The Interdependence of FX and Treasury Bonds Markets: The Case of Colombia

By: Andrey Duván Rincón-Torres
Kimberly Rojas-Silva
Juan Manuel Julio-Román

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Andrey Duván Rincón-Torres*
Kimberly Rojas-Silva†
Juan Manuel Julio-Román‡

Abstract

We study the interdependence of FX and Treasury Bonds (TES) markets in Colombia. To do this, we estimate a heteroskedasticity identified VAR model on the returns of the COP/USD exchange rate (TRM) and bond prices, as well as event-analysis models for return volatilities, number of quotes, quote volume, and bid/ask spreads. The data under analysis consists of 5-minute intraday bid/ask US dollar prices and bond quotes, for an assortment of bond species. For these species we also have the number of bid/ask quotes as well as their volume. We found, also, that the exchange rate conveys information to the TES market, but the opposite does not completely hold: A one percent COP depreciation leads to a persistent reduction of TES prices between 0.05% and 0.22%. However, a 1% TES price increase has a very small effect and not entirely significant on the exchange rate, i.e. a COP appreciation between 0.001% and 0.009%. Furthermore, TRM return volatility increases do not affect bond return volatility but its liquidity, i.e. the bid/ask quote number and volume. These results are coherent with the fact that the FX market more efficiently reflects the effect of shocks than the TES market, which may be due to its low liquidity and concentration on a specific habitat. These results have implications for the design of financial stability policies as well as for private portfolio design, rebalancing and hedging.

Keywords: Spillovers effects; Bond returns; Currency risk; FX market
JEL: F31, G12, G14

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* adrincont@unal.edu.co, Research Intern, Research Unit, Banco de la República and undergraduate in Statistics, Universidad Nacional de Colombia.
† krojassi@banrep.gov.co, Senior Analyst, Operations and Market Analysis Department, Banco de la República.
‡ jjulioro@banrep.gov.co, Corresponding author. Senior Researcher, Research Unit, Banco de la República and part time Associate Professor, School of Economics, Universidad Nacional de Colombia.

La Interdependencia de los Mercados de Dólares y TES: El Caso Colombiano*

Andrey Duván Rincón-Torres[5]
Kimberly Rojas-Silva[6]
Juan Manuel Julio-Román[7]

Resumen

Analizamos la interdependencia entre los mercados de divisas y bonos (TES) en Colombia. Para esto estimamos modelos VAR identificados por heterocedasticidad para los retornos de la tasa de cambio (TRM) y los precios de los bonos, así como también modelos de análisis de eventos para la volatilidad de los retornos, el número y volumen de las ofertas, y los diferenciales de compra y venta, *bid/ask spreads*. Los datos analizados consisten en muestras de cada 5-minutos de precios *bid/ask* del dólar y de ofertas de los bonos, para un conjunto de referencias. Para estas referencias también contamos con el número de ofertas *bid/ask* así como su volumen. Encontramos que la TRM transmite información al mercado de bonos, pero lo opuesto no se da completamente: una depreciación de 1% del peso produce una reducción permanente del precio de los TES de entre 0.05% y 0.22%. Sin embargo, un incremento de 1% del precio de los bonos tiene un efecto pequeño y no enteramente significativo sobre la TRM, i.e. una apreciación del peso entre 0.001% y 0.009%. Adicionalmente, los incrementos en la volatilidad de la TRM no afectan la volatilidad de los retornos de los bonos, pero si su liquidez, es decir, el número y volumen de sus ofertas. Estos resultados son consistentes con el hecho de que el mercado de divisas refleja de manera más eficiente el efecto de los choques que el de bonos, resultado de la baja liquidez y concentración en un hábitat específico de este último. Estos resultados tienen implicaciones importantes para el diseño de políticas de estabilidad financiera, así como también para el diseño de portafolios privados, su rebalanceo y cobertura.

Palabras clave: Interrelación de mercados; Retornos de los bonos; Riesgo de moneda; mercado de divisas
JEL: F31, G12, G14

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[5] adrincont@unal.edu.co, Estudiante en Práctica de Investigación, Unidad de Investigaciones, Banco de la República y Estudiante de Pregrado de Estadística, Universidad Nacional de Colombia.
[6] krojassi@banrep.gov.co, Profesional Experto, Departamento de Operaciones y Análisis de Mercados, Banco de la República.
[7] jjulioro@banrep.gov.co, Investigador Principal, Unidad de Investigaciones, Banco de la República y Profesor Asociado de tiempo parcial, Escuela de Economía, Universidad Nacional de Colombia.

1. Introduction

Establishing the nature of the interdependence[8] between FX and COP denominated government debt bond markets, TES for their name in Spanish, is important for market players and financial authorities as well. Financial theory emphasizes the importance of the link between financial markets in portfolio optimization, hedging and re-balancing as well as in risk management. Likewise, financial authorities underline the importance of these relationships to understand the transmission of shocks, the main input in the design of financial stability policies.

The expected relationship between the price of bonds and the exchange rate might be understood through the interest rate, investment, and trade channels, but this does not necessarily hold in the short run. A price increase in local bonds reduces the local interest rate, thus local financial investments become less attractive compared to foreign ones. As a result, an increasing flow of funds to foreign countries may arise, leading to a local currency depreciation. On the other hand, lower interest rates push investment and GPD, while the weaker exchange rate increases the appetite for local products and services, thus leading net exports to increase and flows of funds to reverse. From this point of view a local bond price fall (a yield surge) leads to local currency depreciation which corrects, to some extent, later.

This is a common finding in developed markets. Chow, Lee and Solt (1997) examined the impact of exchange rate changes on bonds and stocks returns in the US, through regression techniques. They found that bonds are positively exposed to exchange rate changes across all horizons[9], while the effect of unanticipated exchange rate changes on stocks is negative over short horizons and positive over long horizons[10]. In the same vein, Ehrmann, Fratzscher and Rigobon's (2011) results revealed a negative relation between the exchange rate and interest rates (that is a positive relation with bond prices) in the US and the euro area: i) an increase of 100 bp in US yields leads to an appreciation of the exchange rate of 3,5%, and ii) an increase of 100 bp in euro area yields leads to an appreciation of the exchange rate of 4,2%. Similar results may be inferred from Rigobon and Sack (2003).

However, these results might be state or time dependent. For instance, Soenen and Henninger (1988) claim that the sign of the correlation between bond and stock markets is time varying and might be negative under special circumstances. Andersen, Bollerslev, Diebold and Vega (2007), in turn, characterized the simultaneous response of foreign exchange markets, and domestic and foreign stock and bond markets, to real-time US macroeconomic news, using a two-step weighted least squares procedure. For the domestic interactions across US markets, they found that during expansion periods: i) bond prices are negatively affected by an increase in stock prices and USD/EUR appreciation, ii) stock prices profit from higher bond prices and USD/EUR depreciation, and iii) USD/EUR depreciates with an increase in stock prices and bond prices.

Empirical evidence suggests that time and state dependency hold in developing and emerging countries as well. As a matter of fact, a positive link between exchange rates and bond yields in some emerging markets might be associated to risk premia surges. Hoffmann, Shim and Shin (2020), for instance, found that emerging markets with higher shares of local bonds foreign ownership have experienced significantly larger increases in their local currency bond spreads in the wake of the

[8] According to Beirne, Caporale, Schulze-Ghattas,and Spagnolo (2013), interdependence is the relationship between asset classes, on average, over the sample period. Interdependence differs from contagion, as the latter refers to changes in the transmission mechanism between asset classes in crisis times.

[9] Which is consistent with the negative correlation between exchange rate and domestic interest-rate changes.

[10] The effects of the exchange rate on stocks reflects interest-rate and cash -flow effects. In short horizons, both effects are offsetting but complementary over long horizons.

Covid-19 pandemic, a known fact in Colombian markets. The above is due to the mismatch between the currency of the assets (foreign currency) and that of the obligations (local currency) and to the fact that emerging markets bonds duration tends to be larger in USD than in local currency. Under these circumstances, a generalized depreciation episode in emerging markets lowers the value of assets in the foreign investors' home currency terms, which may trigger sales or ex post hedging, pushing up emerging bond spreads due to the exit of foreign investors. As a result, a negative linkage between exchange rate and bond prices arises, contrary to what was found in developed markets.

