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Wilfrido Jurado Pedroza
Banco de México

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Around-the-Clock USD/MXN Volatility: Macroeconomic Announcement Spillovers and FX Market Intervention Mechanisms*

Wilfrido Jurado Pedroza†
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Abstract: This paper advances the literature on the dynamics of the U.S. Dollar-Mexican Peso (USD/MXN) volatility process by leveraging high-frequency data. First, it documents the factors that characterize the intraday volatility process of the USD/MXN exchange rate at high frequencies based on a sample of five-minute returns from 2008 to 2017. Second, it empirically identifies the effects and the relative impact on the USD/MXN volatility process of various macroeconomic announcements, at different frequencies. The results conclude that the most impactful releases are associated with the monetary policy announcements by the Federal Reserve and Banco de México, together with the publication of some U.S. and China macroeconomic data. Furthermore, the results suggest that the different mechanisms implemented by Mexico's FX Commission have accomplished their objective of stabilizing the volatility of the USD/MXN.
Keywords: FX Volatility, Heteroscedasticity, Macroeconomic Announcements, High-Frequency Data
JEL Classification: E5, F31, G12, G14

Resumen: Este artículo se suma a la literatura que estudia la dinámica del proceso de volatilidad del tipo de cambio dólar estadounidense-peso mexicano (USD/MXN) examinando datos de alta frecuencia. En primer lugar, se documentan los factores que caracterizan el proceso de volatilidad intradía del tipo de cambio USD/MXN a altas frecuencias con base en una muestra de intervalos de 5 minutos de 2008 a 2017. En segundo lugar, se identifican empíricamente los efectos y el impacto relativo producidos por la publicación de diversos anuncios macroeconómicos a diferentes frecuencias del proceso de volatilidad del USD/MXN. El análisis concluye que los eventos que producen los efectos más significativos en la volatilidad están asociados a las decisiones de política monetaria de la Reserva Federal y del Banco de México, aunados a la publicación de algunos datos macroeconómicos de las economías de Estados Unidos y China. Asimismo, los resultados sugieren que los diferentes mecanismos de intervención implementados por la Comisión de Cambios cumplen su objetivo de estabilizar la volatilidad del tipo de cambio USD/MXN.
Palabras Clave: Volatilidad del Tipo de Cambio, Heteroscedasticidad, Anuncios Macroeconómicos, Datos de Alta Frecuencia

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† Dirección General de Contraloría y Administración de Riesgos. Email: wjurado@banxico.org.mx.

1 Introduction

Over the last 10 years, the Mexican Peso has become one of the most traded currencies in the world. It is traded 24 hours a day at several financial centers around the world and has an average daily turnover of $113.7 billion according to the Triennial Central Bank Survey on Foreign Exchange published by the BIS on September 2019. These high liquidity conditions produce rich and high quality data, which facilitates the development of models and analyses that further understanding of what drives market risk in the Mexican Peso market at the intraday level.

The dynamics of the U.S. Dollar–Mexican Peso exchange rate (USD/MXN) parity, in particular, have been studied by several researchers, but at a lower frequency perspective, using interday data. Werner A. (1997) registers the statistical features of the USD/MXN exchange rate and its volatility during the period of 1995-1996. Bazdresch, and Werner (2005) defines the exchange rate process by estimating a series of regime switching regressions. Benavides (2006) and Benavides, and Capistrán (2011) characterizes the U.S. Dollar–Mexican Peso exchange rate volatility using combinations of option implied and time series volatility models.

While these studies have contributed to understanding the *interday* dynamics of the USD/MXN exchange rate, it is also important to study and document the processes that define the exchange rate at the *intraday* level since it is relevant for policy makers, investors and risk managers, to determine the likelihood of potential market movements during trading hours. Practical applications of this dynamic's definition include deriving optimal investments strategies; trading/pricing derivatives; market making and identifying market microstructures; developing volatility forecasts and modeling tail events for risk management. Intraday returns extracted from exchange rates could provide central bankers with improved inputs for designing and implementing more informed foreign exchanges rate policies.

