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# The Role of Foreign Investors and Local Agents in the Derivatives Market and their Impact on the Exchange Rate in Colombia: A Wavelet Analysis

**Fredy Gamboa-Estrada**
**Banco de la República**

Chemin Eugène-Rigot 2
P.O. Box 136
CH - 1211 Geneva 21
Switzerland

# The Role of Foreign Investors and Local Agents in the Derivatives Market and their Impact on the Exchange Rate in Colombia: A Wavelet Analysis*

FREDY GAMBOA-ESTRADA+

**Abstract**

Changes in net positions of foreign and local investors in the forward market may have differential effects on the spot exchange rate. This paper assesses the role of different sectors in the derivatives market and their potential impact with other fundamentals on the spot exchange rate in Colombia. Using wavelet band spectrum regressions, I find that changes of net forward positions of foreign investors impact the exchange rate at short terms scales. There is evidence that the real sector has a significant and permanent effect on the spot exchange rate at different frequencies that is higher in the long term. Other fundamentals such as the interest rate differential, CDS, and oil prices affect the exchange rate at lower frequencies, which is consistent with the exchange rate determination puzzle. This approach differs substantially from traditional regression methods such as ordinary least squares (OLS) which are not suitable to identify the relationship between variables at different frequencies over time.

**JEL:** C1, C22, C58, F31, G11.

**Keywords:** Foreign investors, local investors, exchange rate, wavelet analysis, band spectrum regression.

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+ Researcher, Monetary and International Investment Division, Banco de la República. E-mail: fgamboes@banrep.gov.co. Correspondent author at Carrera 7 #14-78, Bogotá, Colombia, Tel. +57 1 3430756.

## 1. Introduction

Over the last decade, the volume traded in the derivatives market in Colombia grew at an annual average rate of 9.2%. According to Cardozo, Rassa and Rojas (2014), the growth of portfolio investment by non-resident agents (offshore) in Colombia, the increase of portfolio investment abroad by pension and severance funds, and the greater demand for hedging by the real sector, especially from importing firms, are the main factors driving the increase in the amounts traded in the derivatives market that have the exchange rate as the underlying asset.

In this context, a key question for policymakers is what role different types of foreign and local investors play in the forward market and the potential impact of the different market participants on the spot exchange rate. Although foreign investors participate with more than 50% of the volume traded in the non-delivery forward market (NDF) in Colombia, other type of investors such as the real sector and pension and severance funds may have an important role in the forward market, and therefore in the spot exchange rate.

My paper enlarges the literature on analyzing the determinants of nominal exchange rates using both the macroeconomic and the microstructure approach to exchange rates, and its contribution is twofold. On one hand, this is the first analysis I am aware of that documents the evolution of different agents in the forward market, and how investor heterogeneity plays an important role in the determination of the nominal exchange rate in Colombia, including the recent period of the Covid-19 pandemic. On the other, I decompose exchange rate movements and its fundamentals at different scales over time using wavelet analysis that allows to identify important features for each variable at different frequencies, and their relationship with the exchange rate returns throughout time. The intuition behind this empirical strategy is that the relationship between nominal exchange rates and its fundamentals may be different at different frequencies and it varies over time. Additionally, investor heterogeneity may be a fundamental factor explaining exchange rate movements in the short run, while macro fundamentals may explain the medium and long run exchange rate behavior.

My approach is based on Filardo, Gelos, and McGregor (2022) that use spectral regression methods to analyze the role of macroeconomic fundamentals in determining the equilibrium real exchange rate at different frequencies (short, medium, and long) in 26 advanced and emerging economies. However, in this paper I focus on the nominal exchange rate, and I use wavelet analysis instead of spectral analysis. The main advantage of wavelet analysis is that I can decompose economic time series into different scales over time without the need to use different algorithms to choose frequency bands corresponding to the short, medium, and long-term.

Wavelet analysis literature in economics is still scarce. However, as Crowley (2005) explains, it is more frequent used in finance as provides more information on variability levels with high frequency data. Although some papers study the pattern of exchange rates at different frequencies using this approach (see, e.g., Udin et al., 2013; Jensen and Whitcher, 2014; Kiermeier, 2014; Andries, Ihnatov and Tiwari, 2016; Firouzi and Wang, 2019; Kuşkaya, Toğuç, and Bilgili, 2022), this is the first paper analyzing the main determinants of nominal exchange rates at different scales.

My methodology entails a two-step estimation procedure. First, I decompose all variables into their time scale components using wavelet analysis, each associated to a specific frequency range. Second, I obtain parameter estimates for each time horizon by regressing exchange rate returns on a sub-set of frequencies rather than the entire frequency band.

I show that investor heterogeneity in the non-forward delivery market (NDF) might play a key role in explaining the spot exchange rate in Colombia as the relationship between exchange rate returns and changes in the accumulated offshore net position in the NDF is very short-term (higher at scales of 4-8 and 8-16 days). The real sector NDF positions have higher effects on the spot exchange rate at low frequencies (scales of 256 days and above). The evidence also provides support of the long-term relationship of traditional macroeconomic fundamentals with the nominal exchange rate as the variation in the exchange rate explained by the interest rate differential, CDS, and oil prices is higher at scales above 256 days.

My empirical analysis contributes to the few studies analyzing the role of different agents in the derivatives market and their impact on the spot exchange rate. The debate focuses on studying the role of speculators in the derivatives market and their effect on exchange rate returns. For instance, Klitgaard and Weir (2004) found that the direction of the exchange rate can be predicted with a probability of about 75% by analyzing the behavior of the currency futures market in the United States. Torre and Provorova (2007) showed that transactions of speculators in the currency futures market in Mexico were fundamental determinants of the fluctuations of the Mexican peso. However, the relationship between these variables was not stable due to the rapid growth of the derivatives market. Vargas, Arenas, and Perrotini (2016) evidenced that the net positions of speculators had a contemporaneous and significant effect on the exchange rate in Brazil.

Regarding the role of the real sector in the derivatives market, Dodd and Griffith-Jones (2006) found that the real sector reacted less to movements in the exchange rate in Chile, and therefore it took fewer positions in the forward market, to the extent that its positions were more hedged in foreign currency. [1] Cardozo, Gamboa and Higuera (2019) found a positive relationship between the accumulated net position of foreign investors in the forward peso-dollar market and the exchange rate returns in Colombia, and a negative relationship for the positions of the real sector in the same market. [2]However, they also found that these effects were not stable over time and the exchange rate was less sensitive to the net purchases of each counterparty in the foreign exchange market, which could be related to the deepening of the forwards market in recent years. Although the evidence for Colombia suggests that the real sector sometimes takes contrary positions to those taken by foreign investors, the econometric estimations showed that the real sector did not have a stabilizing role in the forward market.

Analyzing the main determinants of the exchange rate is still a theoretical and an empirical challenge in the economic literature. As Bacchetta and Wincoop (2006) explain, one of the main issues of international macroeconomics is the low explanatory power of macroeconomic variables for the nominal exchange rate. Usually, the literature analyzes the contemporaneous relationship between the spot exchange rate and its fundamentals, such as interest rates, inflation differentials, the terms of trade, government debt levels, commodity prices, and sovereign risk measures. However, in line with the so-called exchange rate determination puzzle (see e.g., Lyons, 2001; Lyons, 2002; Engel et al., 2008), the drivers of nominal exchange rate-movements may differ across different horizons. The exchange rate determination puzzle is less acute in the long run (Bacchetta and Wincoop, 2006) as macroeconomic fundamentals are more related to exchange rate movements at longer horizons (see, e.g., Mark, 1995). Additionally, exchange rate short-run fluctuations are related to investor heterogeneity as evidenced by the literature of the microstructure approach to exchange rates (see e.g., Evans and Lyons, 2002; Sarno and Taylor, 2003; Evans and Lyons, 2012; Rime et al., 2010; Guo, 2017;).

This article consists of four sections including this introduction. The second section describes the data and stylized facts about the performance of foreign and local investor positions in the NDF market in Colombia, and their relationship with exchange rate returns. Section third presents the empirical approach. The

[1] Before 1998, companies in the Chilean real sector did not hedge the foreign exchange risk arising from the gross external debt. However, at the beginning of 1999, they began to increase their hedging at a large scale in the forward market, to the point that they hedged their exposure to the exchange rate for several years.