In a similar manner, Sensoy and Sobaci (2014) analyzed the interdependence between the exchange and interest rates as well as the stock market in Turkey, by estimating the dynamic correlations between these variables, detecting, and dating volatility shifts through penalized contrast functions, and relating these dynamic correlations with high/low volatility regimes. They found that: i) the dynamic correlations between bond and stock markets are always negative which validates the approach of discounting the expected dividends in calculating stock prices, ii) the strongest dependency is between exchange rate and the stock market as the mean level of the dynamic correlation between these two markets is almost twice that of the others, and iii) there is a positive correlation between bond yields and the exchange rates (that is a negative one between the exchange rate and bond prices), pointing out a common phenomenon observed in many emerging markets and contrasting the theory which states that an increase in the interest rates would attract foreign capital to the country thus lowers the exchange rates[11]. Similar results were also found by Bautista (2003) for the Philippines and in Sanchez's (2008) model. In turn, Andrieș, Căpraru, Ihnatov & Tiwari, (2017) concluded that, in the short run, the linkage between the exchange rate and bond yields is negative while over the long term, they found a positive relationship.

Furthermore, a small role of bonds as a source of shocks has also been found. For instance, Beirne and Giek (2014) assessed the interactions among bonds, stocks, and currencies[12], across countries and regions, and examined whether these relationships change during a period of financial stress, using a global VAR model for over 60 economies (including Colombia). Their findings, which are like Ehrmann, Fratzscher & Rigobon's (2011), indicate that "in times of financial crisis, shocks that emanate from the US (particularly equity shocks) lead to risk aversion by investors in equities and currencies globally and some emerging markets bonds. The effect of bond shocks is not significant regardless the origin of the shock, both on average and in a crisis period."

On the other hand, the relationship between FX and other financial assets markets relates, also, to the adoption of the Inflation Targeting (IT) regime, more specifically to the required exchange rate, TRM for its name in Spanish, flotation. See Hammond (2012). As a matter of fact, under IT floating exchange rates adjust immediately to shocks and foreign economic cycles thus preventing currency crises and allowing the central bank to focus its policies to IT objectives. See Woodford (2003). This argument, together with the efficiency and high liquidity of FX markets, bestows it a special role in the transmission and summarization of the effect of shocks.

This view seems to be particularly important in Colombia where the bond market characterizes for its low liquidity and concentration on species with long remaining maturity, facts that may lead to an inefficient transmission of shocks. Indeed, TES market illiquidity relates to the following issues. First, the total number of bid/ask quotes and realized trades is quite small as to hamper the estimation of

[11] According to these authors, "In many emerging countries with budget deficits, the expectations channel plays an important role in investment. If interest rates increase for any reason, it's generally perceived as an upcoming problem in the country and the hot money tends to leave in a very short time interval."
[12] The exchange rates analyzed in this study were EUR/USD, GBP/USD, and USD/JPY

daily spot curves. See Julio-Román, Mera-Gamboa and Revéiz-Hérault (2002). Second, the market reaches an agreement on the effect of afterhours shocks well into the trading session, contributing to pronounced illiquidity during its first hours. And third, it is likely the market experiences extended stretches of time without new bid/ask quotes, leading to artificially extended bid/ask price duration. However, high liquidity spells do arise on species with long tenors, signifying that the market concentrates on specific habitats. See Fabozzi (2020). These intervals, nevertheless, tend to be short and of varying length. As a result, the liquidity and depth of the TES market might not be enough for an efficient transmission of shocks, even when certain species are liquid.

In this regard, a disconnection between the bond market and macroeconomic fundamentals may occur, affecting bond market liquidity. Although the efficient markets hypothesis states that prices completely and instantly reflect movements in fundamentals, Fama and French (1989), some authors claim that asset prices and fundamentals may be disconnected. See Andersen, Bollerslev, Diebold and Vega (2003). Since closing deals is the confirmation that the market has agreed upon the effect of shocks, a disconnection of financial prices from fundamentals reflects on market illiquidity. See Chordia, Roll and Subrahmanyam (2008), Chung and Hrazdil (2010), and Wei (2018). Thus, market disconnection with fundamentals may be an important source of market illiquidity.

Regarding the analysis of Colombian financial markets linkages, Piljak, V. (2013) found that the bond market was not affected by global macroeconomic factors at all and exhibited a lower correlation with US markets compared to other countries where global macroeconomic factors exerted a greater influence (China and Malaysia, for instance). In terms of interdependence, Beirne and Gieck (2014) revealed that local equity returns are closely linked with global stock market developments and there is also some close relation between global exchange rate returns and equity returns, but there is only sporadic evidence of interdependence between global bonds and local equities.

However, the interrelationship between bond and FX markets has not been studied in Colombia, as far as we know. We try to fill this gap.

In this paper we study the interrelationship between the FX and TES markets in Colombia. For this purpose, we employ a heteroskedasticity identified VAR model for TRM and TES returns, as well as event study models for return volatilities, market quote volumes, number of quotes and bid/ask spreads. These analyses are performed on 5-minute interval sampling within the trading sessions of liquid spells related to specific bond species. To estimate the linkages between these markets, we control for the effect of their own dynamics, intraday seasonality, and macroeconomic surprises. Therefore, our study is closest to Andersen et al (2003) who analyzed the interdependence amongst bond, foreign exchange and equity returns in the US controlling for macroeconomic surprises, and we also follow Dominguez (2006) regarding the need to control for the intraday seasonality of volatility and liquidity.

We conclude that the FX market in Colombia conveys information to the bond market, but its reaction to bond market shocks is quite limited. As a matter of fact, exchange rate depreciation leads to a persistent fall of bond prices which may endure up to 60 minutes after the shock. However, exchange rate volatility shocks do not seem to affect bond volatility but liquidity. An exchange rate volatility shock leads to a sharp fall in the number of bond's market bid/ask quotes and volume, on impact, with a subsequently rapid and important recovery minutes later. Bond market liquidity turns back to normal just 15 minutes after the shock. Furthermore, we found evidence that FX market liquidity increases unleash lagged liquidity surges in the bond market. Finally, bond market shocks do not seem to affect FX market liquidity and volatility, but bond price increases lead to a very small, persistent, and not clearly significant COP appreciation. These results arise form high liquidity spells on longer standing maturity bonds, and thus might not extend to other periods or TES species.

As stated on Beirne, and Gieck (2014), the analysis of interdependencies has several implications of interest to policymakers, because it provides an insight into country-specific financial vulnerabilities. "In order to derive appropriate policy responses, it is crucial that policymakers understand the source and nature of financial exposures".

The asymmetry in the interrelationship of these two markets highlights the size of the exposure of bond portfolios to the exchange rate, a fact that has important implications for portfolio holders and financial authorities as well. As a matter of fact, our results fit Beirne and Giek's (2014), who showed that the effect of bond shocks is not significant regardless the country of origin of the shock, both on average and crisis periods.

The remaining of the paper is organized as follows. In section 2 we summarize the data sources and transformations. The third contains our empirical approach. And the fourth and last comprises the results from where our conclusions above follow.

2. Data

In this paper we employ three datasets that span the January 2015 to October 2020 period. The first contains time stamped bid/ask quotes posted in the secondary spot market of treasury bonds issued in Colombian Pesos by the Colombian central government. The second consists of time stamped bid/ask prices from the US dollar currency market in Colombia. And the last comprises an assortment of time stamped US and Colombian macroeconomic data releases and agents' expectations.

2.1. Local Currency Government Bond Market: TES

The secondary TES market has the following features. Trading sessions run from 8:00 a.m. to 1:00 p.m., Monday through Friday excluding national holidays. The players in this market are the market makers according to the rules established by Ministerio de Hacienda (the Colombian Finance Ministry). For our analyses we exclude stripped bonds and bills, and the species we consider are identified by a mnemonic with prefix TFIT followed by an 8-digit number mmDDMMYY, where mm indicates the years to maturity at the date the bond was issued, and DDMMYY indicate the day, month, and year of maturity[13]. Quote information is recorded in the SEN platform belonging to Banco de la República (the central bank of Colombia - BanRep).

The TES bid/ask quotes dataset contains time stamped quote related events arising during the trading session. These events summarize in "placement" (a trader posts a position, bid/ask, quote for a precise volume of a specific species at a stated price), "modification" (the volume or price of an existing quote is modified, and the modified quote remains active) and "subtraction" (the quote is no longer available).