Several researchers have studied intraday volatility of various financial assets. Andersen and Bollerslev (1997B) documented the intraday volatility dynamic in the foreign exchange rate and equity markets. Andersen and Bollerslev (1998) proposed an approach to capture the intraday activity patterns, macroeconomic announcements, and the interday volatility persistent dynamic that defines the intraday volatility process in the Deutschemark–U.S. Dollar exchange rate, Goodhart et al. (1993) studied the effects of news in the Sterling–U.S. Dollar exchange rate using high-frequency data. Bollerslev et al (2000) used a similar framework as Andersen and Bollerslev (1998) to characterize the intraday volatility in the U.S. Treasury bond futures market. Engle, R. F. and Sokalska, M. E. (2012) proposed a multiplicative component GARCH model for forecasting intraday volatility on more than 2,500 U.S. equities. Finally, Stroud and Johannes (2014) developed a Bayesian method for forecasting the 24-hour high-frequency volatility of index futures.

Motivated by these works, the purpose of this study is to advance the literature on the dynamics of the U.S. Dollar–Mexican Peso volatility process by leveraging high-frequency data. This paper has two objectives. The first is to document the factors that characterize the intraday volatility process of the USD/MXN exchange rate at high frequencies based on a sample of five-minute returns. The second is to empirically identify the effects of various macroeconomic announcements on the USD/MXN exchange rate, and assess the relative impact of these announcements at different frequencies of the volatility process. The analysis will follow a framework suggested by Andersen and Bollerslev (1998) that has been used by others to characterize the simultaneous interaction of different factors that drive the volatility process for different financial assets. The results show that the most impactful releases on the USD/MXN intraday volatility are associated to the Federal Reserve's and Banco de México's monetary policy announcements, along with the publication of some U.S. and Chinese economic data. Additionally, the results suggest that the different mechanisms executed by Mexico's FX Commission have achieved stabilizing the volatility of the U.S. Dollar–Mexican Peso exchange rate parity on the days of implementation.

The article is divided into the following sections. Section (2) makes a brief literature review, and briefly describes the method used in this work. Section (3) describes the data used and their characteristics. Section (4) presents the empirical results and an interpretation thereof. Section (5) concludes.

2 Model

This section provides an abridged literature review of the general papers that study intraday volatility for distinct financial assets, and briefly describes the method used in this work for modeling the intraday volatility of the USD/MXN exchange rate, the one proposed by Andersen and Bollerslev (1998).

The intraday volatility processes that define the evolution of different financial assets have been estimated using a diverse set of techniques and data sets. Here are five relevant studies that have documented these processes. Andersen and Bollerslev (1997B) and Andersen and Bollerslev (1998) characterized the intraday returns of exchange rates using a three factor model, this technique allows to measure the effects of some macroeconomic announcements on the intraday volatility; Bollerslev et al (2000) studied the analogous case for the volatility of the U.S. Treasury bond futures market. Engle, R. F. and Sokalska, M. E. (2012) developed a framework for forecasting the intraday volatility of more than 2,500 U.S. equities using separate companies and pooling cross-section company-level data. Stroud and Johannes (2014) applied Bayesian methods on S&P index futures high-frequency returns during the financial crisis to forecast its intraday volatility.

In the financial time series literature the time-varying volatility model developed in Andersen and Bollerslev (1998) is widely used and has become a standard. The model, defined by Equation (1), considers three important factors that characterize intraday volatility.

$$x_{t,n} = \log P_{t,n}/P_{t,n-1} = \mu + \sigma_{t,n} \cdot s_{t,n} \cdot \epsilon_{t,n} \tag{1}$$

The factor represented by $\sigma_{t,n}$ is the *interday volatility pattern*, which captures highly persistent slow moving volatility that varies dramatically over time. The term $s_{t,n}$ seize the *intraday volatility patterns*, through the two remaining factors, one of these is the strong *periodic/seasonal volatility pattern* reflecting the global migration of trading (open and close of markets), and the other one accounts for shocks of volatility generated by predictable *macroeconomic announcements*. The subscript t refers to day of the return, n represents the time of the day[1], and $\epsilon_{t,n}$ is an i.d.d. error term with mean zero and unit standard deviation.

In order to estimate the three different factors Andersen and Bollerslev (1998) proposed a two-step procedure based on Equation (2), which is a simplification of Equation (1). The first step consists in estimating the parameters in the left side of Equation (2)[2], $\widehat{\mu}$, and $\widehat{\sigma}^2_{t,n}$, and determining the form of the intraday volatility patterns $s_{t,n}$ in the right side of the same equation[3].

