop in $3yTBond$, which is compatible with an expected drop in future policy rate to counteract the tightening reported by Popescu e Smets 2010 and Caldara et al. 2016 amid an environment of higher uncertainty. For robustness, we check the joint responses of VIX, $3yTBond$ and the macro-finance structure of the Brazilian economy to an alternative ordering and verify that the reactions are not economically compatible with the structural innovations we intend to identify.

It is common to derive the components of the nominal term structure endogenously from the equilibrium conditions of no-arbitrage models, as Iania, Lyrio e Moura 2021 do in their analysis for Brazil. We follow Haubrich, Pennacchi e Ritchken 2012 and Joyce, Lildholdt e Sorensen 2010[6] and rely on observables about nominal and real TIR to obtain the inflation risk premium after using a survey on expected inflation, providing the sufficient information to analyze the joint responses across components and maturities. As such, the impulse response function and the decomposition of the FEV ultimately incorporate risk perceptions and prices in which arbitrage opportunities across maturities are also likely to be absent.

Brazil

Several authors analyze the relation between macroeconomics and the Brazilian TIR. Most of them consider the influence of macroeconomic and financial variables without jointly considering the components of the TIR. Interestingly, great attention is devoted to the break even inflation ($BREI$) and to the inflation risk premium. Most papers evaluate conditioned correlation without focusing on the impact of structural shocks. When impulse response functions are analyzed, another major trend is not to consider a general equilibrium perspective, which is another reason why structural shocks are normally not identified, limiting the understanding of the relation between the cyclical evolution of the macroeconomy, the term structure and its components.

We find Iania, Lyrio e Moura 2021 to be a reference closer to ours in the sense that they also evaluate the influence of domestic and global shocks using a macro-finance structure. Our works distinguish in important dimensions. In terms of scope, we conduct a joint analysis of the responses of nominal and real TIR and the inflation risk premium, while their focus is on the risk premia of the nominal TIR. Methodologically, they rely on a no-arbitrage model that incorporates global and domestic macroeconomic factors responsible for driving the dynamics, but without stablishing a structure in which global and domestic macroeconomic variables connect to each other, limiting the understanding of the relation between macro (factors) and financial variables and the economic interpretation of the shocks they analyze. These are important dimensions of our work, as we intend to characterize the relation between forward looking financial variables with the underlying macroeconomic fundamentals responsible for their pricing at the business cycle frequency.

market participants may anticipate a rise in the real rate component of the 3 years TBond under the expectation that the monetary authority may have to fight inflation.

[6] Haubrich, Pennacchi e Ritchken 2012 use nominal yields together with surveys on expected inflation and inflation swap rates (from where they obtain a measure of inflation risk premium) to infer on the term structure of real interest rate. Joyce, Lildholdt e Sorensen 2010 also rely on observables about nominal and real TIR and a survey about expected inflation to obtain the inflation risk premium to estimate a no-arbitrage model for the UK.

Fernandes e Thiele 2015, like us, use a pure econometric approach to also verify the relation between local and global macroeconomic variables with the term structure of BREI. Their results inform about the conditioned correlation between BREI and controls, but do not allow inference on the reactions to structural shocks. As an example, they consider the impact of local sovereign risk, but do not filter away the influence exerted by global factors on the Brazilian sovereign risk.

Reis 2018, Montes e Curi 2017, and Vicente e Graminho 2015 analyze the relation between inflation risk premium and uncertainty of different sources. Reis 2018 encounters a positive relation between the CDS on the Brazilian government nominal bonds and inflation risk premium from 1 to 10 years maturity[7]. Montes e Curi 2017 observe a positive correlation between inflation risk premium and fiscal uncertainty measured as difference in expectations regarding future public debt; and also find a positive correlation between inflation risk premium and uncertainty about the conduct of the monetary policy (or credibility of the monetary followed by the Brazilian Central Bank), which they measure as the deviation between the inflation target determined by the National Monetary Council and expected inflation[8]. Vicente e Graminho 2015 verify a positive relation between inflation risk premium and domestic economic uncertainty (proxied by the local stock market volatility)[9].

These works verify the relation between inflation risk premium with uncertainty of different sources and other macroeconomic variables, but their framework does not enable the understanding of the drivers and channels that jointly determine the pricing of the inflation risk premium and the macroeconomy. We advance in both dimensions since we evaluate responses to exogenous shocks using an econometric structure that easily communicates to a general equilibrium model and allows a structural interpretation of the shocks. Furthermore, our model does not evaluate only the inflation risk premium, but also considers its joint evolution with the nominal and real term structure, providing a broader perspective about the relation between the components of the term structure at different maturities and the macroeconomy.

Besides this introduction, the paper is divided as following. We discuss the data in the next section, explaining in detail the procedure used to decompose the nominal term structure of interest rate into its components. In section 3 we explain the econometric methodology and the restrictions used to accommodate the small open economy hypothesis and to identify the SVAR. The analyses of the impulse response functions are presented in section 4, while the decomposition of the forecast error variance is analyzed section 5. Section 6 concludes.

2 Data

We start by discussing the variables related to the term structure, then moving to global and domestic macroecomic variables.

2.1 The term structure of the interest rate

We use nominal and real term structure of interest rate estimated daily by the Brazilian Association of the Entities in the Capital and Financial Market (in Portuguese, Associação Brasileira das Entidades dos Mercados Financeiro e de Capitais, or simply ANBIMA)[10] according to the model of Svensson 1994. The data used in the estimation correspond to real and nominal future rates on government securities traded in the secondary market.

7 Reis 2018 also encounters a positive but non-significant relation between inflation risk premium and output gap.

8 The Brazilian National Monetary Council determines with at least three years in advance the inflation the Central Bank should target in a certain year.

9 They also verify a negative relation between inflation risk premium and the covariance between consumption variation and future inflation, although significance is detected only at 3 and 4 years horizon. According to consumer based asset pricing models, what we define as inflation risk premium corresponds to the covariance between expected variation in consumption and expected inflation. Negative covariance indicates high inflation in states of nature also associated with smaller consumption, causing consumers to ask for a premium to hold nominal bonds as a compensation for the risk.

10 ANBIMA gently made available the term structure they estimate from September/21/2009 to June/18/2018 together with the parameters and estimated coefficients of the Svensson's model.

Nominal rates and prices come from two different securities: Letras do Tesouro Nacional (LTN), a nominal zero-coupon bond, and Notas do Tesouro Nacional série F (NTN-F), which pays coupon every semester but has its price adjusted to eliminate the effect of the coupon from the prices. The term structure of real interest rate uses information of the secondary market for the Notas do Tesouro Nacional - série B (NTN-B), which is an inflation protected government security that pays the inflation accrued until the maturity plus a real yield known at the time the bond is acquired[11].

Let $r^N_{t,\tau}$ and $r^R_{t,\tau}$ represent, respectively, the nominal and the real rates paid by a bond bought at time t and maturing τ years ahead. We consider $\tau = 1,3,4$, or 12, 36 and 48 months ahead, respectively. The break even inflation (*brei*) is defined as $\pi^{brei}_{t,\tau} = r^N_{t,\tau} - r^R_{t,\tau}$ and we assume $\pi^{brei}_{t,\tau}$ to be formed by two components: $\pi^{exp}_{t,\tau}$, the time t expected inflation accumulated in the 12 months up to τ; and $irp_{t,\tau}$, the inflation risk premium evaluated at time t[12]. It follows that $\pi^{brei}_{t,\tau} = \pi^{exp}_{t,\tau} + irp_{t,\tau}$.

We observe $r^N_{t,\tau}$, $r^R_{t,\tau}$, and, therefore, $\pi^{brei}_{t,\tau}$. We do not observe the inflation risk premium, which is obtained as a residual after using the expected inflation survey conducted by the Brazilian Central Bank (BCB). Every business day the BCB applies a survey with around 130 professionals of consulting firms, banks and asset management firms asking their expectations about macroeconomic variables. Expected inflation is informed for each of the next 18 months and also for the accumulated rate at the end of the next years. Our measure of expected inflation evaluated at a particular month t is constructed by averaging daily median expectations reported during the month[13]. Since we do not have forecasts for each month of the next 4 years, we adopt the following interpolation rule that already considers the fact that we work with $\tau = 1,3,4$ years:

$$\pi^{exp}_{t,\tau} = \begin{cases} 100 \times [\Pi^{11}_{i=0}(1+\pi^s_{t+i}) - 1] & \text{if} \quad t \neq 1 \quad \text{and} \quad \tau = 1 \\ 100 \times [(1+\pi^s_{t,\tau})^{\frac{13-t}{12}}(1+\pi^s_{t,\tau+1})^{\frac{t-1}{12}} - 1] & \text{if} \quad t \neq 1 \quad \text{and} \quad \tau = 3,4 \\ \pi^s_{t,\tau} & \text{if} \quad t = 1 \quad \text{and} \quad \tau = 1,3,4 \end{cases}$$

where the superscript s refers to rates directly observed from the surveys, and $t = 1,2,...,12$ correspond to months of the year, with $t = 1$ being January, $t = 2$ February, and so long.

Our interest in evaluating the responses in the short and middle part of the yield curve justifies working with 1, 3, and 4 years maturity. Another reason for this limit is the absence of surveys about expected inflation for longer maturities[14]. We could incorporate 2 years maturity in the study, but this would substantially increase the number of covariates in each equation, reducing the degrees of freedom in a system that already counts with a high number of variables, as it will become clear later.

Figure 1 shows the evolution of nominal rates, real rates, break even inflation, expected inflation, and inflation risk premium for $\tau = 1,3,4$. Longer maturity yields are normally higher, a common pattern that is related to the larger premium charged to hold assets expiring at longer maturities. It is however worth observing that the difference between 3 and 4 years rates is very small and even negligible in some months, suggesting that the term premium embedded in bonds of these maturities is already very similar.