Bid/ask prices are the best bid/ask quotes and result from sorting the list of active quotes at the specific time and choosing the minimum or maximum quote depending on the position (short/long). These prices are realizations of their corresponding continuous time processes. That is, at any given time

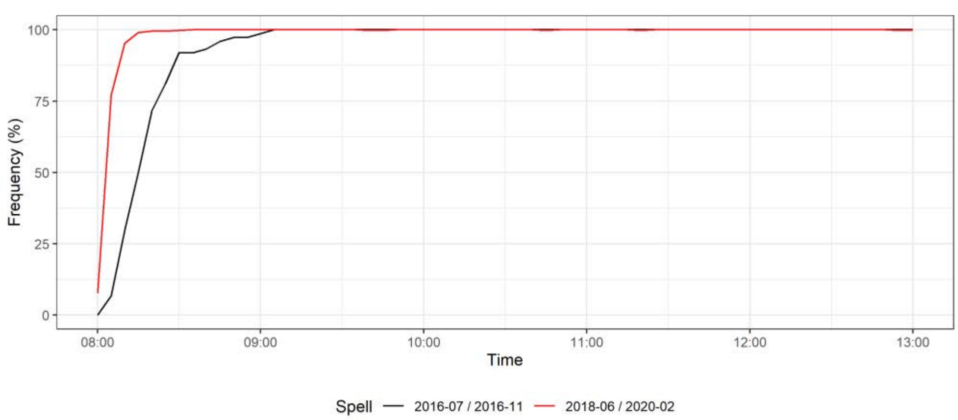
[13] For instance, TFIT16180930 refers to a 16-year maturity bond with maturity date 18-Sep-2030.

the bid/ask price is the corresponding to the latest event that occurred exactly at that time or before. However, Non-Available (NA) bid/ask price records may arise when the list of active quotes at a time mark is empty.

Sampling from these continuous time bid/ask processes is performed as follows. The bid/ask price at 8:00 a. m. corresponds to the recorded at the earliest event up to 8:02 a.m.[14]. The bid/ask price at the upper limit of every five-minute (semi open) interval until 1:00 p.m. is the corresponding to the latest event within the interval.

However, it is worth emphasizing that illiquidity gives rise to extended periods of Non-Available, NA, bid or ask prices especially at market opening. Thus, high liquidity sessions characterize for having a share of NA's below a threshold. This is clearly illustrated in Figure 1, which shows the frequency of bid/ask prices along the day for a period of high liquidity in comparison to a period of low liquidity. This Figure illustrates that illiquidity relates to a reduced frequency of bid/ask prices right after the market opens. In a liquid spell the frequency of bid/ask prices tend to increase (and the frequency of NAs reduce) steeply during the first minutes. This growth staggers in non-liquid sessions. Therefore, market illiquidity relates to a low number of bid/ask quotes during the first hours of the session.

Figure 1. Frequency of bid/ask prices in High Liquidity Versus Low Liquidity Spells



Source: Author's calculations

As a result, a high liquidity spell is defined as a continuous interval of time within which all sessions have high liquidity. In this way, we split the sample into alternating high/low liquidity spells of varying duration depending on the species. Table 1 illustrates these findings for the longest outstanding maturity TES species. For this table the NA threshold is 5/61=8%. However, since most of the missing data appear at the start of the session, the time-marks before 9:00 a.m. were excluded from our analysis. The remaining NA's were imputed from the nearest prices to complete the dataset.

[14] TES quotes from one session do not pass over to the following session.

Table 1. Liquidity Spells and Spell Duration for the Longest Outstanding Maturity TES Species

MNEMONIC	N Sessions	Min Date	Max Date
TFIT16180930	187	1/15/2015	10/20/2015
TFIT16180930	189	3/23/2016	12/29/2016
TFIT16180930	236	6/1/2018	5/21/2019
TFIT16240724	224	1/2/2015	12/2/2015
TFIT16240724	275	12/4/2015	1/20/2017
TFIT16240724	438	6/1/2018	3/16/2020
TFIT16280428	162	1/2/2015	9/2/2015
TFIT16280428	414	7/5/2018	3/11/2020
TFIT16300632	312	6/1/2018	9/11/2019

Source: Author's calculations

Two facts are worth stating from Table 1. First, the longest liquidity spells, barely reach two years of data and the longest standing maturity species reaches a little over a year and a half data. We will concentrate our results on the longer liquidity spells of the TFIT16280428 and TFIT16180930 which required the minimum imputation.

2.2. Foreign Exchange Market: TRM

This market has the following features. Trading sessions run from 8:00 a.m. to 1:00 p.m., Monday through Friday excluding national holidays. Its agents are an assortment of private and government financial intermediaries[15], the Ministerio de Hacienda (the nation's Treasury), and BanRep. This market runs in the SET FX platform of the Colombian Stock Exchange, BVC for its name in Spanish.

This market is very liquid as found by Bejarano-Salcedo, Moreno-Jimenez and Julio-Román (2020). However, the dataset we obtained contains bid/ask prices but no information about quotes. For this reason, the number of quotes and volume quoted is not available for this market. Furthermore, the same sampling procedure described above was performed for the FX market.

2.3. TES and FX Prices and Returns

Following Dominguez (2006) we approximate TES prices as the weighted bid/ask price average at the sample time marks as follows

$$P_{t,n} = \frac{\left[M_{ask} * P_{t,n}^{ask} \; + M_{bid} * P_{t,n}^{bid}\right]}{M_{ask} + M_{bid}}$$

where
$P_{t,n}$ is the price for the n-th interval for the t-th session in the sample
M_{ask} is the volume of the best ask quote

[15] These financial intermediaries receive the authorization from the Junta Directiva del BanRep (BanRep's Board of Governors, JDBR).

M_{bid} is the volume of the best bid quote

For the FX market, where no volumes are available, the price is the simple bid/ask price average.

With these prices at hand, we calculate the *n*th 5-minute interval return on day *t* as the continuously compounded return as follows

$$R_{t,n} = \ln\left[\frac{P_{t,n}}{P_{t,n-1}}\right]$$

At this point it is worth emphasizing that inter-day returns are not considered because of two reasons. First, these returns are calculated from the most volatile prices, the closing price from one session and the opening price in the following, when it is more difficult to obtain a signal. And second, these returns are calculated over several-days' intervals for the opening return after weekends, long weekends and holidays.

2.4. Macroeconomic News Releases, Expectations and Surprises

Time stamped US and Colombian macroeconomic news releases and expectations were obtained from Bloomberg's World Economic Calendar[16], mostly. Announcement time stamps come from the Bloomberg's newsfeed when available, and otherwise from Reuters' newsfeed. Macroeconomic expectations about these data releases, in turn, were retrieved from Bloomberg news.

From macroeconomic announcements and expectations, time stamped standardized macroeconomic surprises were calculated following Andersen et. al. (2003) as follows

$$D_{i,t} = \frac{A_{it} - E_{it}}{\hat{\sigma}_i}$$

where
i: The indicator index
A_{it}: The announced value of indicator *i* at time *t*
E_{it}: The market's expectation of indicator *k* at time *t*
$\hat{\sigma}_i$: The sample standard deviation of the surprise

According to Andersen et. al. (2003) "This standardization affects neither the statistical significance of the estimated response coefficients nor the fit of the regressions compared to the results based on the "raw" surprises, because $\hat{\sigma}_k$ is constant for any indicator *k*".

Finally, the time mark of each surprise is modified to accommodate price's sample marks as follows. Afterhours surprises were assigned the time mark of the following session opening, 9:00 a.m., while intraday surprises were assigned to the next intraday interval time mark.

16 The macroeconomic variables included in the study for US are: GDP, Business Inventories, Construction Spending, ISM Manufacturing, US Leading Index, New Home Sales, Chicago PMI, Trade Balance, Conference Board Consumer Confidence, Jobless Rate, Consumer Credit, FOMC Rate, Budget Statement, Markit Services PMI, Retail Sales, Housing Starts MoM, Nonfarm Payrolls, ADP, Jobless Claims, CPI, IPP, Durable Goods, Factory Orders, Industrial Production and Personal Spending. In the Colombian case, the variables are: Trade Balance, Urban Jobless Rate, CPI, Monetary Policy Rate, Manufacturing Production, Retail Sales and GDP.

In this way, our three datasets are merged through the common sample time marks.

3. Empirical Approach

We estimate TES and TRM market spillovers through heteroskedasticity identified VARs and event study models as in Andersen et al. (2003), Domínguez (2006), and Rigobon (2003). These models aim to estimate the spillovers to and from the TES and FX markets in returns, return volatilities and bid/ask spreads. Spillover from TRM volatility to the number of quotes and volumes in the TES market will also be presented.