[2] The empirical results show that between 2008 and 2015, an increase of one million dollars in net forward purchases by foreign investors depreciated the exchange rate by 0.0009%, while net purchases by the real sector appreciated the exchange rate by 0.0013%. On the other hand, net purchases for the same amount by pension and severance funds depreciated the exchange rate by 0.0010%.

fourth section describes the main results. The last section summarizes the main findings and discusses policy implications.

## 2. Data Description and Stylized Facts

In this section, I describe the data and analyze the main stylized facts about the evolution of NDF market positions of foreign and local investor in Colombia and their relationship with the nominal exchange rate.

Transactions in the derivatives market concentrate in the forward peso-dollar segment, while other instruments such as peso-dollar options and cross-currency swaps have a low market participation. When analyzing the modality of compliance, almost all transactions are carried out with financial compliance. NDF allows dollar market participants to protect themselves against the risk of strong future increases in the exchange rate (depreciation of the peso). For instance, the Central Bank of Colombia sells dollars for one month, at an exchange rate that results from an auction made in the present. If the exchange rate is higher than the auction rate after that month, the monetary authority will pay the buyer the difference in pesos. Otherwise, the buyer will pay the Bank the difference, also in pesos. In this way, whoever has a debt in dollars or must make a payment in dollars will be able to guarantee the price of dollars they require and reduce uncertainty about future dollar payments. The lower uncertainty helps calm the fear of the participants in the dollar market and prevents the latter from suffering excessive shocks.

What is the channel trough which transactions by different type of investors may affect the spot exchange rate in Colombia? Foreign exchange market intermediaries (IMC) in Colombia, generally maintain their foreign exchange exposure very close to zero, which implies that the positions they take in the spot market or in the derivatives market are offset in the same markets. For example, when the offshore sells dollars in the forward market and the IMC buys them, the IMC can sell US dollars in the forward market or sell US dollars in the spot market to not affect its foreign exchange exposure. Through this channel they can influence the pattern of the spot exchange rate, as there is an adjustment in both derivatives market prices as in the spot market prices (DODM, 2014).

With data until January 31, 2023, the offshore actively participate with 51.0% of the volume traded with intermediaries of the foreign exchange market (IMC) in the forward peso-dollar market, 19.7% corresponds to transactions with other IMC, 16.5% corresponds to pension and severance funds (PSF), 9.3% to firms in the real sector, and 3.5% to transactions with other agents such as fiduciaries, insurance firms, stockbroker firms, and the Central Bank of Colombia.

Fig. 1 describes the pattern of the accumulated net position of the offshore, the real sector, pension and severance funds, and the IMC-Intra Group[3] in the forward peso-dollar market. One observes that foreign investors (offshore) usually take long positions in the non-forward delivery market (NDF) to hedge their investments. Although the real sector usually takes long positions with the intermediaries of the foreign exchange market, as the most active firms in the derivatives market are importing firms, in some moments takes contrary positions to the transactions negotiated by the offshore. Pension and severance funds usually take a net selling position in the forward market as they have investments abroad, and to hedge them, they must sell USD in the future, which leaves them with a selling position against the IMC. Additionally, the regulation limits the percentage that can be unhedged abroad, so that selling position is persistent over time. Therefore, the behavior of each of these agents may exert different effects on the spot exchange rate in Colombia. Hence, it is important to understand their role in the forward market.

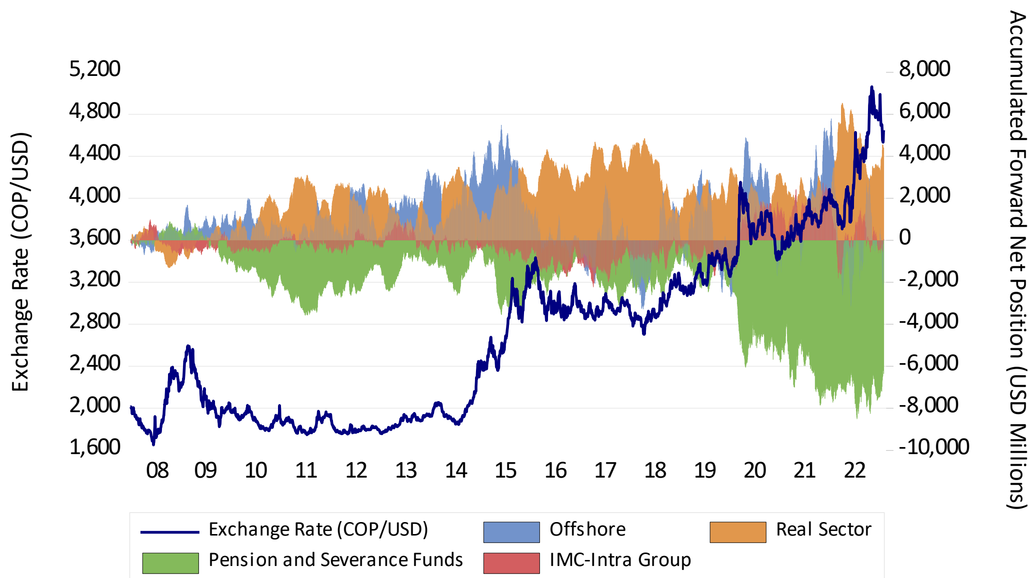


**Fig. 1.** The spot exchange rate and the accumulated forward net position by sector. Source: Banco de la República and author's calculations.

Fig. 2 describes the relationship between exchange rate returns and changes in the accumulated forward peso-dollar net position of the offshore, the real sector, pension and severance funds, and the IMC-Intra Group between January 2008 and January 2023. There is evidence of a positive relationship between the offshore and intragroup forward positions with the exchange rate, and a negative relationship

[3] Corresponds to the transactions between foreign exchange market intermediaries and foreign banks within the same financial group.

between the real sector positions and the exchange rate. On average, when the offshore and IMC-Intra Group purchase US dollars forward the exchange rate depreciates, which does not happen with net purchases of the real sector. The relationship between pension and severance funds positions and the exchange rate although positive it is weak. [4]