All graphs present a spike in 2015-2016, years in which Brazil lost the investment grade status according to the three major risk agencies (Fitch, Moody's, and Standard and Poor's), amid an uncontrolled

[11] The inflation rate that indexes the NTN-B is the consumer price index (IPCA), the reference index for the Brazilian inflation target regime.

[12] A more rigorous approach would also allow for the presence of a convexity term due to Jensen's inequality and a liquidity premium in the formation of *brei*. However, previous studies for Brazil (Vicente e Graminho 2015) and other countries (Joyce, Lildholdt e Sorensen 2010 for UK, and Ang, Bekaert e Wei 2008 for USA) verify that these terms are negligible.

[13] Caldeira e Furlani 2013, Vicente e Graminho 2015, and Mariani e Laurini 2017 show that the median of the inflation forecasts is a good predictor of future inflation.

[14] One could circumvent this limitation by extrapolating after fitting a term structure of expected inflation relying on the Svensson model or any other suitable for this goal. This would require, however, extrapolating for a very long range from the last observed maturity, substantially elevating the imprecision of the estimates about expected inflation.

increase in the public debt and high fiscal deficits. During this period the break even inflation increased substantially to values close to 9% (despite of an inflation target of 4.5%) with the IRP going close to 5%.

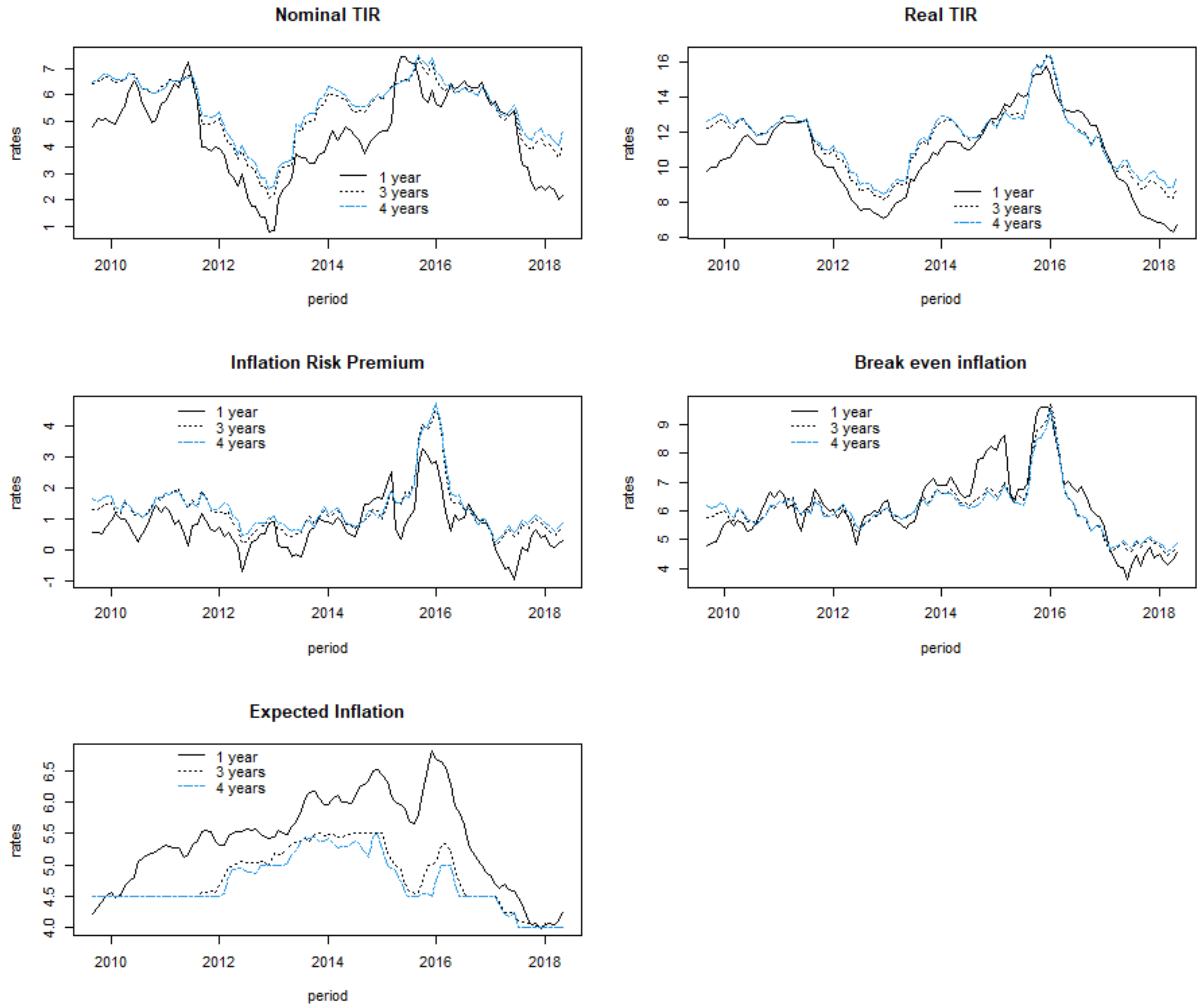

Figura 1 – Nominal interest rate and its components for contracts maturing in 1, 3, and 4 years. Sources: *Central Bank of Brazil* for the raw data on expected inflation, which was further adapted to obtain values for 3 and 4 years ahead expectation regardless of the month of the year the Central Bank survey was conducted. *ANBIMA* for nominal and real interest rates, obtained after applying the Svensson 1994 model to yields on securities of the Brazilian Treasury. Break even inflation equals the nominal rate minus the real rate, and the inflation risk premium is the break even inflation minus the expected inflation.

Table 1 shows the variances of r_τ^N, r_τ^R, π_τ^{brei}, irp_τ, and π_τ^{exp} for $\tau = 1,3,4$. The variance of the inflation risk premium is the only that increases with maturity, which is an expected pattern from a risk measure. The remaining variances fall with maturity, maybe because there is higher uncertainty regarding short run adjustments following shocks compared to more confidence on the fundamentals that determine these variables in the medium run.

Tabela 1 – Variance of the term structure and its components.

Maturity (τ)	r_τ^N	r_τ^R	π_τ^{brei}	irp_τ	π_τ^{exp}
1	5.592	2.683	1.668	0.581	0.518
3	3.614	1.567	0.943	0.682	0.216
4	3.120	1.333	0.787	0.653	0.175

2.2 The other variables

We include variables from which we intend to identify shocks or that synthesize the macroeconomic structure of the economy, which correspond in a large extent to fundamentals that determine the nominal TIR and its components. From *macroeconomic structure of the economy* we mean variables that are normally used in standard DSGE models of a small open emerging economy.

In the domestic macroeconomic block, we include the Emerging Markets Bond Index for Brazil (EMBI BR+), computed by the investment bank JP Morgan Chase, as our proxy for sovereign risk[15]. The EMBI BR+ (or *BR.RISK* hereafter) is reported in terms of excess basis points charged by investors in the secondary market to hold dollar denominated sovereign Brazilian bond issued in the international market. We work with monthly averages of daily information available at *www.ipeadata.gov.br*. The nominal exchange rate of the Brazilian Real against the US dollar ($FOREX$) is included because its response to shocks is ultimately passed through to domestic prices. We use the consumer price index IPCA (P), computed by the Brazilian Institute of Geography and Statistics (IBGE), because it is the reference index for the inflation target regime in Brazil. We include the Brazilian Activity Index (IBC-Br) computed by the Central Bank of Brazil as a proxy for the monthly GDP, which is only available in a quarterly frequency. This index intends to track the country's GDP after compiling information from monthly surveys of several economic indicators. Finally, we incorporate the Brazilian monetary policy interest rate (SELIC). Besides of its relevance for the broad picture about the short run dynamics of the economy, its presence allows a comparison with the movements in the TIR, since SELIC indexes several public securities from which we obtain the term structure. We compute monthly average for SELIC (r^{cb} hereafter) using the daily rates available at *www.ipeadata.gov.br*.

From the global economy we use the volatility index VIX as a proxy for global economic uncertainty. The time series is available at the Chicago Board of Options and Exchange (CBOE) in a daily frequency from which we construct monthly averages. We also include the 3 years US-Tbond ($3yTBond$) as a proxy for perspectives about global monetary policy and from which we identify a global financial shock. We comment more about the economic interpretation of such shock when analyzing the impulse response functions. The evolution of all these series can be assessed in figure 2.

3 The Econometric Methodology

We evaluate the responses to shocks using coefficients from a structural vector autoregressive (SVAR) model that can be represented by the following equation:

$$AX_t = B_0 + \sum_{h=1}^{p} B_h X_{t-h} + \varepsilon_t \tag{1}$$

where t is a time index; X_t is an $n \times 1$ column vector formed by all n endogenous variables; ε_t is also a column vector containing n structural shocks; A is an $n \times n$ matrix containing the instantaneous impact

[15] The relevance of sovereign risk for the business cycle and the pricing of assets is not confined to emerging economies. Itskhoki e Mukhin 2021 find important impact in real and financial variables of developed economies when using an open economy new-keyneisan DSGE model. They show that several exchange rates puzzles (disconnects) are only reconcile when sovereign risk shocks are taken into consideration.