[1]This analysis will use five-minute intraday returns during the 24 hr. trading cycle therefore each day will have 288 intraday returns, i.e. $n =$ 00:00, ..., 23:55.

[2]The Equation (1) can be derived by squaring and applying logs to Equation (2), clearing the variable $s_{t,n}$ and adding and subtracting the term c, which is the expected value of the squared white noise (a constant). The term $\widehat{\nu}_{t,n}$ is clearly random since it is a function of the white noise $\epsilon_{t,n}$.

[3]Andersen and Bollerslev (1998) argue that absolute returns are a common approach for modelling volatility using high-frequency data.

$$2\log\left[|x_{t,n}-\mu|\right]-\log\sigma_{t,n}^2=\underbrace{\mathbb{E}\left[\log\epsilon_{t,n}^2\right]}_{\text{constant}\quad=\quad c}+2\log(s_{t,n})+\underbrace{\log\epsilon_{t,n}^2-\mathbb{E}\left[\log\epsilon_{t,n}^2\right]}_{\text{white noise}\quad=\quad\widehat{\nu}_{t,n}}\tag{2}$$

For modeling the intraday volatility patterns, $2\log(s_{t,n})$, they use the Flexible Functional Form (FFF)[4] proposed by Gallant (1981) defined by Equation (3):

$$\begin{aligned}FFF(\Theta,t,n)=\mu_0+&\sum_{k=1}^{D}\lambda_k I_k(t,n)\\&+\sum_{p=1}^{P}\left(\delta_{c,p}\cdot\cos\frac{p2\pi}{N}n+\delta_{s,p}\cdot\sin\frac{p2\pi}{N}n\right)\end{aligned}\tag{3}$$

where $I_k(t,n)$ will represent dummy variables accounting for the different periodic/seasonal volatility patterns and the macroeconomic announcements occurring at time n on day t, and D represents the total number of these events; the parameters that will seize the effects of each macroeconomic and daily event are λ_k; while $\delta_{c,p}$ and $\delta_{s,p}$ will help to define the seasonal intraday pattern (i.d. $\Theta=\{\lambda_1,\ldots,\lambda_K,\delta_{c,1},\ldots,\delta_{c,P},\delta_{s,1},\ldots,\delta_{s,P}\}$), N represents the number of five-minute windows in a day and P is a tuning parameter determining the order of the Fourier expansion[5].

Once determined the parameters and the *FFF* form described above, the second step consists in estimating the regression defined by Equation (4) using the ordinary least squares method (OLS).

$$\widehat{z}_{t,n}\equiv 2\log\left[|x_{t,n}-\mu|\right]-\log\widehat{\sigma}_{t,n}^2=\widehat{c}+FFF(\Theta,t,n)+\widehat{\nu}_{t,n}\tag{4}$$

In addition to the two-step procedure, Andersen and Bollerslev (1998) propose that the intraday volatility component, $\widehat{\sigma}_{t,n}$, can be estimated using GARCH models fitted with interday

[4]Gallant (1981) introduced the *FFF* method, where the trigonometric terms represent the periodicity of one day.

[5]In this work, P will equal 4 as it was used in Andersen and Bollerslev (1998) and Bollerslev et al (2000).

data and applying the Equation (5), in particular they use an ARMA(0,1) + GARCH(1,1)[6], which will be used also in this analysis.

$$\widehat{\sigma}_{t,n} = \frac{\widehat{\sigma}_{t,\text{ARMA(0,1)+GARCH(1,1)}}}{N^{\frac{1}{2}}}. \tag{5}$$

3 Data

This section describes and gives an overview of the data used in the analysis, as well as shows some graphs of the factors that characterize the intraday volatility of the U.S. Dollar–Mexican Peso exchange rate.

3.1 Mexican Peso Intraday Data

The Mexican Peso has been one of the most traded currency in the world over the last years, it has become the second most traded developing country currency –only surpassed by the Chinese renminbi– and has exceeded the traded volume of some developed market currencies (e.g. Swedish krona, Danish krona)[7]. Since May 2008 is traded 24 hours a day among several trading centers as a result of its inclusion in the Continuous Linked Settlement[8] (CLS) system. This fact has allowed market participants to reduce Mexican Peso's settlement risk, and it has boosted its market deepness. These high liquidity conditions, $113.7 billion in daily trading, produces rich and high quality data to understand what drives market risk in the Mexican Peso market at intraday level.