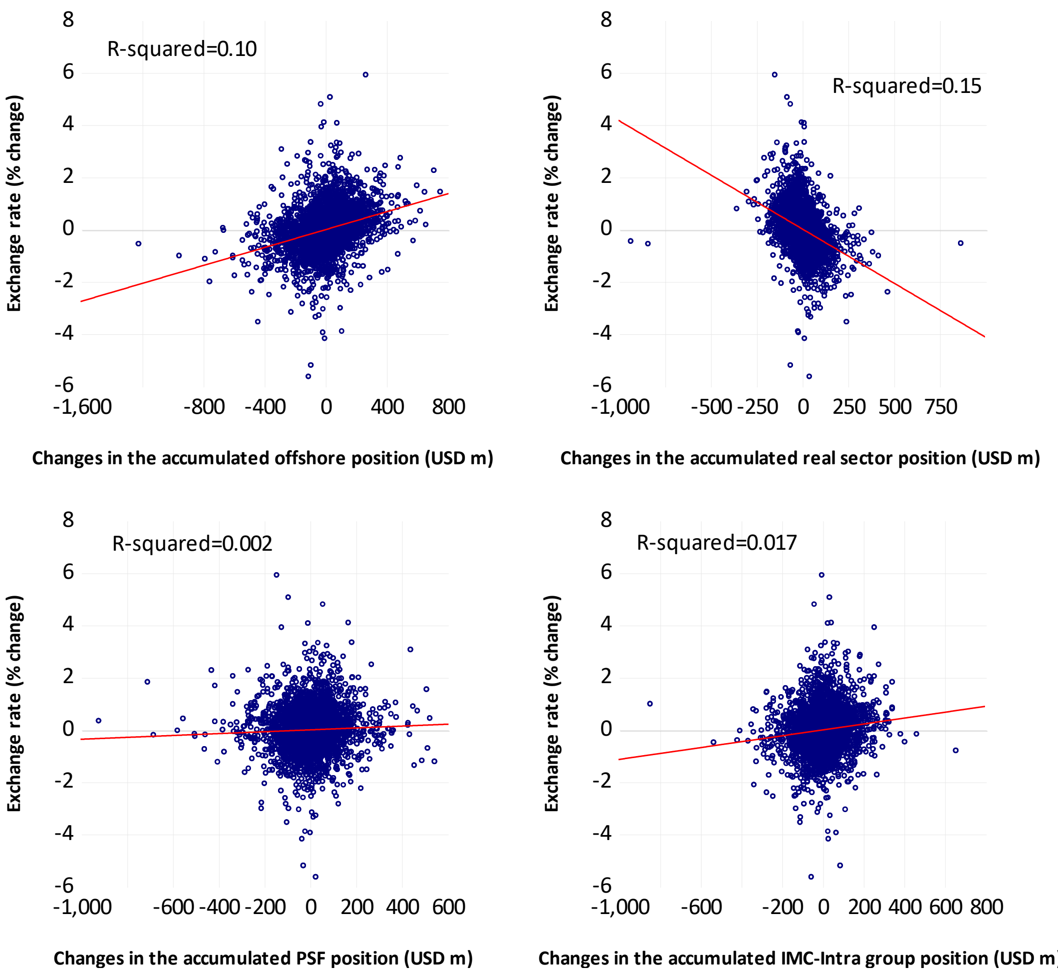


**Fig. 2.** Changes in the spot exchange rate and the accumulated forward peso-dollar net position by sector. Source: Banco de la República and author's calculations.

In Colombia, agents expect that variations in the net positions of foreign and local agents in the forward market other than IMC have an impact on the spot exchange rate (see, e.g., Cardozo, Gamboa and Higuera, 2019). However, the negative

[4] The R-squared for each panel in Figure 2 indicates that 10% of the variation in the exchange rate is explained by offshore purchases in the forward market, 15% is explained by purchases of the real sector, while only 0.2% and 1.7% is explained by purchases of pension and severance funds and the IMC-Intra Group, respectively.

relationship found for variations in the real sector positions and exchange rate returns may be related to the percentage of hedging of these positions. For instance, as Cardozo, Gamboa and Higuera (2019) explain, if a firm has debt in foreign currency but only hedge part of it with a long position in the forward market, the exchange rate will appreciate.

Fig. 3 shows that on average foreign banks participate with 89% of offshore transactions in the NDF market, followed by mutual funds with 10%, and the rest by multilateral organizations and insurance firms. Even though mutual funds only participate with 10% of the volume traded, it is important to analyze if there is any differential effect on exchange rate returns at different scales compared to foreign banks.

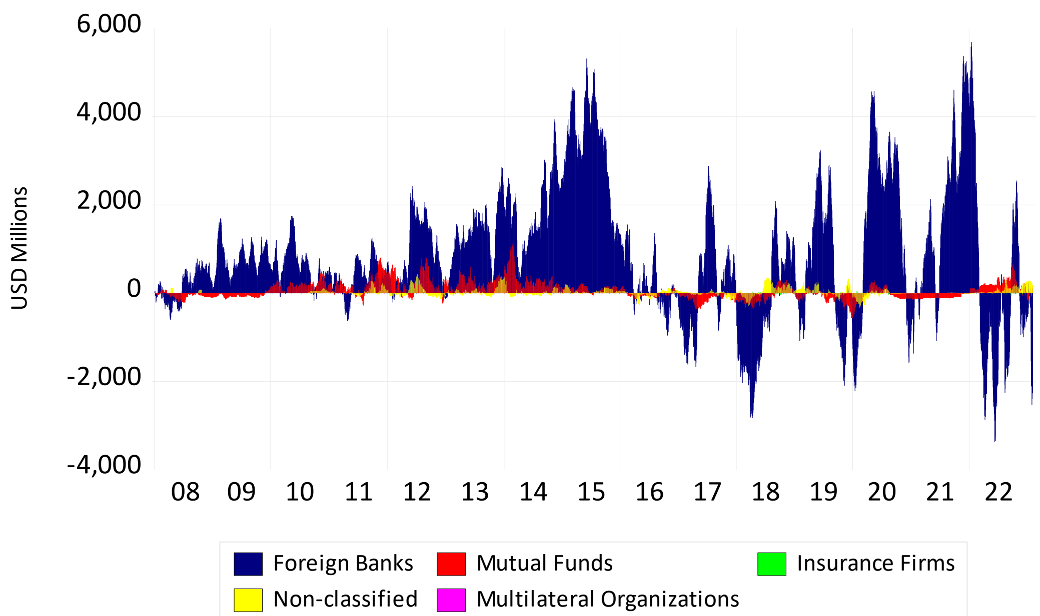


**Fig. 3.** Accumulated forward peso-dollar net position by type of agent in the offshore sector. Source: Banco de la República and author's calculations.

## 3. Estimation Techniques

Wavelet analysis has been applied extensively in disciplines other than economics. This estimation technique is a framework for analyzing time-varying features such as volatility, non-stationarity, and seasonality that is characteristic of most economic time series. This method does not need to impose any assumptions such as stationarity like Fourier spectral analysis does.[5] Therefore, this

[5] Any stationary process has a representation in both the time domain and the frequency domain (Hamilton, 2020). Spectral or frequency domain analysis offers additional

methodology can decompose and reconstruct a time series through wavelet filters, representing a time series signal in the frequency domain, and re-expressing the signal as a linear combination of basis functions.

This approach is a time-frequency analysis that provides information about the main features of a time series at a specific frequency at a given point in time. Therefore, through wavelet analysis I examine the frequency structure of the spot exchange rate and its fundamentals, and then I can perform a time scale decomposition to recognize how the relationship between variables has evolved at different scales rather than at aggregate level.

According to Percival and Walden (2000) wavelets are small waves that begin and die out at a specific finite point in time. They might have different shapes and a fixed number of oscillations which last through a certain period of space and time. Wavelet transformation assumes that frequency content of functions can change over time (they have infinite power). Additionally, wavelet series assume that signals die out (they have finite energy). Wavelets can divide the data into different frequency components and are localized in both time and frequencies. They are useful to analyze different behaviors in different time periods, and suitable to capturing local variation.

### 3.1. Continuous Wavelet Transforms

The basic characteristics of wavelets can be described through the continuous wavelet transform (CWT). Wavelets can be divided by gender and types. Father wavelets $\phi$ and mother waveletes $\psi$ are represented by the following equations:

$$\int \phi(t)dt = 1 \quad (1)$$

$$\int \psi(t)dt = 0 \quad (2)$$

where generally $\phi(t) = \psi(t)^2$. Father wavelets represent the low-frequency (trend) part of the signal while mother wavelets represent the high-frequency (detailed) parts by scale by specifying the amount of dilation of the wavelet (see, e.g. Crowley, 2007). Wavelet transform basically uses two filters at each scale, one low-band filter related to father wavelets and one high-band filter related to mother wavelets. Usually, large scale wavelets are related to low frequencies.

information about the behavior of the time series and the structure of the variance. It is also essential in identifying hidden periodic fluctuations. This analysis tries to determine how important are the cycles of different frequencies in the behavior of a certain time series (Dolinar, 2013). Essentially, it has to do with decomposing a stationary process into a sum of sine and cosine functions with uncorrelated random coefficients. The Fourier analysis assumes that the frequency content of basis functions cannot change over time (they have finite power). Additionally, Fourier series do not die out (they have infinite energy).

Furthermore, there are different types of wavelets. Some are discreet, symmetric, and others asymmetric. Then, for an arbitrary wavelet function $\psi$, the wavelet transform $W_x(s,u)$ for a series $x(t)$ is:

$$W_x(s,u) = \int_{-\infty}^{\infty} \psi_{s,u}(t) x(t) dt\,, \quad s,u \in R, s \neq 0 \tag{3}$$

$$\psi_{s,u}(t) \equiv \frac{1}{\sqrt{s}} \psi\left(\frac{t-u}{s}\right) \tag{4}$$

where $s$ is a scaling parameter that considers the extent of compression or dilation, and $u$ is a location parameter that according to Percival and Walden (2000) indicates if a wavelet is centered or not.