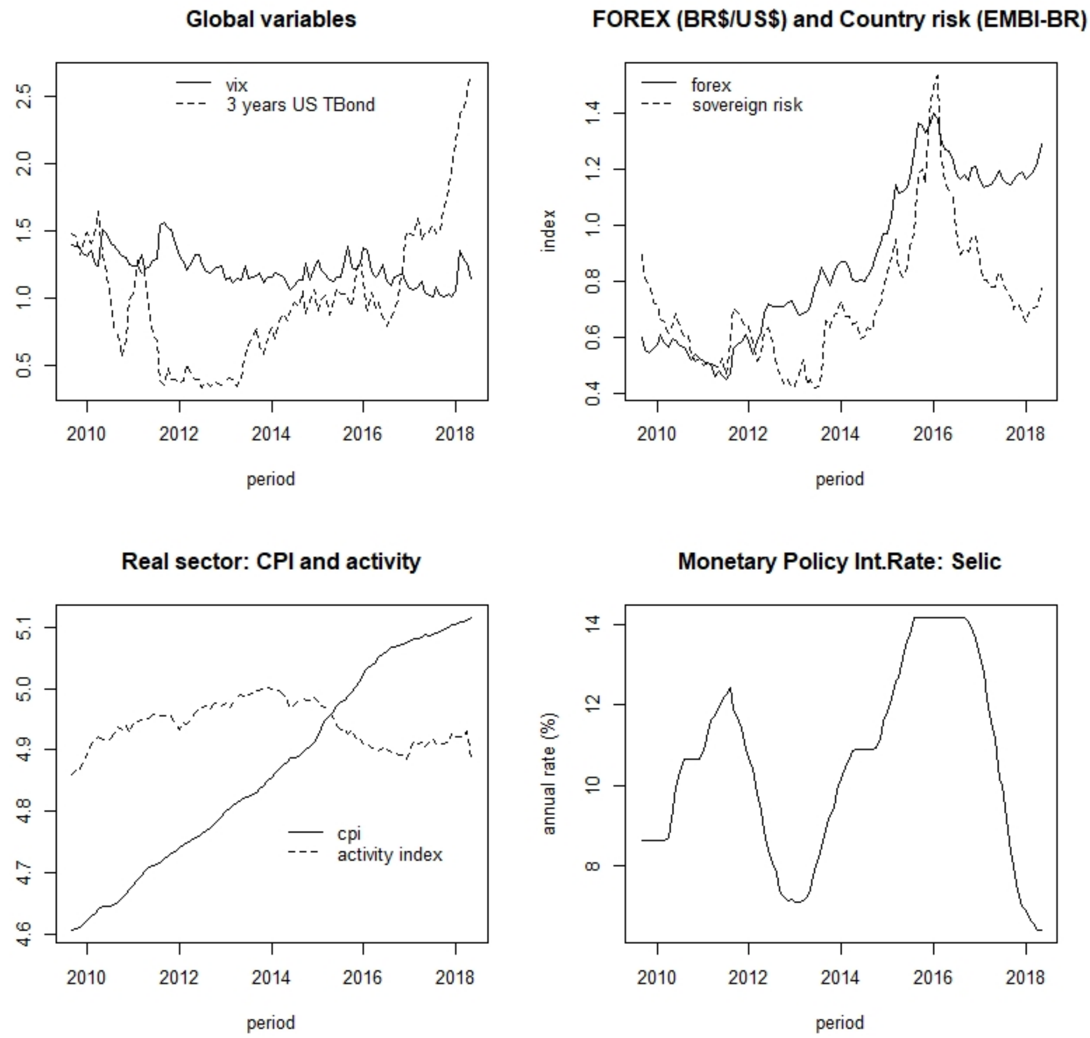

Figura 2 – Global and domestic macroeconomic variables used in the estimation: Sept/2009 - May/2018. Sources: CBOE for daily VIX; FRED - FED Saint Louise for the monthly US 3 years T-Bond; IPEADATA for daily $EMBI-BR$; Brazilian Institute of Geography and Statistics for the CPI, which is actually the IPCA in Portuguese; Central Bank of Brazil for the activity seasonally adjusted index (IBC-BR) and for daily values of the SELIC, which is the Brazilian monetary authority policy rate.

coefficients; B_0 is a $n \times 1$ column vector of intercepts; B_h is an $n \times n$ matrix of autoregressive coefficients; and p is the autoregressive order. The structural shocks are assumed to be independent and identically distributed: $\varepsilon_{it}\varepsilon_{it}^{'} \sim iid(\mathbf{0}; \sigma_i^2 I_n)$, for $i = 1, ..., n$. Pre-multiplying both sides of equation 1 by A^{-1} results in the reduced VAR:

$$X_t = \Phi_0 + \sum_{h=1}^{p} \Phi_h X_{t-h} + e_t \tag{2}$$

where $e_t = A^{-1}\varepsilon_t$, $\Phi_0 = A^{-1}B_0$ and $\Phi_h = A^{-1}B_h$ for $h = 0, 1, \cdots p$. Because we estimate the reduced form, it is required to impose restrictions to identify the structural coefficients and shocks. Our identification strategy is shown next.

3.1 An Empirical Macrofinance Model for Brazil

The structure of vector X is $X = [vix, 3yTBill, br.risk, r_1^R, irp_1, r_1^N, r_3^R, irp_3, r_3^N, r_4^R, irp_4, r_4^N, fx, y, p, r^{cb}]'$[16], where vix, $br.risk$, fx, y and p are natural logarithm of their capital letter counterparts. Since $n = 16$, the dimension of X, Φ_0, and e_t is 16×1, while A, B_h, and Φ_h are 16×16.

Lag Restrictions

We acknowledge the small open economy status of Brazil by imposing zero restrictions on the reduced form VAR to avoid domestic variables from affecting the dynamics of the international variables vix and $3yTBill$. This is accomplished by setting $\Phi_{h,ij} = 0$ for $i = 1, 2,\ j \geq 3$, for all h, where i represents a line and j a column. This restriction means that the international variables form an exogenous block that affects the entire system but are not impacted by the variables from the small economy. This structure justifies our use of the bayesian VAR procedure developed by Zha 1999, designed to consider situations where there is block exogeneity[17].

We impose an additional restriction on the lag structure of the reduced VAR: $\Phi_{h,3j} = 0$, for $j \geq 4$. This guarantees absence of a feedback from the other domestic variables to the sovereign risk ($br.risk$). Since we do not include the set of domestic variables that ultimately determine debt sustainability, feed backs from other variables to sovereign risk would most likely capture a reverse causality influenced by the high correlation between real and financial variables with the sovereign risk.[18]

Impact Restrictions

Our identification strategy of the structural parameters is achieved by imposing zero restrictions on the impact matrix A as follows:

$$A = \begin{array}{cc} & \begin{matrix} \varepsilon^{vix} & \varepsilon^{3yTBill} & \varepsilon^{br.risk} & \varepsilon^{r_1^R} & \varepsilon^{irp_1} & \varepsilon^{r_1^N} & \varepsilon^{r_3^R} & \varepsilon^{irp_3} & \varepsilon^{r_3^N} & \varepsilon^{r_4^R} & \varepsilon^{irp_4} & \varepsilon^{r_4^N} & \varepsilon^{fx} & \varepsilon^{y} & \varepsilon^{p} & \varepsilon^{r^{cb}} \end{matrix} \\ \begin{matrix} vix \\ 3yTbill \\ br.risk \\ r_1^R \\ irp_1 \\ r_1^N \\ r_3^R \\ irp_3 \\ r_3^N \\ r_4^R \\ irp_4 \\ r_4^N \\ fx \\ y \\ p \\ r^{cb} \end{matrix} & \begin{bmatrix}
a_{1,1} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
a_{2,1} & a_{2,2} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
a_{3,1} & a_{3,2} & a_{3,3} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
a_{4,1} & a_{4,2} & a_{4,3} & a_{4,4} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
a_{5,1} & a_{5,2} & a_{5,3} & a_{5,4} & a_{5,5} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
a_{6,1} & a_{6,2} & a_{6,3} & a_{6,4} & a_{6,5} & a_{6,6} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
a_{7,1} & a_{7,2} & a_{7,3} & a_{7,4} & a_{7,5} & a_{7,6} & a_{7,7} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
a_{8,1} & a_{8,2} & a_{8,3} & a_{8,4} & a_{8,5} & a_{8,6} & a_{8,7} & a_{8,8} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
a_{9,1} & a_{9,2} & a_{9,3} & a_{9,4} & a_{9,5} & a_{9,6} & a_{9,7} & a_{9,8} & a_{9,9} & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
a_{10,1} & a_{10,2} & a_{10,3} & a_{10,4} & a_{10,5} & a_{10,6} & a_{10,7} & a_{10,8} & a_{10,9} & a_{10,10} & 0 & 0 & 0 & 0 & 0 & 0 \\
a_{11,1} & a_{11,2} & a_{11,3} & a_{11,4} & a_{11,5} & a_{11,6} & a_{11,7} & a_{11,8} & a_{11,9} & a_{11,10} & a_{11,11} & 0 & 0 & 0 & 0 & 0 \\
a_{12,1} & a_{12,2} & a_{12,3} & a_{12,4} & a_{12,5} & a_{12,6} & a_{12,7} & a_{12,8} & a_{12,9} & a_{12,10} & a_{12,11} & a_{12,12} & 0 & 0 & 0 & 0 \\
a_{13,1} & a_{13,2} & a_{13,3} & a_{13,4} & a_{13,5} & a_{13,6} & a_{13,7} & a_{13,8} & a_{13,9} & a_{13,10} & a_{13,11} & a_{13,12} & a_{13,13} & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & a_{14,14} & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & a_{15,14} & a_{15,15} & 0 \\
a_{16,1} & a_{16,2} & a_{16,3} & a_{16,4} & a_{16,5} & a_{16,6} & a_{16,7} & a_{16,8} & a_{16,9} & a_{16,10} & a_{16,11} & a_{16,12} & a_{16,13} & a_{16,14} & a_{16,15} & a_{16,16}
\end{bmatrix} \end{array}$$

At the top of each column, we refer to shock ε^j that takes the same name of the variable from which the reduced form residual e is decomposed. Each line of matrix A corresponds to one equation, so $a_{i,j}$ indicates the contemporaneous impact of the shock ε^j on the variable situated in line i. Zeroes imply that the shock ε^j does not contemporaneously impact the variable in that specific line. Our interest is to analyze the responses to international shocks ε^{vix} and $\varepsilon^{3yTBill}$ and to domestic sovereign risk premium shock $\varepsilon^{br.embi}$.

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16 Vectors with similar structure are used in other works. For instance, Haubrich, Pennacchi e Ritchken 2012 include a measure of short run real interest rate, inflation expectation and a measure of inflation's central tendency together with the US nominal TIR of several maturities and their components.