[6] The model is defined by the following equations:

$$\begin{aligned} x_t &\sim D(\mu_t, \sigma_t^2); \\ \mu_t &= \mu + u_t + \theta u_{t-1}; \\ \sigma_t^2 &= \omega + \alpha u_{t-1}^2 + \beta \sigma_{t-1}^2. \end{aligned}$$

[7] According to the Triennial Central Bank Survey on Foreign Exchange turnover in April 2016, the turnover of the Mexican currency was 112 USD billions, and in the September 2019 survey's version reached 113.7 USD billions, BIS (2016) and BIS (2019). The Mexican peso was the eleventh most traded currency in the world in 2016 and is the fifteenth in 2019.

[8] The Continuous Linked Settlement (CLS) is an international system that settles foreign exchange transactions in 18 currencies; among them is the Mexican Peso, in March 2017 CLS was settling just over 50% of global FX transactions.

As discussed in Section (1), there is an ample research of the USD/MXN exchange rate volatility at lower frequencies. This work attempts to document the factors that define the intraday volatility process of U.S. Dollar–Mexican Peso exchange rate at high frequencies and the effects of some macroeconomic announcements. To this end, it will be followed the two-step procedure regression model proposed by Andersen and Bollerslev (1998) described in the previous section, using almost ten years of intraday data. The sample data goes from January 14, 2008, through November 8, 2017[9]. The log-returns time series is constructed from five-minute U.S. Dollar–Mexican Peso spot exchange rate[10] quotes from Bloomberg. The time zone of these quotes is Eastern Time (ET)[11]. Additionally, this analysis considers thirty nine macroeconomic announcements from seven economies with data obtained from Bloomberg and Banco de México's official website.

3.2 Interday Volatility Pattern (Daily Effects)

There is a vast literature for modeling interday volatility returns, a widely used class of models are the Autoregressive Conditional Heteroskedasticity (ARCH) models introduced by Engle, R. F. (1982), and later extended by Bollerslev (1986). ARCH models have been used for characterizing the interday factor of intraday volatility, Andersen and Bollerslev (1997B) states that the pervasive intraday periodicity in the return volatility has a strong impact on the dynamic properties of high frequency returns. In order to account for that systematic factor in the high-frequency volatility process, this work will use an ARMA(0,1)+GARCH(1,1) model estimated from daily returns over the sample period[12]. The daily return will be deduced by

[9]The sample initiates from 2008 since it is the year in which the Mexican Peso began to be traded 24 hours.

[10]The five-minutes window was selected since it is the finest sampling interval for intraday returns available since 2008, and as it was argued in Andersen and Bollerslev (1998), a finer time-window could be dominated by the bid-ask bounce effect documented by Guillaume et al. (1995).

[11]The Ester Time is relevant for this analysis for two reasons. First, the American segment or New York trading hours (in Easter Time) constitutes the most active trading period and the region where more of the relevant economic news for the Mexican economy are released. Second, a large part of the Mexican peso trading volume takes place outside of Mexico, being the American segment the region that concentrates most of this trading volume (around 42%).

[12]Andersen and Bollerslev (1998) argue that GARCH(1,1) models are a good approximation for estimating second order dependencies in return series. Andersen and Bollerslev (1997B) suggest to include the MA(1) term in order to account for the "economically minor, but occasionally highly statistically significant, first order autocorrelation in the series". In this work both models are estimated, the pure GARCH(1,1) model and the ARMA(0,1) + GARCH(1,1) model, using the Quasi-Maximum Likelihood Estimation (QMLE) method suggested by Bollerslev and Wooldridge (1992). Based on the information criterion statistics presented in Table (4) in the Appendix the best model is the ARMA(0,1) + GARCH(1,1). Additionally, the Ljung-Box test displayed in Table (6) in the Appendix, shows that for some values of q the null hypothesis is rejected, suggesting that some autocorrelation could persist on both types of standardized residuals. Alternatively, the

Table 1: **Estimates of ARMA(0,1) + GARCH(1,1) Model with Daily USD/MXN Returns**. The model is estimated with data over the sample period from January 14, 2008, through November 8, 2017. μ and θ are the parameters of the ARMA model and ω, α and β are the parameters of the GARCH model. Sources: Own estimations with data from Bloomberg.