#### 3.1.1. Wavelet Power Spectrum

As $W_x(s,u)$ is a continuous wavelet transform of a time series $x(t)$, the wavelet power spectrum is equal to $|W_x|^2$ which can be interpreted as the local variance of the series $x(t)$ or "characteristic scales" as described by Keim and Percival (2010). I implement the Morlet wavelet introduced by Goupillaud et al. (1984) because it is the most suitable type of wavelet for identifying oscillatory components and peaks of a signal. This wavelet has an optimal balance between localization of time and frequency. It allows to decompose a signal into its frequency and phase content over time, and it has better time resolution that other types as identifies accurately localized features in time (Rösch and Schmidbauer, 2016). The mother Morlet wavelet can be written as:

$$\psi^{Morlet}(t) = \frac{1}{\pi^{1/4}} e^{iwt} e^{-t^2/2} \tag{5}$$

where $t$ is the normalized time and $w$ is the angular frequency. The literature prefers to set $w$ equal to 6 since the wavelet provides a good balance between frequency and time localization (Grinsted et al., 2004). I adopt the rectified version of the wavelet transform proposed by Liu et al. (2007) since the wavelet power spectrum is biased in favor of large scales.

#### 3.1.2. Wavelet Coherence

The wavelet power spectrum is useful for revealing dominant scales of variation in the data. However, it is not the appropriate measure to identify information about correlations and dependencies between two time-series. Defining $W_x$ and $W_y$ as the continuous wavelet transform of the time series $x(t)$ and $y(t)$, the cross-wavelet transform is defined as:

$$W_{xy}(s,u) = W_x(s,u) W_y^*(s,u) \tag{6}$$

where $W_y^*$ is the complex conjugate of $W_y$. Its modulus defined as cross wavelet power spectrum describes the covariance of two time series at each scale over time. This measure is corrected according to Veleda et al. (2012) as high frequency patterns tend to be underestimated. However, this measure is difficult to interpret as it depends on the unit of measurement of each series. Therefore, the literature uses the wavelet coherence as a tool to measure the local correlation between two time series at different scales over time, and it is defined as:

$$WC_{xy}(s,u) = \frac{|S(W_{xy}(s,u))|}{S|W_x(s,u)|S|W_y(s,u)|} \quad (7)$$

where $S$ is a smoothing operator applied to both frequency and time. The wavelet coherence analyzes the phase difference or the lags and the lead relationship between two variables through arrows in the spectrum. For instance, if arrows point to the right, that indicates a positive relationship between variables at a given frequency, while if they point to the left the relationship is negative. An upward (downward) arrow indicates that the second variable is leading (lagging) the first one.

### 3.2. Discrete Wavelet Transforms and Multiresolution Analysis

As continuous wavelet transforms are highly redundant in both scale and location, and they are rarely observed, the literature adopts a discrete version. The discrete wavelet transform (DWT) assumes a variable where observations are sampled at evenly spaced points in time.

Any series $y(t)$ can be expressed as a sequence of projections onto father and mother wavelets indexed by both the scale $J$, and the number of shifts of the wavelet for any given scale $k$ (Crowley, 2007). This is called multiresolution analysis (MRA) that refers to the approximation of a time series or signal into its multiresolution components at each scale. According to Bruce and Gao (1996) a representation of the series or signal $y(t)$ can be given by:

$$y(t) = \sum_k S_{J,k}\phi_{J,k}(t) + \sum_k D_{J,k}\psi_{J,k}(t) + \sum_k D_{J-1,k}\psi_{J-1,k}(t) + \cdots. + \sum_k D_{1,k}\psi_{1,k}(t) \quad (8)$$

where the wavelet coefficients are approximately given by the integrals:

$$S_{J,k} \approx \int y(t)\phi_{J,k}(t)dt \quad (9)$$

$$D_{J,k} \approx \int y(t)\psi_{J,k}(t)dt \quad (10)$$

and they are assumed to be orthogonal. The coefficients at each scale are called atom and all of them at each scaled conform what is called a crystal. The number of observations determines the number of scales that can be estimated (only J scales can be used given that the number of observations, $N \geq 2^J$.

Therefore, what is called the multiresolution decomposition analysis (MRA) of a variable $y(t)$ is given by $\{S_J, D_J, D_{J-1}, .... D_1\}$. As Crowley (2007) explains, the MRA provides more information on variability at different scales levels when researchers use high frequency data, and this might be the reason of the more frequent use of wavelet analysis in finance.

I adopt the maximal-overlap discreet wavelet transformation (MODWT) as it does not require a dyadic length, and it is shift-invariant contrary to the DWT. According to Percival and Walden (2000) this methodology avoids the DWTs sensitivity to the choice of the start point for a time series. Under the MODWT, the wavelet variance estimator is more asymptotically than the DWT, the resolution at lower scales improves, and the discretized transform is no longer orthonormal.

According to Percival and Walden (2000) the wavelet coefficients obtained through MODWT can be used to form a multiresolution analysis (MRA) such that when the original time series is shifted by any amount, these coefficients will be shifted by a corresponding amount. Additionally, the MODWT coefficients are related to zero phase filters.

### 3.3. Band Spectrum Regressions using Wavelet Analysis

I examine the relationship between exchange rate returns and changes in the accumulated forward position by type of investor, and other macroeconomic fundamentals at each $J$ scale. First, I use the MRA described in the previous section to decompose each series into a set of different components that correspond to a particular frequency. Second, I run an ordinary least square regression (OLS) with (HAC) errors robust to heteroscedasticity and autocorrelation on a scale-scale basis (see, e.g., Engle, 1974; Harvey, 1978; Granger and Engle, 1983; Phillips, 1991; Ramsey and Lampart, 1998 a,b; Corbae, Ouliaris, and Phillips, 2002; Filardo, Gelos, and McGregor, 2022).

I estimate the following relationship between the spot exchange rate and macroeconomic fundamentals, focusing on the role of different sectors in the non-forward delivery market:

$$\Delta ER_t^f = \beta X_t^f + \alpha Z_t^f + \varepsilon_t^f \tag{11}$$

where ΔER are spot exchange rate returns calculated as the first difference of the logarithm of the Colombian peso – US-dollar exchange rate; X is a vector of macroeconomic fundamentals including credit default swaps (CDS), the interest rate differential (Int-Diff) between the interbank overnight reference rate in

Colombia (IBR) and the overnight index swap rate (OIS) as proxy of the policy rate in the US, oil prices calculated as the first difference of the logarithm of brent oil prices, and the financial conditions in the US; Z is a vector of changes of NDF positions for different sectors. Namely, f indexes the different frequency bands or scales estimated through the MRA. In Appendix A, I report unit root tests to assess stationarity.

## 4. Results

### 4.1. Wavelet Power Spectrum

Plots of the wavelet power spectrum for exchange rate returns and changes in the accumulated forward positions for different sectors provide evidence of dominant scales over time (Fig. 4). The horizontal axis corresponds to the time, and the vertical axes provides the corresponding scales obtained through the wavelet transform. The color code for the power spectrum varies from blue (low power density) to red (high power density). A white contour line is displayed showing the region of significant periods in each variable for each t. This line tests the wavelet power 5% significance level against a white noise null hypothesis. The cone of influence displayed with a shaded area correspond to the region affected by boundary effects as the values of the wavelet transform at the beginning and the end of the time series can be incorrectly computed.

These variables have highly localized patterns at lower scales. Power regions concentrated in 2008-2009, 2015-2016 and 2020, 2022 for exchange rate returns, while for the offshore and PSF significant power regions concentrated after 2015. In the case of the real sector, the variation is more persistent through all the sample. Results for the offshore sector by type of agent indicate that power regions for foreign banks concentrated after 2014, and for mutual funds before that year (see Appendix B).