17 Cushman e Zha 1997 use similar econometric methodology to identify the impact of monetary policy shocks in Canada after controlling for the influence of the US policies and variables, which form an exogenous block.

18 In the context of the Brazilian economy, Lowenkron e Garcia 2007 also assume strong exogeneity of EMBI-BR that functions as a price of risk in a no-arbitrage model intended to discuss the relation between inflation risk premium and monetary policy. Ferreira e Valério 2023 also imposes similar restriction in VARs for Brazil, Chile, Colombia, and Peru.

The zeroes starting at the third column of the first two rows capture the notion that shocks arising from the small open economy do not affect external variables. In the international block, we consider a recursive structure in which ε^{vix} affects contemporaneously vix and $3yTbill$. Since the first measures the implied volatility in the options of the S&P500, it reflects doubts regarding future prices of the companies listed in the index, which ultimately indicates uncertainties about the future of the economy. This is one reason why vix (or the vox[19]) has been extensively used as a proxy for economic uncertainty since Bloom 2009 and why we intend to interpret ε^{vix} as a global economic uncertainty shock. Furthermore, we think of $\varepsilon^{3yTbill}$ being determined by innovations in one of the components of the nominal rate - real rate, expected inflation or inflation risk premium - and that $3yTbill$ should be more responsive to news of different sources than vix, since most shocks affecting prices, economic activity or the stability of the financial system encounter a response from the Federal Reserve, which tends to be priced by futures of nominal rates.

Despite our preference, we acknowledge that determining the appropriate ordering to identify uncertainty and financial shocks together is not a trivial task, since both are extracted from "fast moving"financial variables, being difficult to stablish precedence. This trouble is exacerbated when working with monthly averages from daily observation. In the literature, Popescu e Smets 2010 also place their proxy for uncertainty before a measure of financial risk premia in a SVAR for the Germany economy. Caldara et al. 2016 disentangle uncertainty and financial shocks in a SVAR using a different identification approach that allows both shocks to produce a contemporaneous impact on each other[20]. Regardless of the methodology, common results are obtained, which may serve as a guide when confronting an alternative ordering: an adverse uncertainty shock results in more volatility and in the tightening of the financial conditions, while adverse financial shocks elevate restrictions in the financial market and heighten the uncertainty. Both innovations deteriorate economic activity.

Given the challenge to identify uncertainty and financial shocks, we also estimate a SVAR with a recursive structure different from the one just proposed, so $3yTbill$ would come first. Our decision on which strategy makes more sense is based on the economic interpretation of the responses generated by each ordering. Anticipating, placing vix prior to $3yTbill$ generates responses more compatible with uncertainty and financial shock[21], but we explain these results later when analyzing the impulse response functions.

Regardless the ordering in the international block, we allow ε^{vix} and $\varepsilon^{3yTbill}$ to instantaneously affect all domestic financial variables. Since we work with monthly frequency data, it is unlikely that economic activity (y) and the consumer price index (p) contemporaneously react to the financial shocks we consider. For the same reason, none of the shocks arising at the domestic financial sector is allowed to instantaneously influence y and p, the reason why there are zeros in the lines associated with both variables in matrix A. We allow the policy interest rate r^{cb} to react on impact to any shock under the argument that the Central Bank board and its high staff continuously monitor market conditions to which they could react to[22]. This justifies non-zeroes in the last line of matrix A.

The innovation $\varepsilon^{br.risk}$ is traditionally referred to as a sovereign risk premium shock, which can

19 vox is similar to vix, but it is based on the implied volatility of options of the S&P100 and it is available since the 1980s.

20 The identification strategy of Caldara et al. 2016 rely on the penalty function approach (see Faust 1998 and Uhlig 2005). In the context of their SVAR, the identification of uncertainty and financial shocks uses the criterion that each shock should maximize the impulse response of its respective target variable over a pre-specified horizon.

21 Although an alternative ordering of the international variables affects the economic meaning of the shocks and their contribution to explain the FEV, the joint contribution of global shocks to explain domestic FEV is not affected. Nevertheless, the identification strategy should be cautiously designed for interpretation purposes. For instance, Ferreira e Valério 2023 show that a VAR identified with a global commodity price index prior to VIX (which is the approach adopted by Iania, Lyrio e Moura 2021) does not produce economic sensible impulse response functions: a sudden rise in prices, normally viewed as an adverse supply shock, reduces the VIX; and an unanticipated fall in VIX, normally interpreted as a reduction in uncertainty, causes the commodity price index do fall.

22 In their analysis of the Canadian economy, Cushman e Zha 1997 also justify the possibility of an instantaneously move of the policy rates based on the assumption that central bankers follow almost in real time the evolution of international and domestic variables.

represent reactions to news that affect the perception on the ability of the Brazilian Treasury to meet its financial obligations in the future without having to incur in some form of default, which includes inflation (a partial default). Some examples we have in mind: news about election pools; debates in the national parliament over subjects that may impact the dynamic of the public debt; the announcement of policies with similar impact, or signals arising from any of the three powers that would ultimately affect the perspectives about the debt trajectory or even the proper management of other macroeconomic policies, which may include institutional matters. We allow $\varepsilon^{br.risk}$ to affect all domestic financial variables and the policy rate instantaneously, but not the domestic real sector variables (y and p).

Interesting to observe that ε^{vix}, $\varepsilon^{3yTbill}$, and $\varepsilon^{br.risk}$ may be thought as shocks to prices of risk of different sources affecting the term structure, in the spirit of no-arbitrage affine macro-finance models like that of Hördahl, Tristani e Vestin 2006 and others, except that in our case vix, $3yTbill$, and $br.risk$ are totally exogenous from the evolution of the term structure of the interest rate. The remaining domestic macroeconomic variables can also be interpreted as prices of risk, but in their case a feedback is allowed with the term structure, as in Hördahl, Tristani e Vestin 2006.

Since it is not our goal to study other shocks, the identification strategy just discussed suffices to our analyses, especially because it does not seem economically reasonable other strategies that would place any of the remaining variables of our system before vix, $3yTbill$, or $br.risk$.

4 Results - Impulse Response Functions

This section reports the impulse response functions and their interpretation, starting with the impact of global shocks and then moving to sovereign risk shock. The VAR is estimated with six lags ($p = 6$), which is sufficient to whiten the residuals and to filter any seasonality in the TIR that could eventually occur from a flawed extraction of the coupon from the prices[23]. We use the same priors proposed by Sims e Zha 1998 and Zha 1999, which are designed for cases where non-stationary variables are present in the VAR. Further details are in appendix 1.

4.1 Global Shocks

We start discussing the impact of global shocks in the international macro-finance structure of our model, then we analyze their influence on the macroeconomic variables before discussing the reactions of the term structure.

Response of the International Bloc

The first two columns of Figure 3 show responses following the international shocks ε^{vix} and $\varepsilon^{3YTBill}$, respectively. The first two lines bring the responses of vix and $3YTBill$, in this order.

[23] For the sake of keeping a shorter length for this article, we do not report the statistics about the residuals, which we are glad to provide upon request.

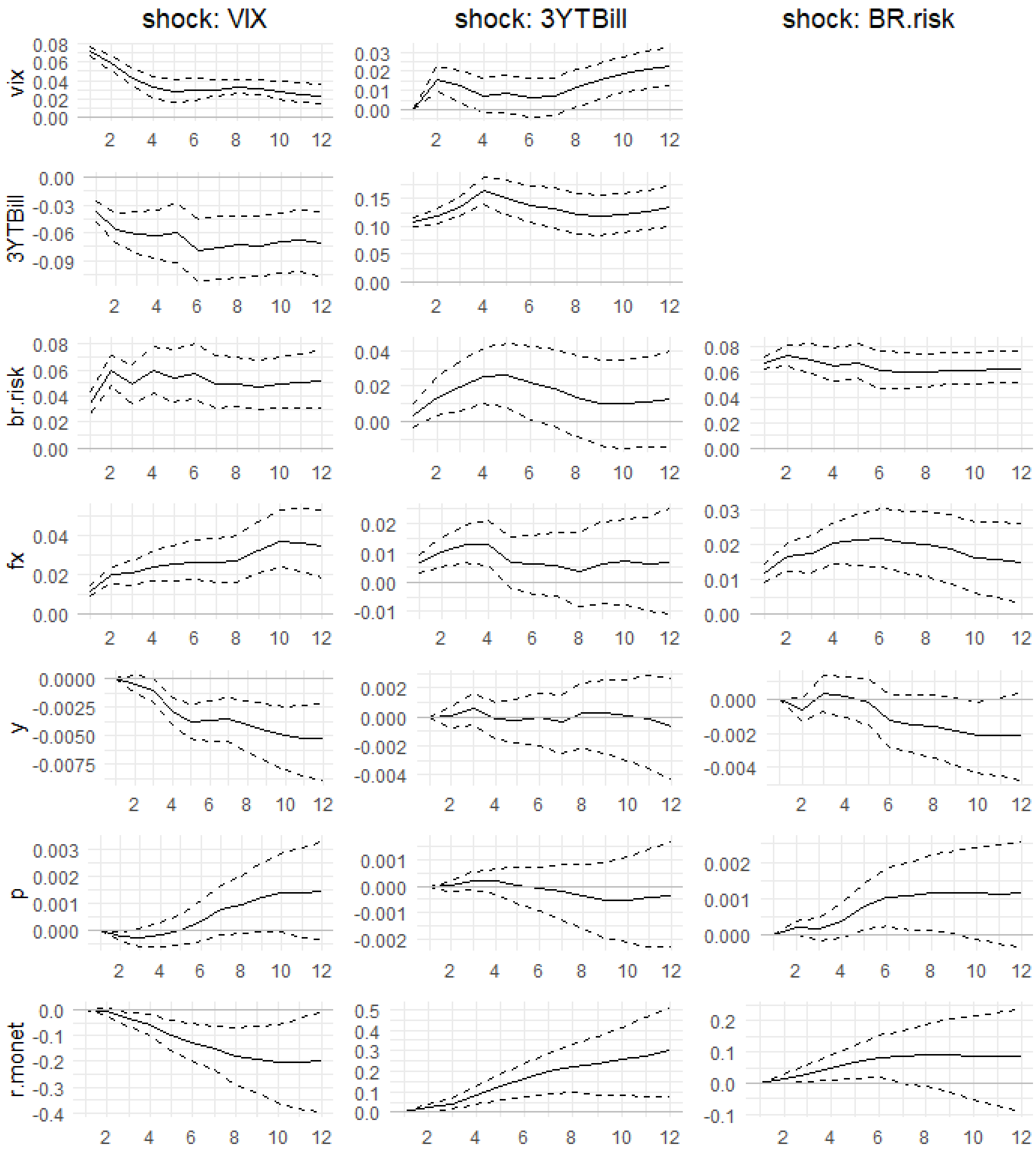

Figura 3 – Impulse response functions. Dashed lines represent the 68% confidence interval.