Following these authors, we employ macroeconomic news surprises and lags of the dependent variable as controls. Furthermore, whenever intraday seasonality of the regressor/dependent variable is suspect, it is included in the estimation as shown below.

3.1. The Interdependency of TES and TRM Returns

Spillovers between the returns of the TRM (*k=0*) and TES (*k=1*) markets may be studied through the reaction of $R_{t,n}^{k}$ to the contemporaneous and lagged returns of the complementary market, $R_{t,n}^{1-k}$, controlled for the dynamic response to its own lags, $R_{t,n}^{k}$, and the lead and lagged effect of macroeconomic surprises, $D_{t,n+i}^{k}$ as follows

$$R_{t,n}^{k} = \alpha_0 + \sum_{i=1}^{m} \alpha_{2,i}^{1-k} R_{t,n}^{1-k} + \sum_{i=1}^{m} \alpha_{3,i}^{k} R_{t,n}^{k} + \sum_{k=1}^{K} \sum_{i=-m}^{m} \alpha_{1,i}^{k} D_{t,n+i}^{k} + \varepsilon_{t,n}^{k} \tag{1}$$

where:

k is the type of asset (*k=1* for bonds and *k=0* for the exchange rate).
$R_{t,n}^{k}$ is the *n*-th return in day *t.*
$D_{t,n+i}^{k}$ is the standardized news' surprise for announcement i at the *n-i* time interval of day *t*
$\varepsilon_{t,n}$ is a white noise error term

By assigning *k* to its two possible values (*k=1* for bonds and *k=0* for the exchange rate), a two-equation VAR model in the vector process $\boldsymbol{R}_{t,n} = \begin{bmatrix} R_{t,n}^{k} & R_{t,n}^{1-k} \end{bmatrix}^T = \begin{bmatrix} R_{t,n}^{TRM} & R_{t,n}^{TES} \end{bmatrix}^T$ arises from Equation (1) with Reduced Form Errors, RFE, in vector $\boldsymbol{\varepsilon}_{t,n} = \begin{bmatrix} \varepsilon_{t,n}^{k} & \varepsilon_{t,n}^{1-k} \end{bmatrix}^T$.

The parameters on interest in this paper are responses to Structural Form Errors, SFE, in vector $\boldsymbol{\vartheta}_{t,n} = \begin{bmatrix} \vartheta_{t,n}^{k} & \vartheta_{t,n}^{1-k} \end{bmatrix}^T$ where the relationship between RFE and SFE is given by

$$\boldsymbol{\vartheta}_{t,n} = \boldsymbol{A}\boldsymbol{\varepsilon}_{t,n} \tag{2}$$

with

$$\boldsymbol{A} = \begin{bmatrix} 1 & a_{12} \\ a_{21} & 1 \end{bmatrix}$$

where the scalars a_{12} and a_{21} determine the contemporaneous interaction between market returns.

Identification of these parameters may be achieved under the assumptions that the structural errors are zero mean as well as their cross products, $E_t\left[\vartheta_{t,n}^{k} \times \vartheta_{\tau,m}^{1-k}\right] = 0$, and have conditional heteroskedasticity to $\mathcal{F}_t$ denoting the information available until time t,

$$E\left(\boldsymbol{\vartheta}_{t,n}\boldsymbol{\vartheta}_{t,n}{}^{T}\middle|\mathcal{F}_t\right) = \boldsymbol{\Sigma}_{t|t-1} = \boldsymbol{A}\boldsymbol{H}_{t|t-1}\boldsymbol{A}^{T}$$

where we assume

$$\boldsymbol{H}_{t|t-1} = diag(h_{t,n}^{k}, h_{t,n}^{1-k})$$

In the context of identification typically low order GARCH (1,1) specifications are required, such that the individual variances exhibit a dynamic structure as:

$$h_{t,n}^{k} = (1 - \gamma^{k} - g^{k}) + \gamma^{k} h_{t,n}^{k} + g^{k} \vartheta_{t,n}^{k}$$

$$h_{t,n}^{1-k} = (1 - \gamma^{1-k} - g^{1-k}) + \gamma^{1-k} h_{t,n}^{1-k} + g^{1-k} \vartheta_{t,n}^{1-k}$$

Under suitable distributional and parametric restrictions, GARCH parameters are all positive and $\gamma^{j} + g^{j} < 1 \;\; j = k, 1-k$, Sentana and Fiorentini (2001) showed that the structural parameters in $\boldsymbol{A}$ are uniquely identified if there are at least $K-1$ GARCH-type variances present in $\boldsymbol{H}_{t|t-1}$. The parameters γ^{j}, g^{j} and a_{ij} can be estimated by maximum likelihood.

3.2. Intraday Seasonality

In their role of risk and liquidity indicators, return volatility, the bid/ask spread, the number of quotes and total quote volume within intraday intervals tend to be related. As a matter of fact, at session opening the number and volume of quotes is small, which leads to a wide bid/ask spread and large return volatility. As the market progressively agrees on the effect of after-hours shocks, the number and volume of quotes increase, leading to narrowing bid/ask spread and shrinking return volatility. This trend continues until midday when the highest market liquidity arises, which reflects in the largest number of quotes and quote volume, the smallest bid/ask spreads and return volatility within the session. Afterwards, a slight downward trend in the number of quotes and quote volume occur, which is accompanied by an upward bid/ask spread and return volatility trend until the session closes.

As a result of these intraday systematic patterns, seasonality may emerge. This intraday volatility and bid/ask spread seasonality should resemble a smile, while the corresponding number of quotes and quote volume ought to look like inverted smiles. See Dominguez (2006) and Bejarano-Salcedo, Moreno-Jimenez and Julio-Román (2020), for instance. Not considering this seasonality may negatively affect the estimation of the interrelationship between the two assets as pointed out by Dominguez (2006).

We estimate this intraday seasonality through spline functions. We depart from the Fast Fourier Transform specification employed by Dominguez (2006, Eq. 4-8 pp. 1057-1058) because of the lack of fit observed in her Figure 1. We propose, instead, to fit cubic splines. A spline is a very flexible function which consists of a set of cubic functions continuously joined at several points of time (nodes) within the session, that also has continuous derivatives. These restrictions lead to the existence of unique cubic spline basis, that is a set of variables in $\boldsymbol{\varsigma}_{\tau,n}$, that engender any other spline. A detailed description of the construction of these spline bases may be found in De Boor (2003) and Julio-Román et.al. (2002, Sec. 4.2.1.). Every spline can be written as a linear combination of the spline basis, that is $\boldsymbol{\varsigma}_{\tau,n}^{T}\boldsymbol{\beta}$, at every time τ within the session.

In the case of the return volatility seasonality, we replace Dominguez (2006, Eq. 7 pp. 1058) by

$$f_{t,n} = \boldsymbol{\varsigma}_{t,n}^{T}\boldsymbol{\beta} + \varepsilon_{t,n} \tag{4}$$

so that the volatility seasonal is calculated from

$$s_{t,n}^{\sigma} = \frac{T e^{\hat{f}_{t,n}/2}}{\sum_{t=1}^{T}\sum_{n=1}^{N} e^{\hat{f}_{t,n}/2}} \tag{5}$$