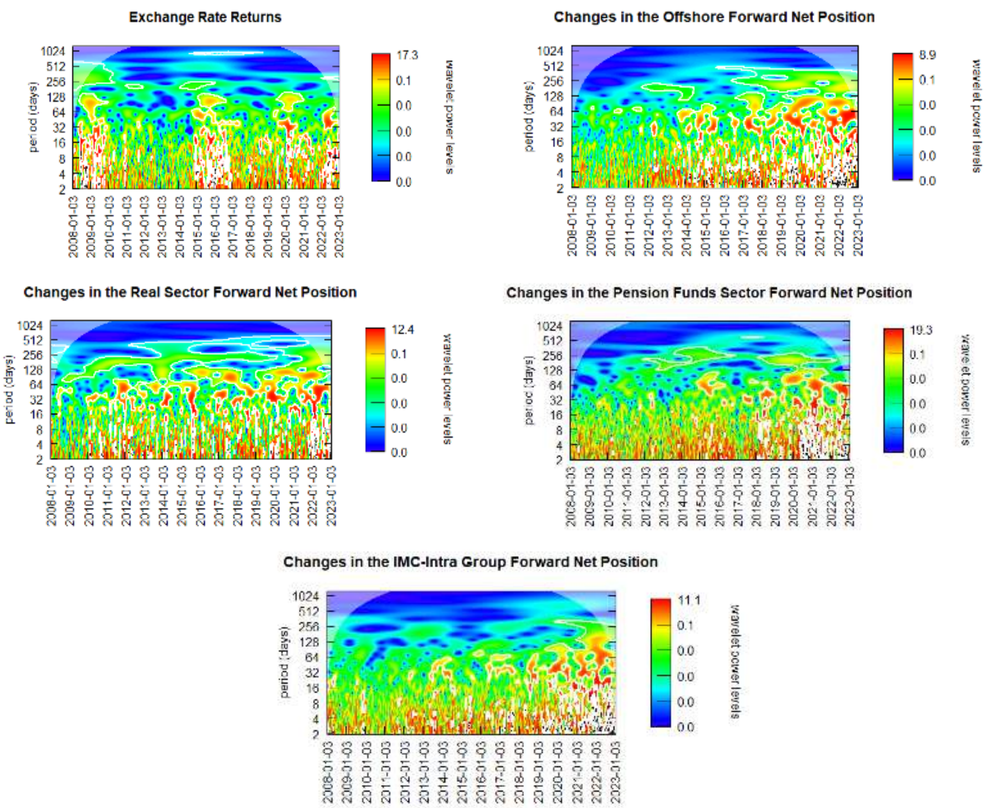


**Fig. 4.** Wavelet power spectrum for exchange rate returns and changes in the accumulated forward positions of the offshore, the real sector, pension and severance funds, and IMC-Intra group. Notes: the horizontal axis represent the time period studied, and the vertical axis provides the corresponding frequencies or scales obtained through the wavelet transform. Periods in the vertical axes correspond to $2^J$, where $J$ is the scale. Thus, the 1-2 scale corresponds to the time horizon of 2 to 4 days, the 2-3 scale corresponds to the time horizon of 4 to 8 days, etc. Warmer colors (red areas) represent regions with significant power density or variability. A white contour line is displayed showing the region of significant periods in each variable for each t. This line tests the wavelet power 5% significance level against a white noise null hypothesis. The cone of influence displayed with a shaded area correspond to the region affected by boundary effects. *Source:* Author's calculations.

### 4.2. Wavelet Coherence

In Fig. 5, I show the wavelet coherence between changes in the forward positions of different sectors (the first variable $x$), and exchange rate returns (the second variable $y$). The horizontal axis refers to time while the vertical axis to scales. The color range for the wavelet coherence ranges from blue (low correlation) to red (high correlation). Regions of strong coherence between exchange rate returns and changes in the offshore position are evident at lower scales in the first middle part of the sample but after 2018 there are some localized high correlations at higher scales (red areas). The correlation is more persistent at different scales through the whole sample for exchange rate returns and changes in the real sector forward positions. For the case of pension and severance funds, there are only some localized high correlations at the 256 days scale but at other scales there is not any relationship. Something similar happens to the IMC-Intra Group where just few localized episodes of high correlations are found over time.

Foreign banks had a higher correlation with exchange rate returns at lower scales before 2015, and then increased for higher scales, while for mutual funds that relationship has been weak over time (See Appendix C). The phase difference described by the arrows in the wavelet coherence plot indicates that the offshore is leading the exchange rate mostly during the significant high coherence periods, and they move in the same direction (in phase), while the opposite happens for the real sector as they move in the opposite direction (anti-phase).

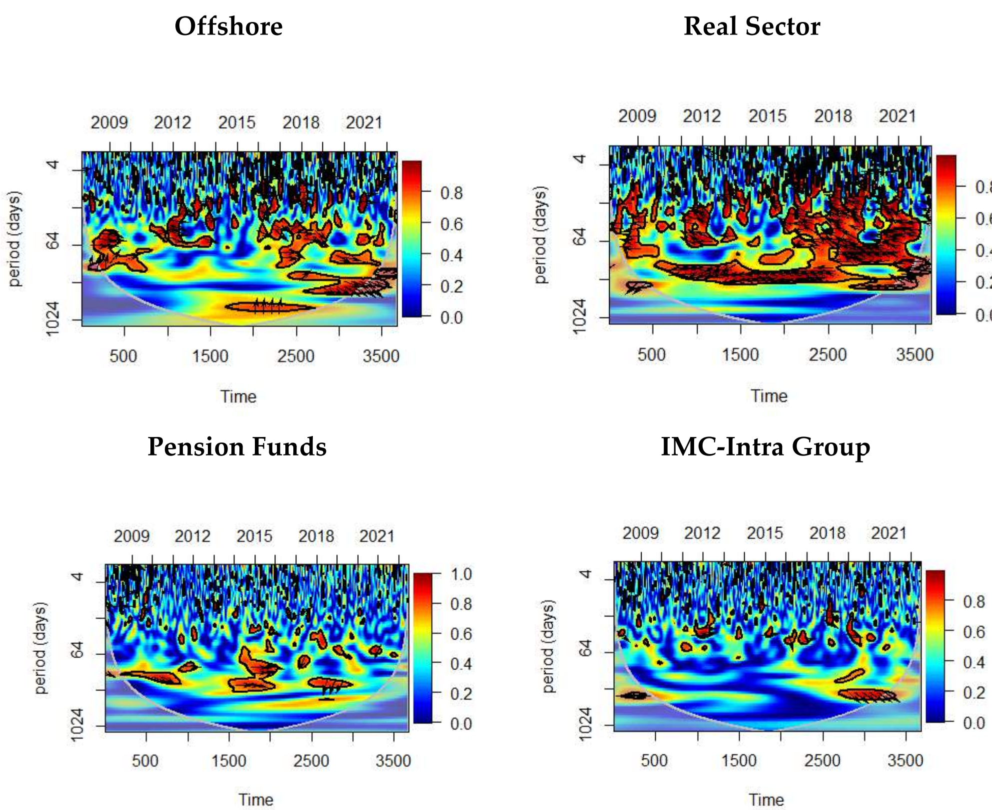


**Fig. 5.** Wavelet coherence between exchange rate returns and changes in the accumulated forward positions of the offshore, the real sector, pension and severance funds, and the IMC-Intra Group. Notes: the horizontal axis corresponds to the time, and the vertical axis provides the corresponding scales obtained through the wavelet transform. Warmer colors (red) represent regions with significant interrelation (high coherence). A black contour line is displayed showing the region of significant wavelet coherence for each t using Monte Carlo methods. This line tests the 5% significance level of the null hypothesis that coherency is zero. The cone of influence displayed with a shaded area correspond to the region affected by boundary effects. *Source:* Author's calculations.

### 4.3. Multiresolution Analysis

I estimate the MODWT coefficients for the multiresolution analysis of exchange rate returns, and other explanatory variables using the Daubechies (1992) least asymmetric wavelet filter with 8 nonzero coefficients. This filter has a near zero phase shift which implies that the estimated wavelet coefficients line up in time with those events affecting more the pattern for each variable (Jensen and Whitcher, 2014). I describe the MRA of exchange rate returns and changes in the offshore forward position in Figs. 6 and 7.