An unexpected 1 standard deviation rise in ε^{vix} (approximately 8.5%) elevates the market volatility and causes an immediate 3bps drop in the $3yTBill$, as if market participants expected the FED to set nominal rates below pre-shock level the future. These reactions seem consistent with a positive ε^{vix} being interpreted as an adverse uncertainty shock of similar nature as that of the 2008/09 financial crisis, which led the FED to reduce its policy rate to values close to zero amid a recession and freezing of the financial market. A complementary view is that agents increase the purchase of US Treasury securities in search for protection, moving their prices up and returns down.

An unexpected 1 standard deviation rise in $\varepsilon^{3YTBill}$ (which is equal to 0.1 or 10 basis points) causes $3YTBill$ to increase and to persistently remains above pre-shock level during the first year following the shock. The volatility index raises probably reflecting higher uncertainty about future monetary policy, a response consistent with $\varepsilon^{3YTBill}$ being interpreted as an innovation caused by news that lead market participants to expect a contractionary policy by the FED. Considering the reactions of the Brazilian economy (in the next subsection) and the results of Ang, Bekaert e Wei 2008 showing that 80% of the unconditional variance of the 3 months nominal rate of the US government bond and 71% of the 5 years is explained by expected inflation[24], an adverse shock to expected inflation is likely the most appropriate interpretation for the augment in $\varepsilon^{3YTBill}$.[25]

Comparing our results with those of Popescu e Smets 2010 and Caldara et al. 2016 is not so straightforward because the variables they extract the financial shock from are of different nature than ours. Popescu e Smets 2010 use a financial risk premia measure, while Caldara et al. 2016 use corporate bond credit spreads[26]. In both cases, an adverse financial shock elevates the proxy for uncertainty and the financial tightness, expressed by higher premium and spread. In our case, the positive perturbation in $\varepsilon^{3YTBill}$ augment volatility and $3YTBill$, which tend to heighten restrictions in the financial sector. When exposed to an adverse uncertainty shock the comparisons are no longer so direct: it leads to a tightening in their measures of financial condition (premium and spreads) but to a fall of $3YTBill$ in our case. This last response is however compatible with an expected drop in future policy rate, possibly to counteract the tightening reported by Popescu e Smets 2010 and Caldara et al. 2016 amid a higher uncertainty.

We find the responses from an alternative identification scheme, with $3YTBill$ coming first, less sensible. For instance, vix drops following a sudden rise in $\varepsilon^{3YTBill}$, and the augment in ε^{vix} leads to an insignificant fall in $3YTBill$. In the appendix we show that the responses of the Brazilian variables also suggest that this alternative ordering provokes reactions that do not make much economic sense, but we will turn more to this next.

Response of Domestic Macroeconomic Variables

In this subsection we evaluate the responses of domestic macroeconomic variables, which, to some extent, are the fundamentals behind the pricing of the nominal TIR and its components. These responses start in the third line of Figure 3.

A sudden rise in ε^{vix} increases the Brazilian sovereign risk and devalues the local currency, which are expected movements following a sudden augment in global economic uncertainty. The CPI starts rising significantly after 5 months, which is a likely consequence of the currency devaluation. Despite the higher inflation, the policy interest rate falls in the year following the shock, suggesting a greater concern with the adverse effects on domestic activity that falls below pre shock trend, a result that is also verified in other countries[27]. The drop in the policy interest rate following a rise in global uncertainty, and in the VIX in particular, is also verified by Ferreira e Valério 2023 for Brazil and for Colombia, with an insignificant reaction in Chile and Peru. Bhattarai, Chatterjee e Park 2020 obtain inconclusive results for a pool of emerging economies in Latin America[28]

The positive shock $\varepsilon^{3YTBill}$ also elevates $embi-br$ and the currency to devaluate, a response consistent with the risk adjusted uncovered interest rate. Differently from the previous shock, now a higher vix and $3YTBill$ act in the same direction to produce this depreciation. Local activity and CPI do not

[24] The results obtained by Ang, Bekaert e Wei 2008 are based on estimation of an arbitrage free model using quarterly data for the US nominal TIR from 1952 to 2004. They also estimate that 20% of the unconditional variance of 3 months and 5 years nominal rate are due to the real rate, and 10% of the 5 years are due to inflation risk premium.

[25] Supply and demand shocks at global level or in the USA are likely the primitive drivers behind an expected inflation shock identified from a perturbation in $\varepsilon^{3YTBill}$. Despite of acknowledging this, specifically identifying global supply and demand shocks is beyond the goals of this paper. An extensive joint analysis of the influence of such shocks in global and Brazilian economies can be found in Ferreira e Valério 2023.

[26] Specifically, they use the excess bond premium (EBP) of Gilchrist and Zakrajˇsek (2012), which is an estimate of premium beyond the compensation for expected losses demanded by bond investors for bearing exposure to U.S. nonfinancial corporate credit risk.

[27] Bloom 2009 is one of the first to interpret shocks to vix as an economic uncertainty shock, and finds a negative response of the USA activity following an exogenous rise in vix. According to Carrière-Swallow e Céspedes 2013, the contractionary severity of such shock is larger in emerging economies, which, according to them, may be related to a less developed financial sector. Filho 2014, Barboza e Zilberman 2018, and Ferreira e Valério 2023 also detect an adverse effect of higher global uncertainty in the activity of the Brazilian economy.

[28] Using a panel VAR, Bhattarai, Chatterjee e Park 2020 find different reactions for short run policy rate depending on the proxy of uncertainty used and on the identification strategy. They verify that long run nominal interest rates in the emerging economies to rise unequivocally.

respond significantly[29], but the policy rate increases, a reaction also consistent with the interpretation that $\varepsilon^{3YTBill}$ captures news regarding future inflationary pressure in the USA (and likely in the world), which may explain the raise in the Brazilian monetary policy interest rate as a movement to avoid future inflation.

We refer to the appendix for comments on some of the responses when the identification strategy has $3YTBill$ preceding vix. Besides having vix falling, the positive innovation $\varepsilon^{3YTBill}$ does not produce any significant reaction in the Brazilian sovereign risk nor in the exchange rate. These responses are hard to reconcile with a sensible economic interpretation for the shock $\varepsilon^{3YTBill}$.

Response of the Term Structure of Interest Rate

The response of nominal and real rates, and inflation risk premium can be assessed in Figure 4. Figures 5 and 6 show the impact in the shapes of term structure of these variables after 1, 3, and 9 months following the shock.

TIR response to ε^{vix}

Figure 4 shows a drop in 1, 3, and 4 years real rates following the shock ε^{vix}, but with no significant impact response. Figure 5 shows this invariant response on impact (month M1), but a downward move of the real TIR after 3 and 9 months. In both cases, shorter maturity rates fall more intensively, resulting in steeper curves than before the shock. In the case of the nominal rates, the 1 year maturity significantly falls during the first year, which is consistent with the policy rate reaction and indicates a proper anticipation of the monetary policy by market participants. The nominal 3 years rate falls and the 4 years elevates, but these are mostly not significant[30]. At the end, the nominal TIR becomes steeper.

[29] Our result is similar to that of Akinci 2013, who does not detect a significant reaction in the activity of emerging economies caused by the rise in a benchmark global interest rate after controlling for risk factors.

[30] Our results are opposite to the findings of Bhattarai, Chatterjee e Park 2020, who estimate a panel VAR with 16 emerging countries and verify a rise in short (policy) and long run nominal interest rates following a sudden increase in VIX.