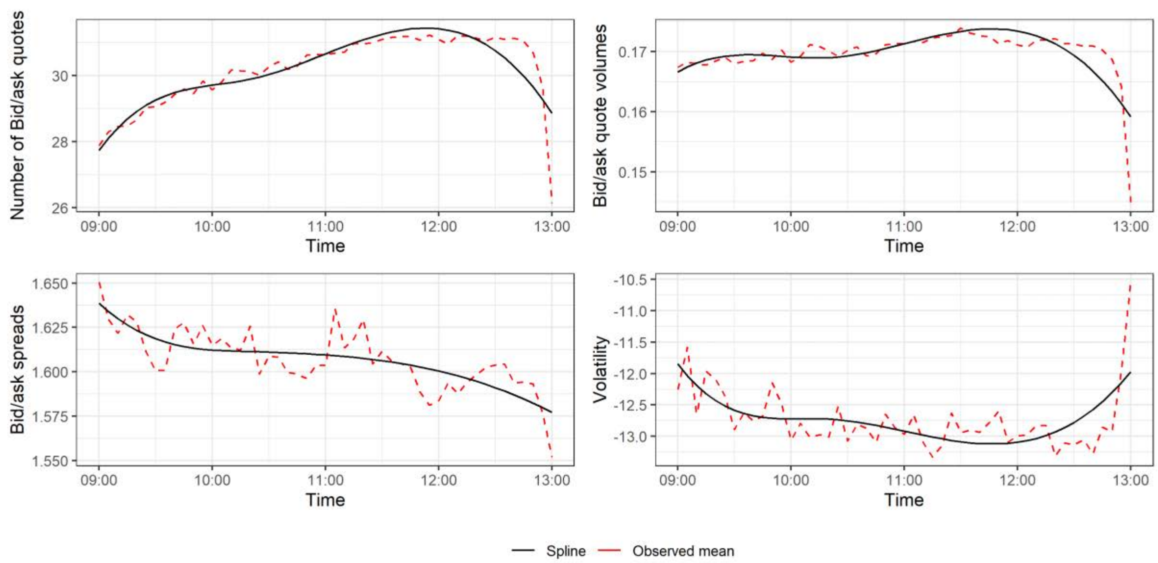
For the bid/ask spread, the number and volume of quotes, the dependent variable in Equation (4) is the variable of interest as follows

$$x_{t,n} = \boldsymbol{\varsigma}_{t,n}^{T}\boldsymbol{\beta} + \varepsilon_{t,n} \tag{6}$$

and its seasonality estimate becomes $s_{t,n}^{x} = \boldsymbol{\varsigma}_{t,n}^{T}\widehat{\boldsymbol{\beta}}$, where $x_{t,n}$is either the bid/ask spread, the number of quotes or the volume of active quotes at the upper limit of each intraday interval.

A sample of these estimates for the TES species TFIT16180930 may be found in Figure 2.

Figure 2. Intraday Seasonality Estimates for TFIT16180930



Source: Author's calculations

Figure 2 reveals important features of the bond market in Colombia. First and foremost, the behavior of intraday volatility, bid/ask quote volume and the number of bid/ask quotes is the expected as described above. The bid/ask spread, however, looks odd at the very end of the session. The observed average spread (the dashed red line), has the expected behavior right up to 12:45 p.m. The spread starts high at the session's opening and reduces as the market cumulates and agrees on information. This trend reverses close to noon until 12:45 p.m. when it drops first slightly and then abruptly at

1:00 p.m. As a result, the spline approximation, which is heavily influenced by the data points at the start and end of the session, does not look like a smile but a smirk. This phenomenon is associated to the difficulty agents face to fulfill their trading quota during the most liquid times in the session. This fact compels them to modify their quota conditions to close operations right before the end of the session while other agents retire or let die their positions. Under these circumstances a bid/ask price drop might be observed at the end of the session.

3.3. The Interdependency of TES and TRM Return Volatility, Bid/Ask spread, Number and Volume of Quotes

Let $x_{t,n}^{k}$ denote either the seasonally adjusted squared return (${R_{t,n}^{k}}^{2} - {\hat{s}_{t,n}^{\sigma_k}}^{2}$), the seasonally adjusted bid/ask spread $S_{t,n}^{k} - \hat{s}_{t,n}^{S_k}$, the seasonally adjusted number of quotes within an intraday interval $N_{t,n}^{k} - \hat{s}_{t,n}^{N_k}$, or the seasonally adjusted quote volume $V_{t,n}^{k} - \hat{s}_{t,n}^{V_k}$, in the *k*-th market. Spillovers between the TRM (*k=0*) and TES (*k=1*) markets may be studied through the reaction of $x_{t,n}^{k}$ to the contemporaneous and lagged quantity in the complementary market, $x_{t,n-i}^{1-k}$, controlled for the dynamic response to its own lags, $x_{t,n-i}^{k}$, and leads and lags of macroeconomic surprises, $D_{t,n+i}^{k}$ as follows

$$x_{t,n}^{k} = \alpha_0 + \sum_{i=0}^{m} \alpha_{2,i}^{1-k} x_{t,n-i}^{k} + \sum_{i=1}^{m} \alpha_{3,i}^{k} x_{t,n-i}^{1-k} + \sum_{k=1}^{K} \sum_{i=-m}^{m} \alpha_{1,i}^{k} D_{t,n+i}^{k} + \zeta_{t,n}^{k} \quad (7)$$

where:

k is the type of asset (*k=1* for bonds and *k=0* for the exchange rate).
$R_{t,n}^{k}$ is the *n*-th return in day *t*.
$D_{t,n+i}^{k}$ is the standardized news' surprise for announcement i at the *n-i* time interval of day *t*
$\varsigma_{t,n}$ is a white noise error term

By replacing *k* by *1-k* in Equation (7) a two-equation system that determines the interrelationship of volatilities and bid/ask spreads of TES and TRM markets arise. Since no information about the number or volume of TRM quotes is available, equation (7) may be estimated for the TES market only. For TES number of quotes and quote volume we replace the number of bid/ask quotes and their volume in the FX market by its seasonally adjusted squared return. In this way, a response to risk shocks emerges.

4. Results

The results are contained in five subsections, each relating to the estimation of the interrelationship between TES and TRM returns, square returns and bid/ask spreads, as well as the response of the number and volume of bid/ask TES quotes to square TRM returns.

4.1. The Interdependency of TES and TRM Returns

Return interdependency results obtained from the estimation of the two versions of Equation (1), *k*=0 and *k*=1, may be found in Figures 3 and 4. Figure 3 displays the response of TES returns (top panels) and prices (bottom panels) to an exchange rate shock while Figure 4 shows the response of exchange rate returns (top panels) and the exchange rate (bottom panels) to a bond return shock. In these Figures the left-hand side panels portray the results for TFIT16280428, while the right-hand side ones refer to TFIT16300632.

Identification of the contemporary response of TRM and TES returns to SFE shocks was performed as described in Section 3.1. These estimates are as follows

TFIT16280428

$$\widehat{\boldsymbol{A}} = \begin{bmatrix} 1 & -0.001364 \\ -0.066949 & 1 \end{bmatrix}$$

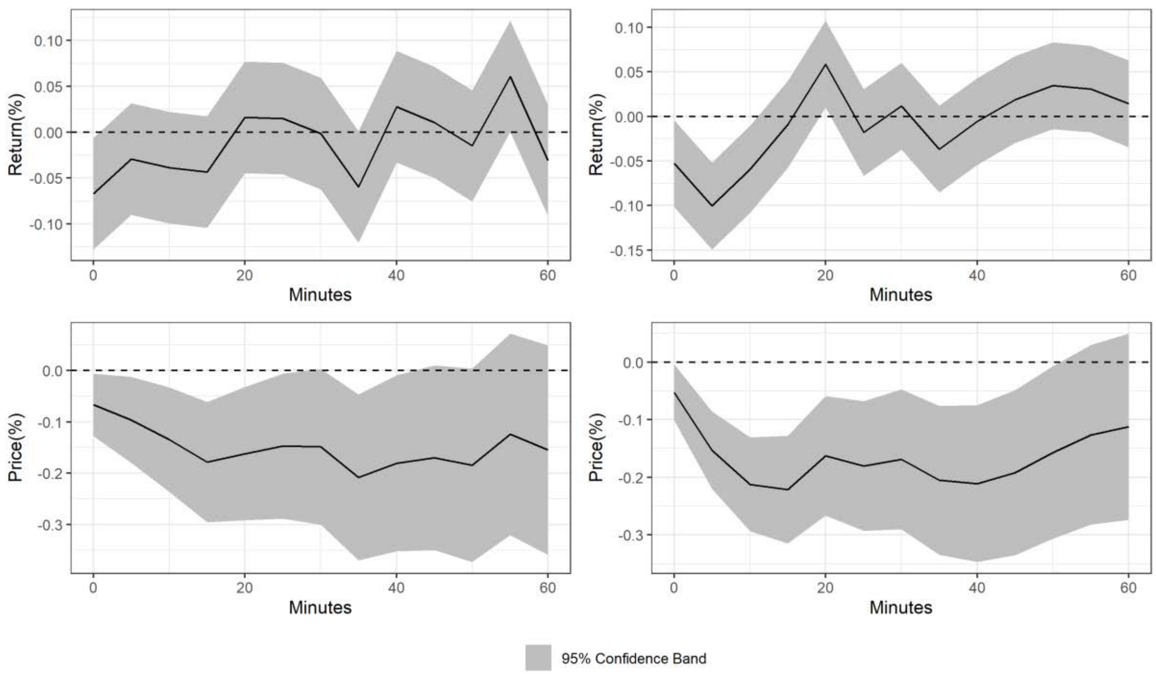
TFIT16300632

$$\widehat{\boldsymbol{A}} = \begin{bmatrix} 1 & -0.007007 \\ -0.010175 & 1 \end{bmatrix}$$

where the response vector is $\boldsymbol{R}_{t,n} = \begin{bmatrix} R_{t,n}^{TRM} & R_{t,n}^{TES} \end{bmatrix}^T$.