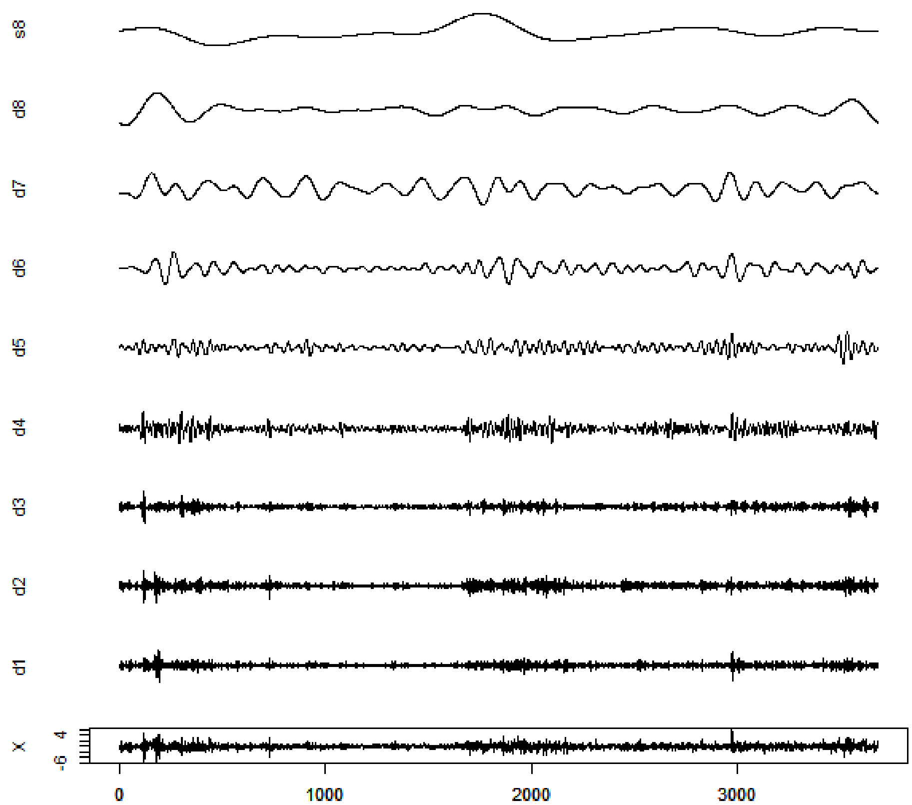


**Fig. 6.** Multiresolution analysis for exchange rate returns. Notes: wavelet and scaling coefficients over the time period January 2, 2008 through January 31, 2023. *Source:* Author's calculations.

Each figure consists of individual plots of the wavelet details over the entire sample up to 8 levels. To achieve appropriate resolution, I choose the number of scales to be 8. Each D represents the variation of the exchange rate returns at a localized interval in time where the scales J= 1, 2, … correspond to variations at the 2-4 days scale, 4-8 and so on and so forth.

The wavelet smooth S8 measures the long-term variation of exchange rate returns at time scales associated with 256 days or above. Focusing on S8, I can infer that there is a slow and moderate long trend cycle except for the period between December 2014 and October 2015 that coincides with the important depreciation of the peso due to the fall in oil prices that could affect that long-term exchange rate variation.

The details at scales 1 to 7 reveal the impact that some specific events may have on exchange rate returns. For instance, the global financial crisis at the beginning of the sample, the drop of oil prices between 2014 and 2015, the Covid-19 pandemic, and the end of 2022 were events in which the Colombian peso depreciated the most over the period of analysis. I evidence a similar pattern for the long-term variation of changes in the offshore forward net position in 2015 due to the shock to world oil prices, and there was more volatility at the end of the sample for the wavelet details.

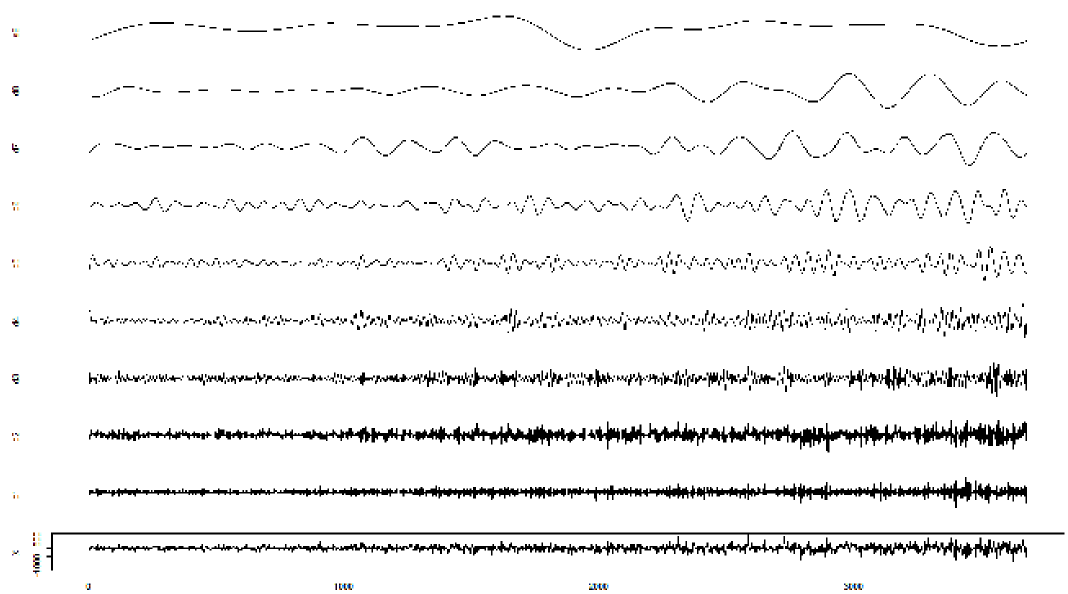

**Fig. 7.** Multiresolution analysis for changes in the offshore forward net position. Notes: wavelet and scaling coefficients over the time period January 3, 2008 through January 31, 2023. *Source:* Author's calculations.

### 4.4. Band Spectrum Regressions

After decomposing each regression variable using MRA, I regress exchange rate returns on changes in the forward positions for different sectors, and other fundamentals at various time scales according to Eq. 11. I summarize the results in Table 1.[6]

There is evidence of a positive relationship between changes in the offshore forward net position and exchange rate returns at short-term frequencies. However, this relationship becomes negative at scales over 256 days. I find a

[6] Oil prices and the exchange rate are included in the regressions as the first difference of the logarithm. The local interest rate is included as the first difference.

significant influence of the offshore in explaining exchange rate returns at high frequencies of 4 to 8 and 8 to 16 days (scales D2 and D3). For instance, an increase of USD1000 m at those frequencies depreciates the exchange rate by 1.8% and 1.5%, respectively, while aggregating over time scales yields to a depreciation of 1.1%. Foreign banks and mutual funds are the main players of the offshore sector in the forward market. Therefore, analyzing in detail the pattern of these agents gives evidence of a significant influence of mutual funds in explaining exchange rate returns at different frequencies even that their share in the forward market is only 10% of the volume traded by the offshore. In Appendix D, I describe in detailed the results for the offshore classified in foreign banks and mutual funds.

The real sector has a negative relationship with the exchange rate over time for all scales. Changes in its position in the forward market have significant influence on exchange rate returns at different scales. However, the effect is higher at low frequencies (over 256 days). Although the offshore participates with more than 50% of the volume traded in the forward market, and the real sector only contributes with 9%, I find evidence that changes in the real sector forward positions have a higher effect on exchange rate returns than the observed for the offshore. For instance, USD1000 m purchases in the forward market by the real sector yield to an appreciation of the currency between 1.5% and 4.9%.

The coefficients for PSF and IMC-Intra Group are positive as expected for lower scales. However, the sign of the coefficients switches for higher scales. Furthermore, the effect of changes in the forward positions of these sectors on the exchange rate is higher at lower frequencies.

Other fundamentals such as the interest rate differential, CDS, oil prices, and US financial conditions have the expected signs, except for the interest rate differential at some scales. In line with the exchange rate determination puzzle, the impact of these variables on the exchange rate is higher at lower frequencies, except for the US financial conditions which have a permanent effect. This confirms the long-term nature of these fundamentals in explaining the exchange rate.

As it is difficult to tell if the exchange rate returns and the control variables included in the OLS regressions are the same at the borders, I decompose each variable using the MRA that considers boundary effects. Therefore, I apply the MODWT to the reflected series, and re-estimate Eq. 11. The previous results are robust to this methodology as there is evidence that changes in the offshore positions impact the exchange rate at short terms scales, and the real sector has a permanent effect at different scales. Finally, I find similar results for traditional fundamentals (Appendix E).