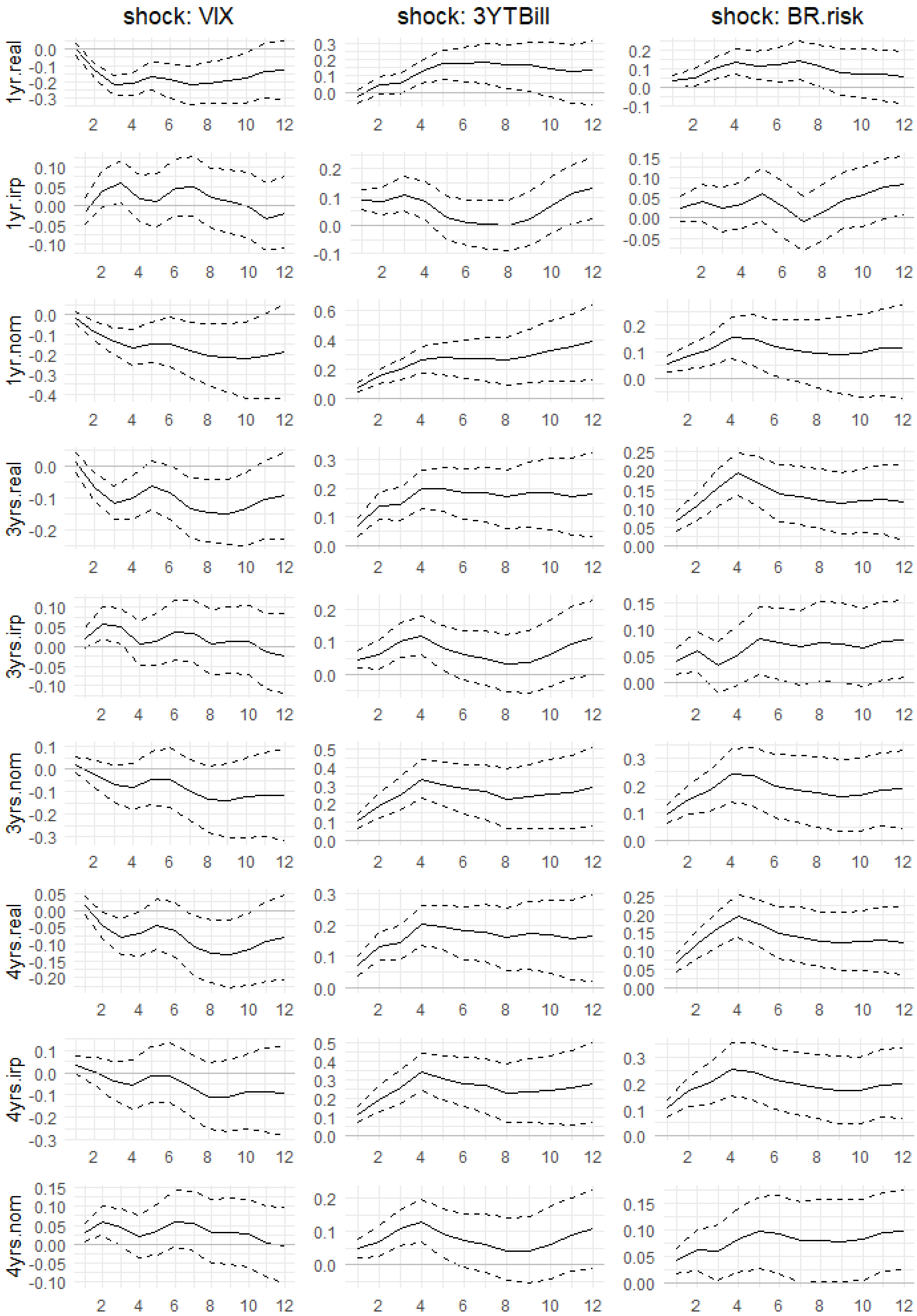

Figura 4 – Impulse response functions. Dashed lines represent the 68% confidence interval.

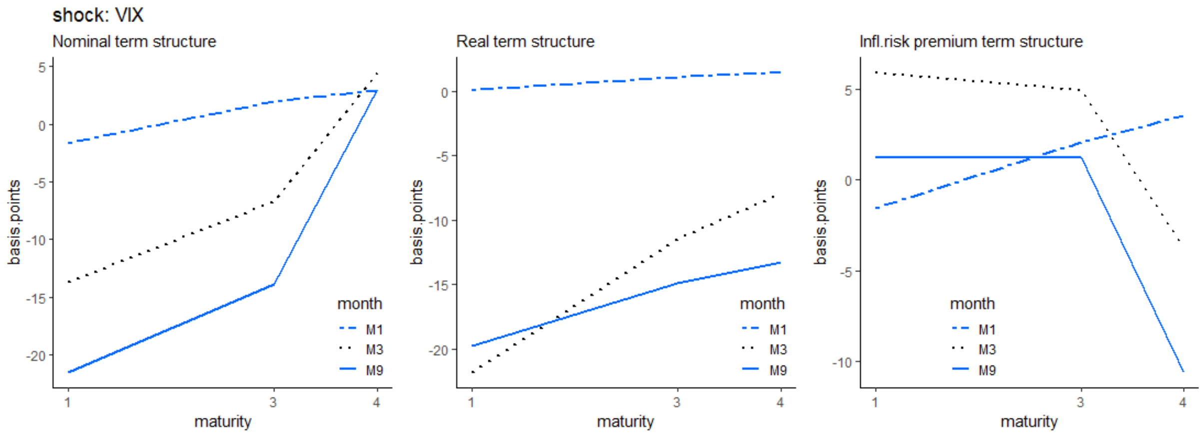

Figura 5 – The impact of a shock ε^{vix} on the term structure of nominal and real rates and of the inflation risk premium. The numbers indicate basis point reaction from pre-shock levels.

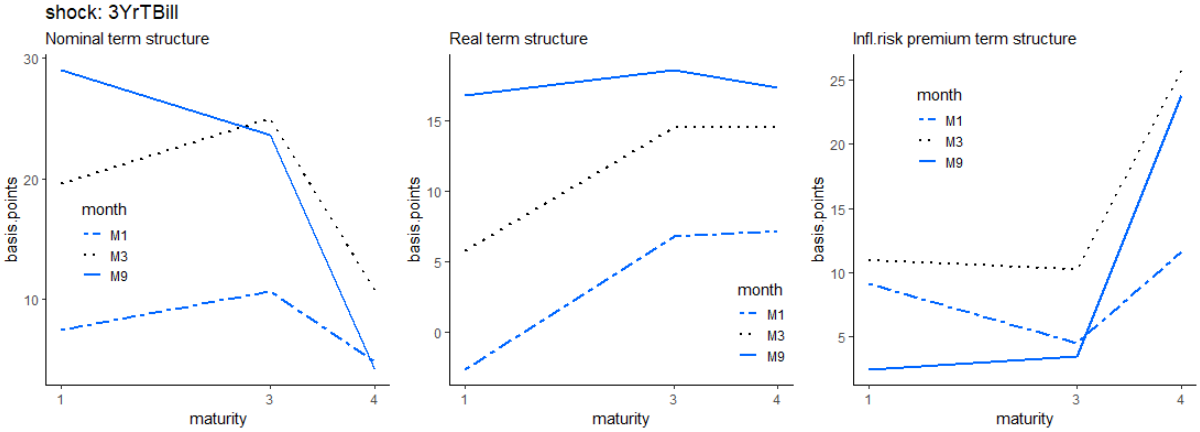

Figura 6 – The impact of a shock $\varepsilon^{3YTbill}$ on the term structure of nominal and real rates and of the inflation risk premium. The numbers indicate basis point reaction from pre-shock levels.

Regarding the inflation risk premium (IRP), only the 3 years premium reacts significantly with a small increase during the first quarter after the shock. If this premium is related to doubts regarding the trajectory of future inflation, as several works suggest[31], this uncertainty rapidly returns to pre shock level.

TIR response to $\varepsilon^{3YTBill}$

The second column of Figure 4 shows a significant rise in nominal and real rates of all maturities after the shock $\varepsilon^{3YTBill}$. These dynamics are consistent with the response of the domestic Central Bank that raises nominal policy rates, showing again a correct assessment of market participants about the policy reaction. Furthermore, the reactions are consistent with $\varepsilon^{3YTbill}$ representing a shock to expected inflation worldwide.

Figure 6 shows an upward move of the nominal TIR with the slope modifying over the months. Initially, the magnitude of the rise is relatively similar across maturities, keeping the curvature of the TIR unchanged. The curvature alters after 3 months, since r_3^N rises more than r_1^N and r_4^N, and because r_1^N increases almost twice as much as r_4^N. It is not clear if the nominal TIR 9 months after the shock becomes flatter than pre shock or negative sloped. For sure, the modification in the slope is mainly caused by the rise in r_1^N and r_3^N, since the 4 years rate does not move significantly.

The responses in the real TIR are easier to characterize. It moves upward on impact and in the months that follow (at least during the first 9 months), becoming steeper on impact and 3 months later due to a more intense rise at longer maturities. After 9 months, however, the real rates of all maturities are almost 16 basis points higher than pre-shock levels, indicating a parallel upward shift.

The term structure of IRP becomes steeper, with a significant rise in irp_3 and irp_4, with the latter being approximately 15 bps and 20bps higher than the former after 3 and 9 months, respectively. irp_1 does not react significantly. This more intense elevation at longer maturities is also consistent with the interpretation that $\varepsilon^{3YTbill}$ captures an expected inflation shock that elevates uncertainty about future inflation trajectory worldwide.

4.2 Domestic Risk Premium Shock - $\varepsilon^{br.risk}$

Macroeconomic Responses

The positive shock $\varepsilon^{br.risk}$ elevates $br.risk$ in approximately 7% on impact and persistently remains above pre shock trend during the first year. The mechanism of the risk adjusted interest parity causes an

[31] Söderlind 2010 and D'Amico, Kim e Wei 2018 find a positive correlation between inflation risk premium and different measures of uncertainties about future inflation. Garcia e Werner 2010 reach similar conclusion for the Euro Zone and Durham 2006 for Germany and UK.

immediate currency depreciation of 1.2% which peaks at 2.2% six months after the shock. Activity falls below pre-shock trend, but this drop becomes significantly only after 5 months. CPI increases, a likely response to the currency depreciation, forcing the Central Bank to rise the policy rate.

Interesting to observe in figure 3 that the domestic impulse responses following ε^{vix} are very similar to those provoked by $\varepsilon^{br.risk}$, except for the reaction of the domestic policy rate, which expands in the first case contracts in the second. To the extent that both capture uncertainty shocks, one possible explanation for the difference resides on the more acute drop of economic activity in the presence of ε^{vix}, which may weight more on the Central Bank's decision. Another (not competing) explanation is that depending on the magnitude of the international uncertainty shock, liquidity problems in a global scale may arise, which can lead Central Banks to adopt policies to inject more liquidity in the economy to prevent bank runs and bankruptcy in the financial sector. And yet another explanation is that an adverse sovereign risk premium shock, normally related to news suggesting a poor management of macroeconomic policies, results in the monetary authority acting strongly to show commitment to stability regardless the short run costs in terms of GDP.

The response of the term structure of interest rate

Real and nominal TIR of 1, 3, and 4 years maturity significantly increase following the shock, which, to some extent, represent a correct anticipation of the reaction conducted by the central bank. As shown in Figure 7, the curves move upward already on impact, moving further up 3 months later and remains between these two curves 9 months after the shock.