Figure 3. Response of Bond Returns and Prices to an Exchange Rate Return Shock

TFIT16280428 TFIT16300632

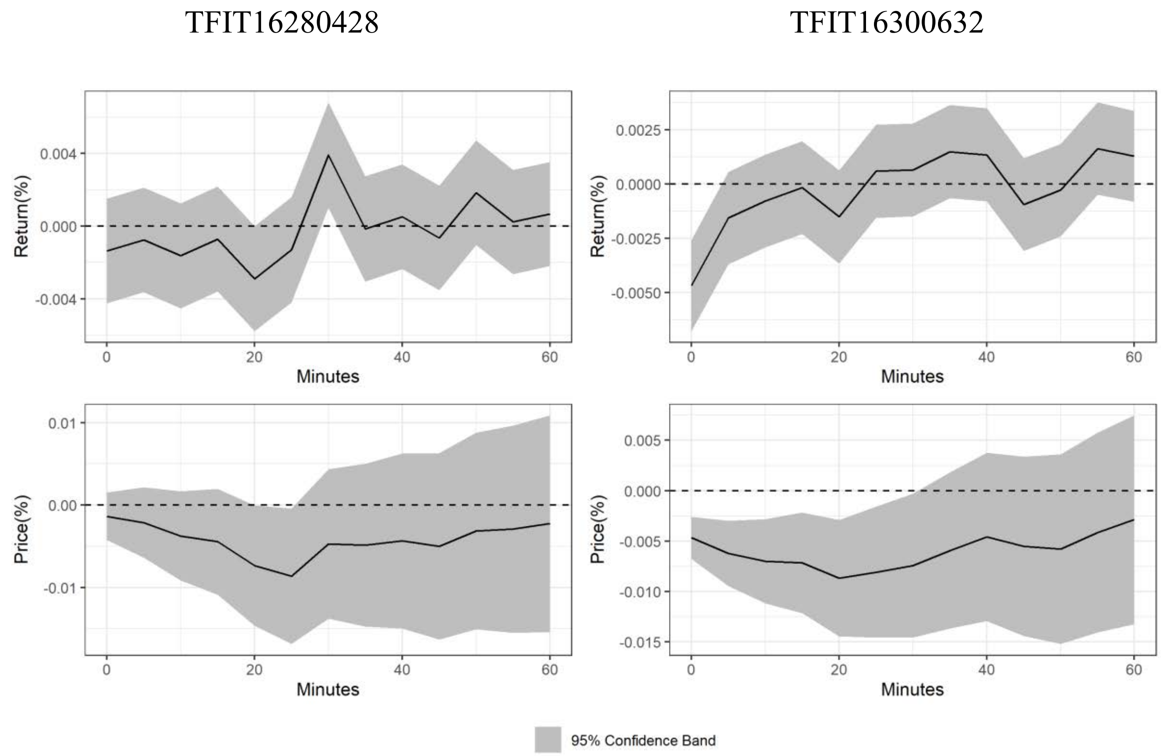


Source: Author’s calculations

The results in Figure 3 conclusively show that a 1% exchange rate return increase leads to a significant contemporary TES price drop, which is sustained for approximately one hour. As a matter of fact, the left-hand side panels reveal that a 1% exchange rate return shock leads to a significant contemporary return drop of 0.07% in TFIT16280428, with no significant return effect afterwards. However, this species returns remain non significantly negative during the following 15 minutes. As a result, a contemporaneous TFIT16280428 price drop of 0.07% is observed. This price drop widens to 0.18% 15 minutes and to 0.22% 35 minutes after the shock and remains border line significant until 50 minutes after the shock. The right-hand side panels, in turn, show a contemporary TFIT16300632 price drop of 0.06%, which reaches about 0.22% 15 minutes after. The effect of this shock on this species price dies out slowly and is close to 0.11% after one hour.

The effect of the foreign exchange shock on the bonds in the Colombian case is at odds with Andersen et al (2003), Chow et al (1997) and Ehrman et al (2011) results for the American and European markets. Nonetheless, our results are coherent with some of the existing evidence in other emerging markets such as Sensoy et al (2014), Sanchez (2008), Bautista et al (2003), Andrieș et al (2017) and Hoffmann et al (2020) for the Turkish, Philippines, Romanian and other markets from Asia and Latin America.

Figure 4. Response of the Exchange Rate and its Returns to a Bond Return Shock



Source: Author's calculations

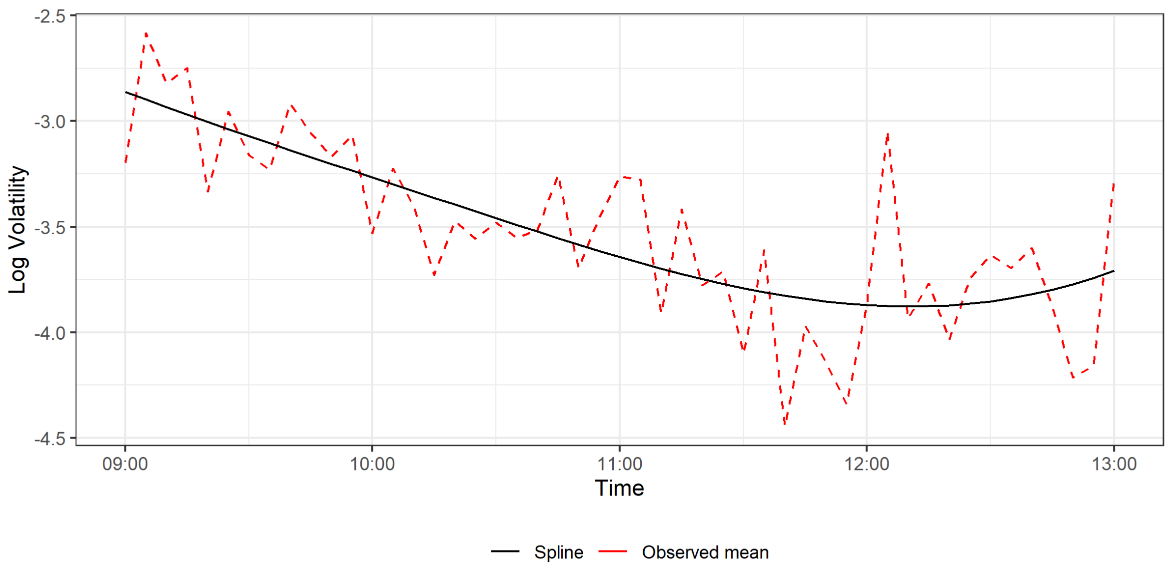
Figure 4 leads us to conclude that a 1% TES return increase leads to an ambiguous and very small COP appreciation which is short lived. As a matter of fact, a 1% TFIT16280428 return increase leads to a contemporary and non-significant COP appreciation of 0.001%, which increases up to a border line significant 0.09% 25 minutes later, to vanish afterwards. A similar response arises after a 1% TFIT16300632 return increase. On impact, a 0.004% COP appreciation shows, which increases to 0.008% 20 minutes after, to disappear 30 minutes after the shock.

The impact in the Colombian case contradicts the results of Andersen et al (2003), who exposed that an increase in US bond prices leads to an USD/EUR depreciation. However, the small and nonsignificant effect of a bond shock in the Colombian FX market is coherent with the findings of Beirne and Giek (2014), who proved that the effect of bond shocks is not significant regardless the country of origin of the shock, both on normal and crisis periods.

4.2. The Interdependency of TES and TRM Volatility

According to Dominguez (2006), to measure the interdependence of bonds and exchange rate volatility, intraday volatility seasonality must be considered. The intraday TES returns volatility estimate is shown in the bottom-right panel of Figure 2. For exchange rate returns this estimate may be found in Figure 5, which shows a persistent volatility decline until midday when a minimum is reached, coinciding with the highest liquidity of the market. This figure is remarkably different from its TES counterpart, bottom-right panel in Figure 2. In the former a minimum is reached quite rapidly, while in the latter volatility remains in a plateau.