**Table 1.** Aggregate and time scale regression analysis for exchange rate returns (03/01/2008-31/01/2023) - OLS

| | Aggregate | S8 | D8 | D7 | D6 | D5 | D4 | D3 | D2 | D1 |
|---|---|---|---|---|---|---|---|---|---|---|
| Intercept | **0.0274** | **0.0175** | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | (0.0103) | (0.0008) | (0.0007) | (0.0011) | (0.0029) | (0.0035) | (0.0045) | (0.0027) | (0.0021) | (0.0018) |
| Offshore | **0.0011** | **-0.0005** | **-0.0007** | **0.0007** | 0.0003 | **0.0006** | 0.0002 | **0.0015** | **0.0018** | **0.0008** |
| | (0.0001) | (0.0002) | (0.0001) | (0.0001) | (0.0002) | (0.0002) | (0.0002) | (0.0002) | (0.0001) | (0.0001) |
| Real Sector | **-0.0023** | **-0.0049** | **-0.0035** | **-0.0018** | **-0.0029** | **-0.0026** | **-0.0041** | **-0.0040** | **-0.0024** | **-0.0015** |
| | (0.0003) | (0.0004) | (0.0002) | (0.0003) | (0.0003) | (0.0003) | (0.0003) | (0.0004) | (0.0003) | (0.0004) |
| Pension Funds | **0.0010** | **-0.0048** | **-0.0014** | **0.0016** | **0.0012** | **0.0007** | **0.0006** | **0.0011** | **0.0014** | **0.0009** |
| | (0.0002) | (0.0004) | (0.0002) | (0.0002) | (0.0003) | (0.0003) | (0.0002) | (0.0003) | (0.0002) | (0.0002) |
| IMC - Intra | **0.0008** | **-0.0081** | **-0.0017** | **-0.0014** | -0.0003 | **0.0010** | **0.0005** | **0.0010** | **0.0014** | **0.0005** |
| | (0.0001) | (0.0004) | (0.0003) | (0.0002) | (0.0003) | (0.0002) | (0.0002) | (0.0003) | (0.0002) | (0.0002) |
| CDS | **0.0256** | **0.0836** | **0.1113** | **0.0860** | **0.0291** | **0.0535** | **0.0204** | **0.0149** | **0.0236** | **0.0324** |
| | (0.0056) | (0.0057) | (0.0069) | (0.0052) | (0.0054) | (0.0068) | (0.0053) | (0.0053) | (0.0043) | (0.0063) |
| Int - Diff | -0.2813 | **-0.6914** | **-4.7663** | **-4.2209** | **1.9401** | **0.9923** | -0.2337 | **-0.8038** | **-0.7229** | 0.0411 |
| | (0.1819) | (0.1679) | (0.3184) | (0.3708) | (0.7054) | (0.4981) | (0.3913) | (0.3439) | (0.2843) | (0.2080) |
| Oil Prices | **-0.0497** | **-0.1380** | -0.0037 | **-0.0492** | **-0.0457** | -0.0075 | **-0.0801** | **-0.0651** | **-0.0486** | **-0.0394** |
| | (0.0064) | (0.0074) | (0.0136) | (0.0086) | (0.0184) | (0.0143) | (0.0103) | (0.0127) | (0.0099) | (0.0086) |
| US Financial Conditions | **-0.5646** | **-0.4785** | **-0.4489** | 0.1576 | **-0.4800** | 0.2225 | **-0.5987** | **-0.9031** | **-0.5713** | -0.4671 |
| | (0.1963) | (0.2138) | (0.1989) | (0.1343) | (0.2308) | (0.1726) | (0.2155) | (0.2113) | (0.2538) | (0.2639) |
| R2 | 0.3641 | 0.8643 | 0.9383 | 0.8568 | 0.6257 | 0.6268 | 0.4858 | 0.4575 | 0.3880 | 0.2782 |

Notes: *HAC* standard errors in parenthesis. Regressors significant at 5% in bold.
*Source:* Author's calculations.

## 5. Conclusions

Evaluating the main determinants of the exchange rate is still a theoretical and empirical challenge for the literature. The exchange rate determination puzzle explains that macroeconomic fundamentals fail to explain the exchange rate in the short run because they are not able to capture investor heterogeneity, and they are more related to long term movements of the nominal exchange rate. In this paper, I use a novel methodology called wavelet analysis to decompose the behavior of the exchange rate and its fundamentals at different scales over time. Traditional factors determining the exchange rate such as credit default swaps, the interest rate differential, oil prices, and financial conditions in the US play an important role in explaining exchange rate behavior. However, I include the changes of net positions of foreign and local agents in the forward market as an important driver of the spot exchange as they can influence exchange rate movements in the short run.

The results indicate a strong correlation between exchange rate returns and the positions of foreign investors in the NDF market at high frequencies, while the correlation of exchange rate returns with the real sector is permanent at different frequencies but higher at the lower ones. Although foreign banks are the most important players in the offshore sector, there is evidence that mutual funds positions in the NDF market can have a significant effect on the spot exchange rate in Colombia at higher frequencies. Finally, according to the exchange rate determination puzzle, the results suggest that the variation of the exchange rate explained by traditional macroeconomic fundamentals such as the interest rate differential, CDS, , and oil prices is higher at scales above 256 days.

These results have important policy implications, as the volume traded in the forward market by foreign agents and the real sector can destabilize the foreign exchange market, especially at high frequencies which may affect the effectiveness of monetary policy.

Further areas of research may incorporate explaining why the offshore and the real sector have differentiated effects on the exchange rate at different horizons. Also, it is important to understand their motives of investment in the forward market. Finally, as positions of the real sector in the forward market have a more permanent effect on the nominal exchange rate, it is crucial to understand if importing or exporting firms are the ones driving this result.

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## **Appendix A.** Unit root tests

| Variable | ADF test | ADF p-value | PP test | PP p-value |
|---|---|---|---|---|
| log(exchange rate) | -0.084 | 0.949 | -0.049 | 0.953 |
| Offshore | -13.505 *** | 0.000 | -51.805 *** | 0.000 |
| Real Sector | -16.350 *** | 0.000 | -52.145 *** | 0.000 |
| Pension Funds | -15.010 *** | 0.000 | -59.943 *** | 0.000 |
| IMC-Intra Group | -17.804 *** | 0.000 | -56.001 *** | 0.000 |
| CDS | -3.285 ** | 0.016 | -3.393 ** | 0.011 |
| Int - Diff | -1.554 | 0.506 | -0.854 | 0.803 |
| log(oil prices) | -2.590 * | 0.095 | -2.185 | 0.212 |
| US Financial Conditions | -3.150 ** | 0.023 | -3.382 ** | 0.012 |

Note: Offshore, real sector, pension funds, and IMC-Intra Group correspond to the changes in the accumulated position in the forward market. The null hypothesis for the ADF and PP tests is non-stationarity. *, **, *** represent significance at 10%, 5% and 1% level, respectively. Source: Authors' calculations.

## **Appendix B.** Wavelet power spectrum for the offshore

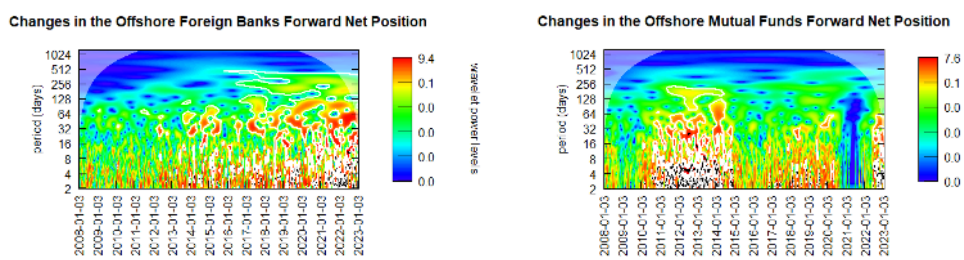


**Fig. B.1**. Wavelet power spectrum for the changes in the accumulated forward positions of the offshore by type of agent. Notes: the horizontal axis corresponds to the time, and the vertical axis provides the corresponding scales obtained through the wavelet transform. A white contour line is displayed showing the region of significant periods in each variable for each t. This line tests the wavelet power 5% significance level against a white noise null hypothesis. The cone of influence displayed with a shaded area correspond to the region affected by boundary effects as the values of the wavelet transform at the beginning and the end of the time series can be incorrectly computed. *Source:* Author's calculations.