The real TIR becomes unequivocally steeper due to a higher increase in the rates at longer maturities. The curvature of nominal TIR modifies, since r_3^N increases more than r_{1N} and r_{4N}, with these two heightening in a similar magnitude.

irp_1 does not react significantly, probably reflecting less uncertainty about the short run impact of the shock on inflation. irp_3 rises and becomes significant over time. irp_4, however, reacts positively and significantly throughout the entire year following the shock. A possible reason for these differences is that $\varepsilon^{br.risk}$ most likely captures long run uncertainties regarding the fiscal sustainability of the public debt and, consequently, about the capacity to roll over future maturing debt, which normally results in large currency devaluations and high inflation. Overall, the term structure of *IRP* becomes much steeper. No less important is the high persistence of these responses that lasts throughout the entire year following the shock, maintaining the cost of financing the public debt much higher[32].

[32] Montes e Curi 2017 and Reis 2018 also verify a positive relation between different metrics of fiscal uncertainty with the inflation risk premium in Brazil. Montes e Curi 2017 use as a metric for fiscal uncertainty surveys conducted with professionals of the financial sector and consulting firms to compute the dispersion of their forecasts about the level of public debt. Reis 2018 relies on prices of *Credit Default Swap* to secure against an eventual default on the Brazilian Federal debt to proxy for fiscal uncertainty. Vicente e Graminho 2015 also encounter a positive relation between domestic uncertainty and inflation risk premium but using the volatility of the Brazilian stock market as a proxy for uncertainty, which likely captures a broader risk perspective than the fiscal uncertainty we approach.

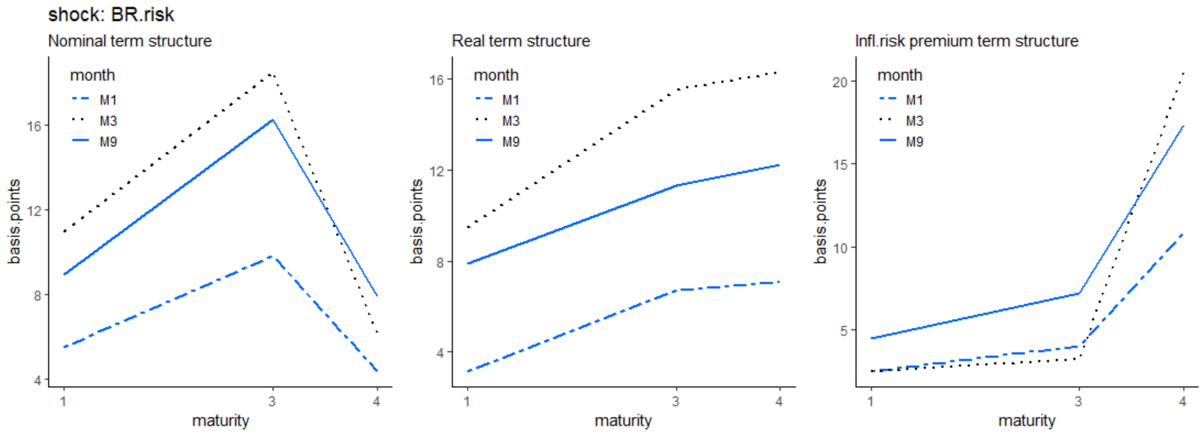

Figura 7 – The impact of a shock $\varepsilon^{br.risk}$ on the term structure of nominal and real rates and of the inflation risk premium. The numbers indicate basis points reaction from pre-shock levels.

5 Results - Forecast Error Variance Decomposition (FEVD)

Before analyzing the importance of each specific shock for the forecast error variance (FEV) of the term structure, it is informative to observe the influence of them on vix, $3YTBill$, and $br.risk$. ε^{vix} contributes with approximately 80% for the FEV of $3YTBill$ for 3 to 12 months ahead forecasting. The contribution of $\varepsilon^{3YTBill}$ for the FEV of vix ranges from 3.7% to 11.4%, for 3 and 12 months forecasting, respectively. These proportions reveal the importance of the joint modeling of external variables to improve the measurement and identification of the shocks. As a thought experiment, conclusions about the influence of $\varepsilon^{3YTBill}$ based on a model incorporating only $3YTBill$ would possibly be imprecise, since the effects of uncertainty shocks would not be filtered way from $e^{3YTBill}$.

Along the same line, it also deserves attention that the contribution of ε^{vix} for the FEV of Brazilian sovereign risk ranges from 32% to 37% for forecasts up to 1 year, with a smaller contribution of $\varepsilon^{3YTBond}$ (around 4%). Again, if one wishes to more precisely measure the impact of $\varepsilon^{br.risk}$, it is necessary to filter the influence of global risk factors away from $e^{br.risk}$.

The joint contribution of ε^{vix}, $\varepsilon^{3YTbill}$, and $\varepsilon^{br.risk}$

The joint contribution of global shocks varies from 30% to 41% for the FEV of the 1 year nominal rate in forecasts ranging from 3 to 12 months. Adding the influence of $\varepsilon^{br.risk}$ hightens the contribution to 37%-46%. For r_3^N the contribution of global innovations varies from 24% to 37%, and from 39% to 54% when $\varepsilon^{br.risk}$ is added. In the case of r_4^N, global shocks contribute with around 17%, which elevates to 23%-35% after incorporating the influence of $\varepsilon^{br.risk}$.

In the case of 1 year real rate, the contribution of global shocks we study varies from 28% to 37% for forecasts up to 1 year, but the proportion explained by our identified shocks elevates to 32%-44% when adding the influence of $\varepsilon^{br.risk}$. ε^{vix} and $\varepsilon^{3YTbill}$ explain together 29% to 40% of the FEV of 3 years real rate; the explained proportion increases to 47%-59% after adding the contribution of sovereign risk shocks. High explained percentages are similarly verified for the FEV of r_4^R.

In the case of the FEV of IRP_1, ε^{vix} and $\varepsilon^{3YTbill}$ jointly contribute with 14%-20% for forecasts from 3 to 12 months, and the proportion raises to 17%-26% after summing the contribution of $\varepsilon^{br.risk}$. Similar numbers are observed for IRP_3, but a much larger influence is encountered for IRP_4: 24%-37% only for global shocks, and 41%-57% after adding the influence of $\varepsilon^{br.risk}$.

Summarizing, the shocks we study explain a very large proportion of the forecast error variance of the nominal and real rates, and inflation risk premium.

FEV due to ε^{vix}

ε^{vix} explains about 10% of the FEV of R_1^N regardless of the forecasting horizon, but only modestly contribute for the FEV at the middle part of the curve (R_3^N and R_4^N).

The contribution for the FEV of R_1^R ranges between 20.7%-25.6% for forecasts from 3 to 12 months. The contribution for the FEV of R_3^R reaches 11.2% for 12 months forecast, and 8.5% for R_4^R. The influence for the FEV of IRP.

FEV of shock $\varepsilon^{3YTBill}$

Shocks $\varepsilon^{3YTBill}$ have substantially contributed for the forecast error variance of the nominal TIR in all maturities we study. For 3 months forecasting, $\varepsilon^{3YTBill}$ has been responsible for 21.4%, 23.3%, and 12.1% of the FEV of R_1^N, R_3^N, and R_4^N, respectively. The influence increases for 6 and 12 months forecasts, situating around 29% for R_1^N, 33% for R_3^N, and 16% for R_4^N.

Similar relevance is observed for FEV of the real TIR, specially at the medium part of the curve. For R_3^R and R_4^R, shocks $\varepsilon^{3YTBill}$ have been responsible for about 21% of the FEV for 3 months forecasting, and close to 30% for 6 and 12 months forecasting. These innovations also explain a considerable proportion of the FEV at the short end of the real TIR (R_1^R) for 6 and 12 months forecasting: 11.7% and 13.0%, respectively.

The FEV of IRP due to $\varepsilon^{3YTBill}$ is also high. For 1 and 3 years IRP, it explains between 11%-17% for 3, 6, and 12 months forecasting horizons. The contribution for IRP_4 is even larger, varying from 23.9% to 34.4%. This high contribution seems in agreement with the interpretation that $\varepsilon^{3YTBill}$ most likely captures an inflation news shock worldwide.

FEV of shock $\varepsilon^{br.risk}$

$\varepsilon^{br.risk}$ is another important driver of the FEV of the nominal TIR, especially at the middle part of the term structure. For R_3^N, the contribution is 14.3%, 18.6%, and 16.9% for 3, 6, and 12 months ahead forecasting; and 6.4%, 11.1%, and 16.0% in the case of R_4^N. For R_1^N the influence is smaller, but still reaches 8.4% for 6 months horizon forecasting.

Brazilian sovereign risk shocks have been even more important for the FEV at the medium part of the real curve. The influence varies from 17.3% to 22.9% for R_3^R, and from 21.3% to 26.7% for R_4^R. $\varepsilon^{br.risk}$ is also an important determinant of the FEV for IRP, particularly the 4 years with a contribution ranging between 16.8%-21.1%.

The influence of $\varepsilon^{br.risk}$ in the nominal TIR and its components, especially at the medium part of the term structure, show the potential of this domestic shock to affect important investment decisions, since long term loans are heavily influenced by the rates at the medium and long part of the yield curve. It is also clear extraordinary impact it may exert on the cost of the public debt.

6 Final Remarks

We propose an empirical macrofinance model for Brazil to study the impact of shocks to domestic sovereign risk, global economic uncertainty and global finance on the term structure of nominal interest rate of the Brazilian Treasury bonds and two of its components - real interest rate and inflation risk premium - at 1, 3 and 4 years maturity. The global shocks are derived from the volatility index VIX and the US 3 years T-bond. Our model provides a unified structure of the relation between macro-finance variables at global and domestic levels. The results we encounter are based on impulse response functions and decomposition of the forecast error variance after estimating a BSVAR with a block recursive restriction to accommodate the small open economy hypothesis and a structural relation between variables at the world level.