Figure 5. Exchange Rate Returns Intraday Volatility Seasonal Estimate



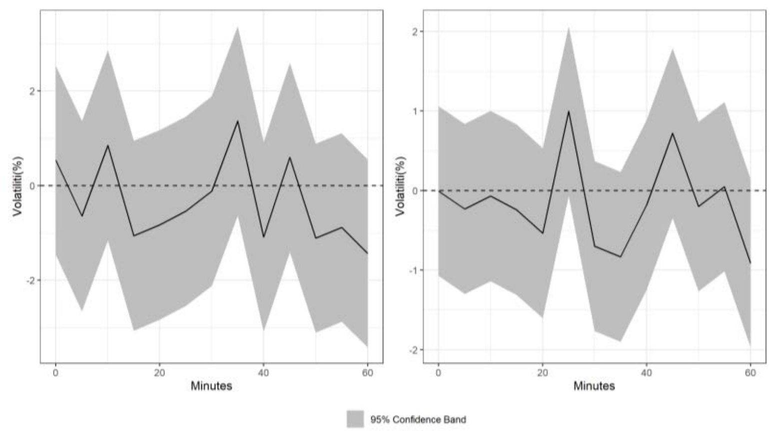
Source: Author's calculations

The interrelationship between bonds and exchange rate excess (over the seasonality) volatility arises from the estimation of Equation (7) for k=0 and k=1. These models explain the excess squared return in one market as a function of the excess squared return in the second market, controlled for the market's own dynamics and the effect of news surprises.

The results are shown in Figures 6 and 7, whose left-hand panels refer to the TFIT16280428 species and the right-hand side to TFIT16300632. Figure 7 depicts the response of bonds excess volatility to an exchange rate volatility shock, and Figure 8 portrays the response of TRM excess volatility to a TES volatility shock.

Figure 6. Response of Bonds Excess Volatility to an Exchange Rate Excess Volatility Shock

TFIT16280428 TFIT16300632

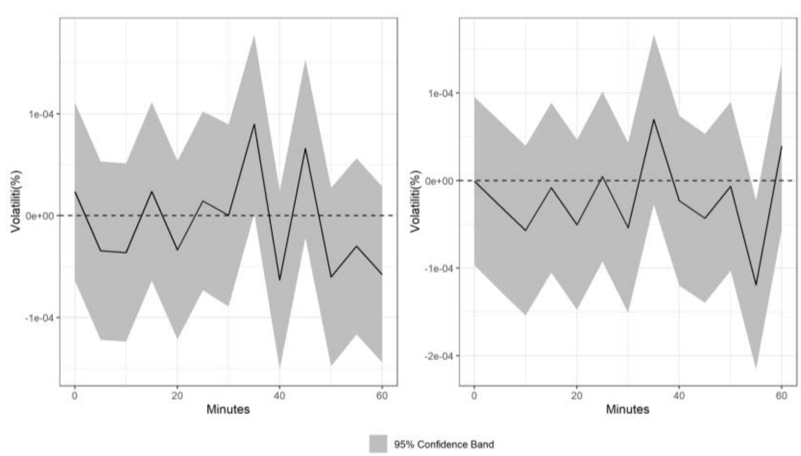


Source: Author's calculations

Figure 6 shows that excess exchange rate volatility does not affect bond volatility. A single fact may help explain this result. After an exchange rate risk shock, bond market liquidity might be affected as follows. The bond market traders might show less willingness to close trades and post a below normal number of bid/ask quotes. These facts reduce the frequency of bid/ask price changes, thus increasing bid/ask price duration. This extended duration may lead, even, to a lower bond return volatility rather than a higher one. Therefore, exchange rate volatility shocks may not translate into higher bond return volatility but to lower bond market liquidity. We explore this link below.

Figure 7. Response of the Excess Volatility of the Exchange Rate to a Bond Volatility Shock

TFIT16280428 TFIT16300632



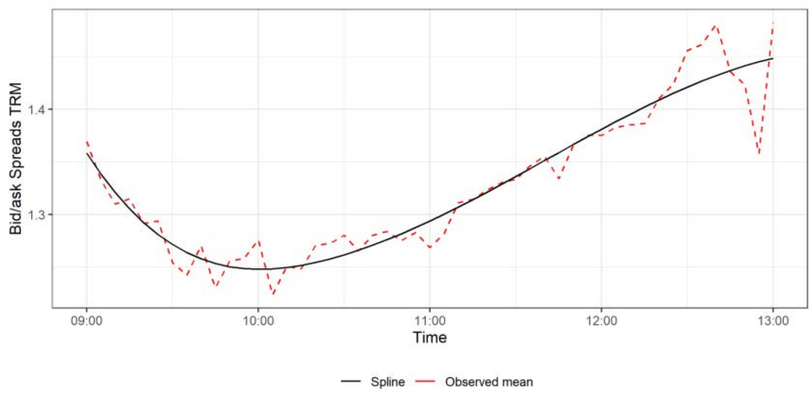
Source: Author's calculations

The results in Figure 7, however, cannot be interpreted in the same manner as those of Figure 6 since the FX market is quite liquid. In this case, the lack of exchange rate excess volatility resulting from a bond return volatility shock seems to be genuine. Thus, increase bond volatility does not seem to have an impact on exchange rate volatility.

4.3. The Interdependency of TES and TRM Bid/Ask Spreads

Bid/Ask spreads have a well-known systematic intraday behavior related to market liquidity. An estimate of the bid/ask bond spread may be found in the bottom-left panel of Figure 2. The exchange rate bid/ask spread may be found in Figure 8. This spread has the expected smile shape derived from the fact that liquidity is high in the FX market in Colombia.

Figure 8. TRM Returns Intraday Bid/Ask Seasonal Estimate

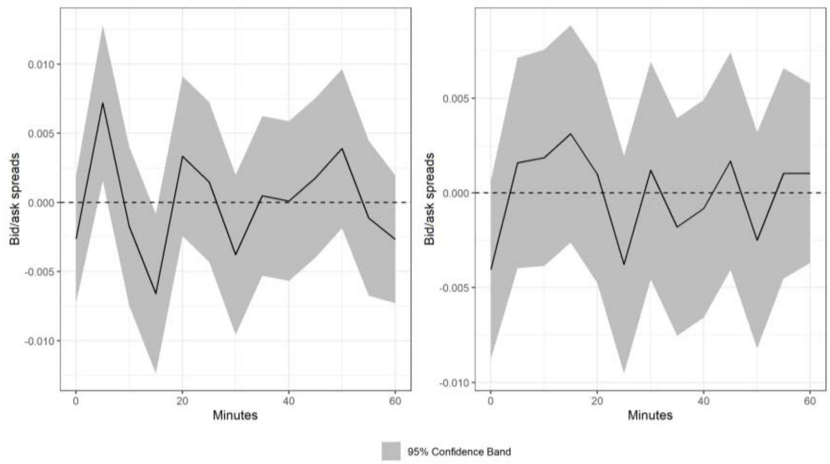


Source: Author's calculations

The estimated spillovers between FX and bond market's spreads come from the estimation of Equation (7) for k=0 and k=1. In these estimations excess (with respect to its seasonality) bid/ask spreads in one market are explained by excess spreads in the other market. Controls for the effect of macroeconomic surprises and the regressand's market dynamics are also included.