**Appendix C.** Wavelet coherence for the offshore sector

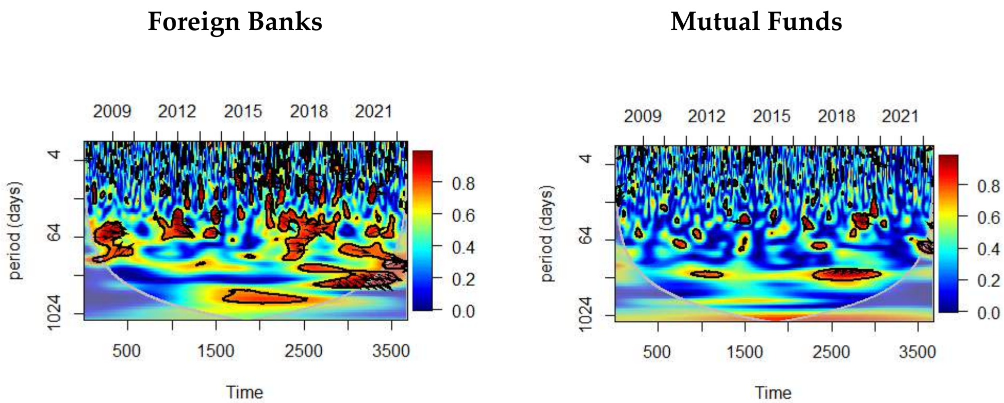


**Fig. C.1.** Wavelet coherence between exchange rate returns and changes in the accumulated forward positions of the offshore by type of agent. Notes: the horizontal axis corresponds to the time, and the vertical axis provides the corresponding scales obtained through the wavelet transform. Warmer colors (red) represent regions with significant interrelation (high coherence). A black contour line is displayed showing the region of significant wavelet coherence for each t using Monte Carlo methods. This line tests the 5% significance level of the null hypothesis that coherency is zero. The cone of influence displayed with a shaded area correspond to the region affected by boundary effects. *Source:* Author's calculations.

**Appendix D.** Aggregate and time scale regression analysis for exchange rate returns and the offshore by type of agent (03/01/2008-31/01/2023) - OLS

| | Aggregate | S8 | D8 | D7 | D6 | D5 | D4 | D3 | D2 | D1 |
|---|---|---|---|---|---|---|---|---|---|---|
| Offshore | **0.0011** | **-0.0005** | **-0.0007** | **0.0007** | 0.0003 | **0.0006** | 0.0002 | **0.0015** | **0.0018** | **0.0008** |
| | (0.0001) | (0.0002) | (0.0001) | (0.0001) | (0.0002) | (0.0002) | (0.0002) | (0.0002) | (0.0001) | (0.0001) |
| Foreign Banks | **0.0011** | -0.0003 | **-0.0006** | **0.0007** | 0.0003 | **0.0006** | 0.0003 | **0.0014** | **0.0018** | **0.0008** |
| | (0.0001) | (0.0002) | (0.0001) | (0.0001) | (0.0002) | (0.0002) | (0.0002) | (0.0002) | (0.0002) | (0.0001) |
| Mutual Funds | **0.0005** | **-0.0206** | **-0.0039** | **0.0009** | 0.0004 | -0.0005 | -0.0007 | **0.0018** | 0.0003 | **0.0006** |
| | (0.0002) | (0.0015) | (0.0009) | (0.0004) | (0.0009) | (0.0007) | (0.0004) | (0.0005) | (0.0003) | (0.0003) |
| Other controls | YES | YES | YES | YES | YES | YES | YES | YES | YES | YES |

Notes: The first line corresponds to the estimations of the offshore reported in Table 1. The results for foreign banks and mutual funds correspond to the estimations of Eq. 11 using information of these agents instead of the aggregated position of the offshore. *HAC* standard errors in parenthesis. Regressors significant at 5% in bold. *Source:* Author's calculations.

**Appendix E.** Aggregate and time scale regression analysis for exchange rate returns by reflecting the series (03/01/2008-31/01/2023) - OLS

| | Aggregate | S8 | D8 | D7 | D6 | D5 | D4 | D3 | D2 | D1 |
|---|---|---|---|---|---|---|---|---|---|---|
| Intercept | **0.0274** | **0.0156** | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | (0.0103) | (0.0012) | (0.0007) | (0.0011) | (0.0028) | (0.0035) | (0.0045) | (0.0027) | (0.0021) | (0.0018) |
| Offshore | **0.0011** | **-0.0017** | **-0.0004** | **0.0007** | 0.0002 | **0.0005** | 0.0003 | **0.0015** | **0.0018** | **0.0008** |
| | (0.0001) | (0.0002) | (0.0001) | (0.0002) | (0.0002) | (0.0002) | (0.0002) | (0.0002) | (0.0001) | (0.0001) |
| Real Sector | **-0.0023** | **-0.0051** | **-0.0031** | **-0.0017** | **-0.0030** | **-0.0027** | **-0.0041** | **-0.0040** | **-0.0023** | **-0.0015** |
| | (0.0003) | (0.0005) | (0.0002) | (0.0003) | (0.0003) | (0.0003) | (0.0003) | (0.0004) | (0.0003) | (0.0004) |
| Pension Funds | **0.0010** | **-0.0047** | **-0.0012** | **0.0018** | **0.0012** | **0.0006** | **0.0005** | **0.0011** | **0.0014** | **0.0009** |
| | (0.0002) | (0.0004) | (0.0002) | (0.0003) | (0.0003) | (0.0003) | (0.0002) | (0.0003) | (0.0002) | (0.0002) |
| IMC - Intra | **0.0008** | **-0.0076** | **-0.0025** | **-0.0004** | -0.0003 | **0.0009** | **0.0006** | **0.0010** | **0.0013** | **0.0005** |
| | (0.0001) | (0.0006) | (0.0003) | (0.0002) | (0.0003) | (0.0002) | (0.0002) | (0.0003) | (0.0002) | (0.0002) |
| CDS | **0.0256** | **0.0766** | **0.0780** | **0.0677** | **0.0303** | **0.0528** | **0.0200** | **0.0149** | **0.0238** | **0.0324** |
| | (0.0056) | (0.0066) | (0.0059) | (0.0064) | (0.0055) | (0.0066) | (0.0052) | (0.0053) | (0.0043) | (0.0063) |
| Int - Diff | -0.2813 | -0.1399 | **-4.5244** | **-3.1518** | **1.9169** | **1.1606** | -0.1634 | **-0.7880** | **-0.7476** | 0.0453 |
| | (0.1819) | (0.1964) | (0.3171) | (0.3901) | (0.6969) | (0.4498) | (0.3817) | (0.3449) | (0.2814) | (0.2083) |
| Oil Prices | **-0.0497** | **-0.1695** | **-0.0661** | **-0.0449** | **-0.0457** | -0.0091 | **-0.0797** | **-0.0653** | **-0.0483** | **-0.0394** |
| | (0.0064) | (0.0094) | (0.0129) | (0.0096) | (0.0176) | (0.0141) | (0.0103) | (0.0126) | (0.0099) | (0.0086) |
| US Financial Conditions | **-0.5646** | **1.3521** | **-1.2446** | -0.0141 | **-0.4507** | 0.2174 | **-0.6254** | **-0.8970** | **-0.5693** | -0.4666 |
| | (0.1963) | (0.2825) | (0.2545) | (0.1454) | (0.2261) | (0.1694) | (0.2180) | (0.2109) | (0.2528) | (0.2640) |
| R2 | 0.3641 | 0.7678 | 0.9306 | 0.8494 | 0.6243 | 0.6272 | 0.4904 | 0.4558 | 0.3888 | 0.2782 |

Notes: *HAC* standard errors in parenthesis. Regressors significant at 5% in bold.
*Source:* Author's calculations.