Tabela 2 – Forecasting error variance decomposition

Shock	forecast horizon	R_1^N	R_3^N	R_4^N	R_1^R	R_3^R	R_4^R	IRP_1	IRP_3	IRP_4
	3 months	8.5	1.1	4.1	25.6	8.2	4.3	2.8	4.2	0.5
ε^{vix}	6 months	9.8	1.4	3.7	23.5	7.1	3.8	2.6	2.8	0.5
	12 months	11.5	4.4	3.5	20.7	11.2	8.5	2.9	2.2	2.4
	3 months	21.4	23.3	12.1	2.4	20.5	21.6	14.7	11.1	23.9
$\varepsilon^{3YrTBond}$	6 months	29.0	33.1	15.3	11.7	29.2	30.6	12.4	13.9	34.0
	12 months	29.9	32.5	16.0	13.0	28.7	29.5	16.8	14.9	34.4
	3 months	7.1	14.3	6.4	4.9	18.3	22.8	1.6	4.2	16.8
$\varepsilon^{br.risk}$	6 months	8.4	18.6	11.0	7.8	22.9	26.7	3.0	7.5	21.1
	12 months	4.9	16.9	16.0	6.0	17.3	21.3	6.4	11.6	20.0

Forecast error variance for 3, 6, and 12 months ahead forecast. The results are based on the identification of matrix *A* already described.

A global economic uncertainty shock increases the volatility of expected prices of the S&P500 and reduces the 3 years US TBond. The Brazilian term structure of nominal interest rate becomes steeper because of a more intense drop in shorter term yields and no significant response at longer maturity. A similar pattern is observed for real yields, except that 4 years maturity yield also falls. Inflation risk premium is less responsive to a global uncertainty shock.

A sudden rise in the US 3 years Tbond, which, according to our identification, seems to capture an expected inflation shock, elevates volatility (VIX). The Brazilian term structure of nominal interest rates moves upwards and becomes either flatter or negative sloped because of a smaller rise in yields at longer maturity. The term structure of real yields also moves upwards and becomes slightly flatter. The TIR of inflation risk premium moves upwards and becomes initially steeper because of a more intense rise at longer maturity but returns to pre-shock shape later. These are all consistent reactions to a shock that augments inflation uncertainties worldwide.

A local adverse sovereign risk shock moves the Brazilian nominal TIR upwards and alters the curvature, as the 3 years maturity yield increases more than the 1 and 4 years rates. The structure of real rates also moves upwards and becomes steeper. The term structure of inflation risk premium also becomes steeper, with an intense rise at longer maturity and an insignificant reaction at the short end of the curve. We find this pattern consistent with news about policies that elevate the uncertainty about debt sustainability, also augmenting doubts about the trajectory of future inflation.

The shocks we identify explains a very high proportion of the unexpected movements in the term structure. Their joint contribution for the forecast error variance of nominal rates for 3 to 12 months forecasts are 37%-46% for 1 year maturity, 39%-54% for 3 years maturity, and 23%-35% for 4 years maturity. For the real interest rates, the estimated contributions are 32%-44% for 1 year maturity, and 47%-59% for 3 and 4 years maturities. For the FEV of the inflation risk premium the contribution is 17%-26% for 1 year maturity, becoming much higher for 4 years maturity: 41%-57%.

Individually, world economic uncertainty shocks do not explain much of the unexpected change in the nominal yields and in the inflation risk premium but do so for the real rate maturing in 1 year: around 22% of the FEV for 3-12 months forecasts.

Innovations to the 3 years US Tbond explain 21%-29% of the FEV of 1 year nominal yield on Brazilian Treasury securities, 23%-33% for the 3 years and 12%-16% for 4 years. The influence in the 1 year real rate situates close to 12%, reaching 21%-30% for 3 and 4 years maturity. In the case of the inflation risk premium, the contribution is 11%-17% for the inflation risk premium implicit in 1 year rate, and 24%-34% for bonds maturing in 3 and 4 years.

Finally, innovations in the Brazilian sovereign risk premium only slightly contribute for the FEV of the 1 year nominal rate (maximum of 8%), but the influence is larger for 3 and 4 years nominal yields: 14%-19% and 6%-16%, respectively. The impact on the real yield is also more expressive at these maturities: 17%-23% and 21%-27%, in this order. The influence on inflation risk premium is particularly relevant for bonds maturing in 4 years: 17%-21%.

The strong relation between VIX and the 3 years US nominal rate shows the importance of specifying models for small open economies where global variables form a separate block to capture their equilibrium relation, which ultimately allows a better identification and economic interpretation of external shocks. As an example, we verify that the Brazilian economic activity does not significant react to innovations in the US 3 years nominal rate after we control for external risk, a result previously observed by Akinci 2013. Similarly, the significant response of the Brazilian sovereign risk premium to global shocks shows the importance of filtering the influence of external variables to infer about the influence of the country risk premium. Trying to integrate these relations in canonical arbitrage-free macrofinance equilibrium models is challenging but seems a fruitful venue for future research.

APPENDIX

1 Bayesian priors for the VAR estimation

In order to estimate the Bayesian VAR we use priors suggested by Sims e Zha 1998 that were also used by Zha 1999. We combine two unit root priors: the Minnesota prior and the sum-of-coefficients prior. The Minnesota prior imposes the restriction that coefficients on the first lag has prior mean of 1. This is done by creating variables such that for the i'th equation, a set of $k-1$ dummy observations, indexed by $j = 1,...,m$, $l = 1,..., p$, is inserted in the data sample, with data taking the values specified by equation 3:

$$y_i(r, j)\ ; r = 1,...,k-1; j = 1,...,m = \begin{cases} \mu_1\mu_2\sigma_r/l^{\mu_4}, & \text{if } r = j, r \leq m \\ 0, & \text{otherwise} \end{cases}$$

$$x_i(r,s)\ ; r = 1,...,k-1; s = 1,...,k-1 = \begin{cases} \mu_1\mu_2\sigma_r/l^{\mu_4}, & \text{if } r = s, \\ 0, & \text{otherwise} \end{cases} \tag{3}$$

where μ_1, μ_2 and μ_4 are hyperparameters. μ_1 controls the overall tightness of Φ_0; μ_2 controls the relative tightness of the matrix Φ_h, and μ_4 controls the tightness on lag decay. These hyperparameters are set at the default values suggested by Sims e Zha 1998 and Zha 1999, which are, respectively, 1, 0.5 and 1.

The sum-of-coefficients prior is used in cases where there is a belief that the variables have a unit root, which is captured by using a prior that the coefficients on the lags of the dependent variable sum to 1. This is achieved in a system of m equations, l lags and k coefficients, by introducing m observations, indexed by i, of the form:

$$y(i, j)\ ; i = 1,...,m; j = 1,...,m = \begin{cases} \mu_5\bar{y}_{0i}, & \text{if } i = j, \\ 0, & \text{otherwise} \end{cases}$$

$$x(i,s)\ ; i = 1,...,m; s = 1,...,k = \begin{cases} \mu_5\bar{y}_{0i}, & \text{if } i = j, \text{ all l }, \\ 0, & \text{otherwise} \end{cases} \tag{4}$$

where $\bar{y}_{0i}$ is the average of initial values of the variable i and μ_5 is a hyperparameter that controls the weight of the prior. For instance, as $\mu_5 \to \infty$, the model tends to a form that can be expressed entirely in terms of differenced data. We μ_5 at its default value of 1.

2 Impulse Response Functions with an alternative ordering

The following figure shows the impulse responses from an alternative ordering: vix does not affect $3YrTBill$ on impact, but it is instantaneously influenced by shocks to $3YrTBill$.

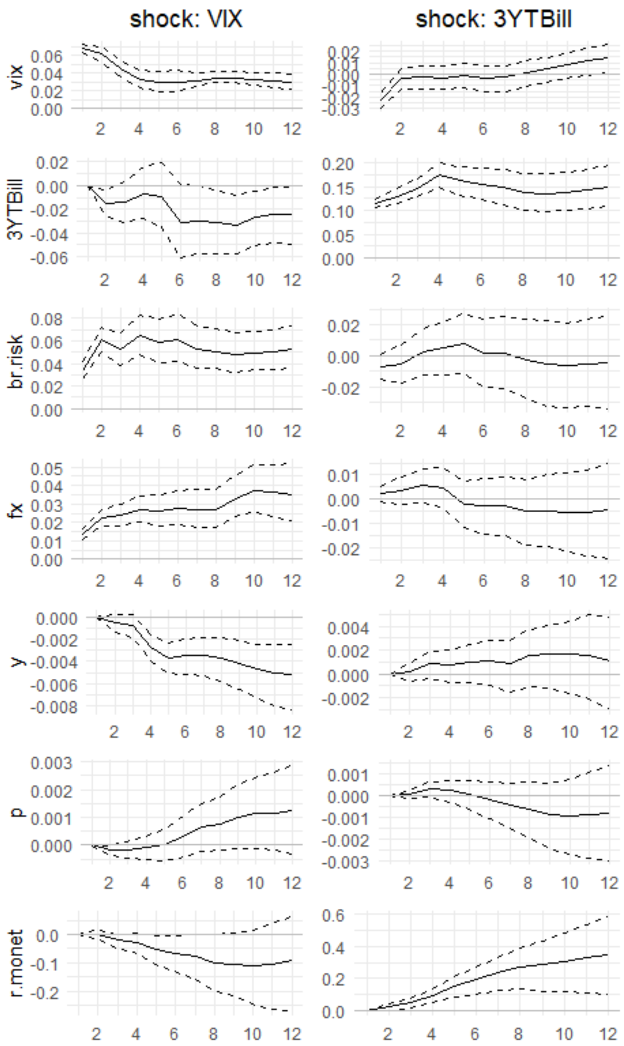

Figura 8 – Impulse response functions. Dashed lines represent the 68% confidence interval. These impulse responses are based on an alternative identification strategy where vix does not affect $3YTBill$ contemporaneously but suffers an immediate influence of a shock to $3YTBill$.

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