Summary	Estimate	Std. Error	$t-$value	$Pr(>\|t\|)$
μ	0.00001	0.00012	0.04913	0.96081
θ	-0.10683	0.02134	-5.00533	0.00000
ω	0.00000	0.00000	3.77590	0.00016
α	0.13978	0.01601	8.72857	0.00000
β	0.84414	0.01807	46.70572	0.00000

Equation (6)[13].

$$x_t = \log P_{t,288}/P_{t-1,288} \tag{6}$$

Table (1) shows the statistics of the fitted data for ARMA-GARCH model defined in Section (2). The intraday volatility component, $\widehat{\sigma}_{t,n}$, will be estimated using the ARMA(0,1) + GARCH(1,1) model and applying Equation (5) of Section (2).

3.3 Intraday Volatility Pattern

The intraday volatility pattern is characterized by two factors, one associated to calendar effects, which accounts for trading patterns during the 24-hours trading cycle, and the macroeconomic announcement effects factor generated by predictable announcements.

Durbin-Watson test shows similar results for some levels of q; Table (7) displays these statistics. Later in the analysis, it will be used Newey and West (1987) method for standard errors to account for this autocorrelation.

[13]The daily returns are calculated from 00:00 to 00:00 of the next day, this time window is selected for a main reason, usually when the MFXC announces a FX policy (the description of this type of macroeconomic announcements will be cover in the next section) is as a result of an increment in the volatility of the FX rate before the announcement, these increments have happened sometimes at the London and Tokyo trading sessions, and usually the announcements are released at the New York trading hours. Since one of the objectives of this work is to assess the effect of the FX policies in the volatility in the day of the announcement, then it is important to include that information in the daily volatility of that day. Another time window that could be intuitive for the analysis, is from 08:00 to 08:00 of the next day, that is when the New York session begins - the trading session in Mexico- but as it was pointed before, some of the volatility burst have happened before this opening time. Table (5) in Appendix shows the parameters of the ARMA(0,1)+ GARCH(1,1) for the 8:00 to 8:00 time window, where it can be seen that the results are similar of the ones related to the 00:00 to 00:00 window presented in Table (1).

3.3.1 Periodic/Seasonal Volatility Patterns

Intuitively, one pattern that could produce increments in the volatility at a daily basis are the opening times since these take place systematically at the same time every day. Figure (1) shows the volatility activity in the 24-hours trading cycle represented by the average absolute intraday returns for each five-minute interval over the sample period, where it can be observed significant increments in volatility at 3:00 ET, 8:00 ET, and 20:00 ET, hours that are associated with the opening FX-trading times for London, New York and Tokyo. The biggest jumps in these opening times are in Tokyo and London, that could be explained by the fact that investors use the currency as a general proxy for risk, correlations are high enough that the hedges often work. The strong correlation in general makes that market participants in the Tokyo and/or London markets trade the currency in order to hedge their risk before the New York market opens. Additionally, the trading hours where most of economic data or events associated with Mexico and U.S. economy are released correspond to the New York trading session that goes from 8:00 ET to 17:00 ET. Figure (1) shows that during this period –blue box– volatility exhibits the highest levels[14]. After New York's close, volatility decreases until the Tokyo opening, where it displays increments again.

Day-of-the-week patterns are also considered. Figure (2) displays the volatility level for the different trading days, where Mondays usually show lower average levels of intraday volatility, whereas Thursdays higher.

3.3.2 Macroeconomic Announcements

Previous works have identified that the release of macroeconomic announcements produces short-lived increases in the volatility, Andersen and Bollerslev (1998) documented these effects in the Deutsche Mark–U.S. Dollar volatility, Bollerslev et al (2000) in the U.S. Treasury bond market, and Adams et al (2004), Andersen et al (2007B), Andersen et al (2007A) and Stroud and Johannes (2014) in the equity market. In particular, this paper analyses 39 macroeconomic announcements from seven economies to identify which of them have significant effects in the USD/MXN volatility.