Figure 9. Response of Bonds Excess Bid/Ask Spread to an Exchange Rate Excess Bid/Ask Spread Shock

TFIT16280428 TFIT16300632

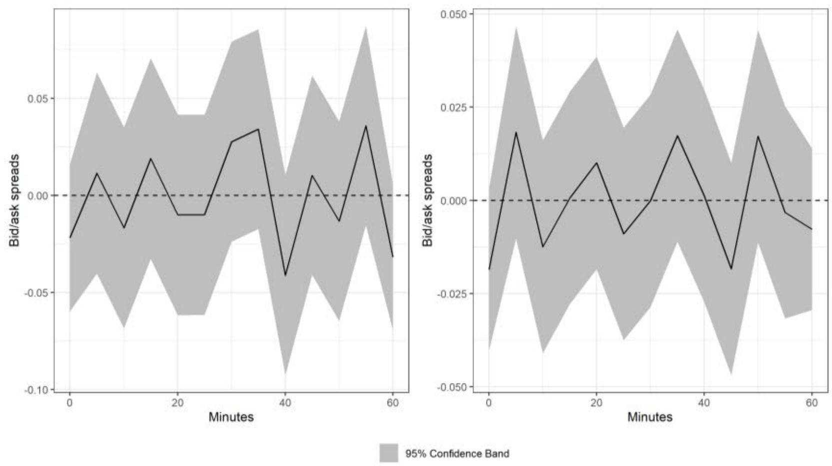


Source: Author’s calculations

Figure 9 suggests that excess exchange rate spread increases bond spread with a lag. This result is clearly illustrated in the case of the TFIT16280428 where a significant excess spread is observed 5 minutes after the shock. A similar increase that lasts longer but not significantly occurs for TFIT16300632, where the spread increase occurs during the following 20 minutes after the shock, but this increase is not significant. This lack of significance may be due to the reduced sample size employed as the last line of Table 1 shows. Therefore, exchange rate risk and/or liquidity innovations seem to affect the risk and/or liquidity of the TES market. This result seems to agree with the fact that exchange rate volatility does not affect bond volatility but its liquidity, as stated above. More direct evidence regarding this point may be found below.

Figure 10. Response of the Excess Bid/Ask Spread of the Exchange Rate to a Bond Bid/Ask Spread Shock

TFIT16280428 TFIT16300632



Source: Author's calculations

Figure 10 shows that the FX market bid/ask spread is not affected by shocks in the bid/ask spread of bonds. Thus, bond risk and/or liquidity does not affect exchange rate risk and/or liquidity.

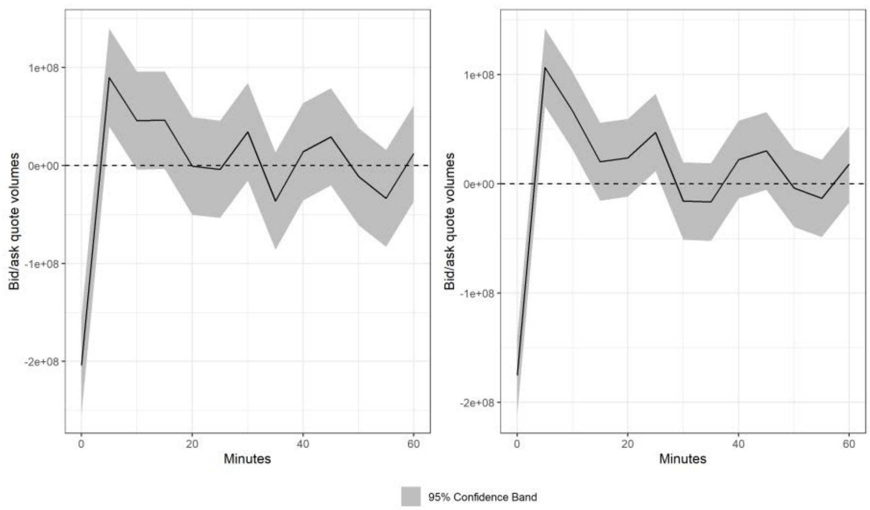
4.4. The Response of TES Bid/Ask Quote Volume to a TRM Volatility Shock

The seasonal behavior of bonds bid/ask quote volume may be found in the top-right panel of Figure 2. This figure reproduces the inverted smile shape expected of market liquidity within a session.

To study the effect of exchange rate volatility shocks on bond liquidity we estimate Equation 7, where the regressand is the excess bid/ask quote volume (over its seasonality) with respect to the excess square TRM return (over its seasonality) controlled by macroeconomic surprises and lags of the regressand. The effect of exchange rate volatility shocks on bond liquidity is contained in Figure 11.

Figure 11. Response of the Bond Bid/Ask quote Volume to an Exchange Rate Volatility Shock

TFIT16280428 TFIT16300632



Source: Author's calculations

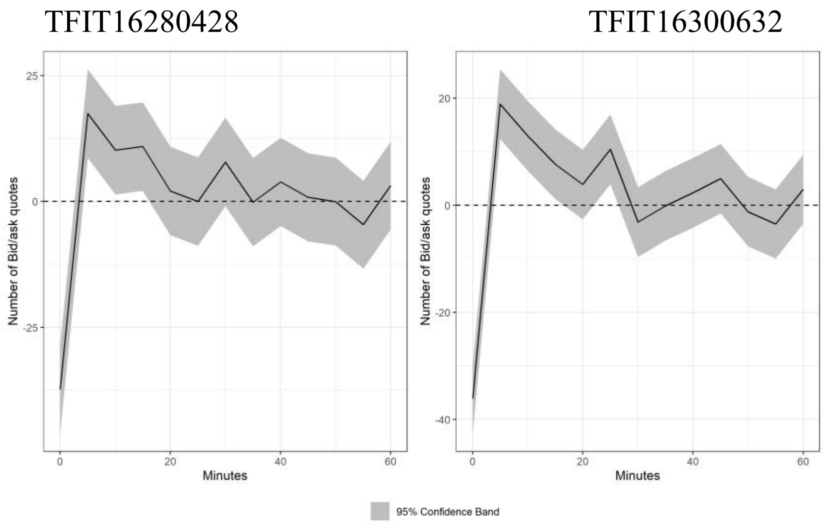
Figure 11 reveals that excess volatility in the FX market leads to bond market illiquidity on impact, with a subsequent rebound and rapid correction soon afterwards. This liquidity fall and its subsequent recovery are statistically significant as well as high in value but short lasting. The market returns to normal just 15 minutes after the shock. This phenomenon might be explained by the fact that Colombian bond traders usually withdraw their quotes after a volatility shock to the FX market occurs, and rapidly reestablish them once the new information is processed.

4.5. The Response of the Number of TES Bid/Ask Quotes to a TRM Volatility Shock

An alternative bond liquidity indicator is the number of bid/ask quotes posted within the 5-minute interval. Its seasonal behavior may be found in the top-left panel of Figure 2. Consistent with the bid/ask volume, the shape of the number of bid/ask quotes along the session resemble the inverted smile expected of market liquidity.

The estimated response follows the lines of the 4.5 subsection by replacing the bid/ask volume by the bid/ask quote number. This response may be found in Figure 12.

Figure 12. Response of the Number of Bid/Ask Bond Quotes to an Exchange Rate Volatility Shock



Source: Author's calculations

Figure 12, not surprisingly, reveals reveal the same information as the response of bond's bid/ask volume. Exchange rate volatility events create bond market illiquidity on impact with a subsequent rapid recovery. The bond market return to normal within 15 five minutes of the volatility shock. As stated in the previous section, this phenomenon might be explained by the fact that Colombian bond traders usually withdraw their quotes after a volatility shock to the FX market occurs, and rapidly reestablish them once the new information is processed.

5. Conclusion

The Colombian FX market plays a key role in the transmission and summarization of shocks to local financial markets due to several reasons. First and foremost, Colombia is a small open economy that follows the IT regime. Under these circumstances the exchange rate adjusts immediately to shocks and foreign economic cycles thus preventing currency crises and allowing the central bank to focus its policies to reaching IT objectives. Second, the FX in Colombia is highly liquid which facilitates the efficient transmission of shocks. And third, the local bond market characterizes for its low liquidity and concentration on long maturity species thus hampering the efficient transmission of shocks. Therefore, a disconnection between the local bond market and macroeconomic fundamentals may arise. These facts show in the interrelationship between the Colombian FX and bond markets.

In this paper we showed that bond prices react to FX shocks, but the opposite does not hold in an economically important or significant way. Furthermore, exchange rate risk shocks do not seem to shift bond market volatility but liquidity, thus reducing sharply the number of bond's market bid/ask quotes and volume, on impact, with a subsequently rapid and important recovery minutes later. We found, additionally, that FX market liquidity increases unleash lagged liquidity surges in the bond market. Finally, bond price shocks do not seem to affect the liquidity or volatility of the FX market. These results arise form high liquidity spells on longer standing maturity bonds, and thus might not extend to other periods or TES species.

These results have important implications for financial stability analyses. As a matter of fact, these results provide the parameters for (i) stress testing scenarios on financial portfolios under exchange rate shocks, and (ii) to refine the measurement of financial institutions' balance sheets to exchange rate shocks. These results shed light, also, on the source of risk in portfolio management and optimization involving TES.

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