The announcements related to the Mexican economy are one of the most intuitive to be assessed. Figure (3) shows the average five-minute volatility on dates where there are at least

[14]It also can be observed that after the New York opening time there are several volatility jumps, these are associated to the publication of different economic variables, which will be analyzed in the next section.

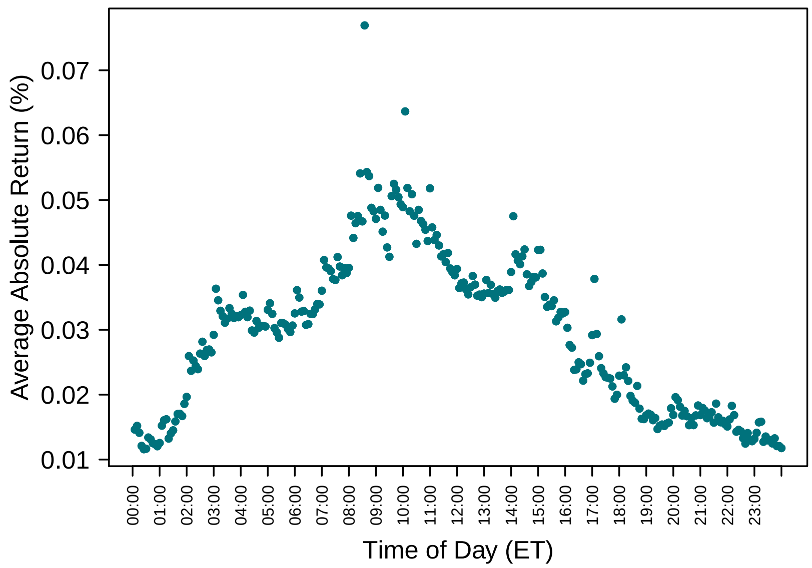

Figure 1: **Intraday volatility**. It shows the average absolute five-minute USD/MXN return over the sample period, January 14, 2008, through November 8, 2017. The lapse in red represents the trading hours of Tokyo that goes from 20:00 to 04:00 ET of the next day, the lapse in green the time in London that goes from 03:00 to 12:00 ET, in blue the time in New York that goes from 08:00 to 17:00 ET and the lapse in grey the time in Sydney that goes from 17:00 to 02:00 ET of the next day, it is noteworthy that some trading times overlap and they can be different during the daylight saving time period. Sources: Own estimations with data from Bloomberg.

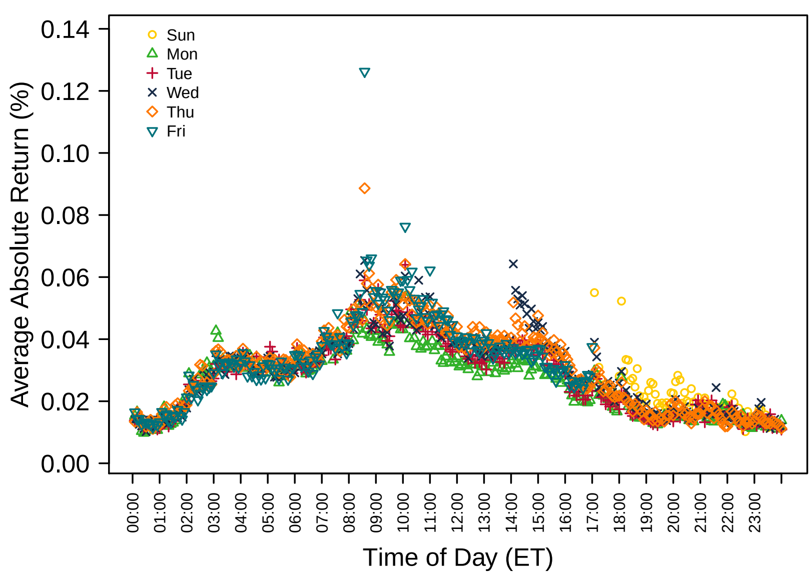

Figure 2: **Day of the week**. It shows the average absolute five-minute USD/MXN return over the sample period (January 14, 2008, through November 8, 2017) from Sunday to Friday. Sources: Own estimations with data from Bloomberg.

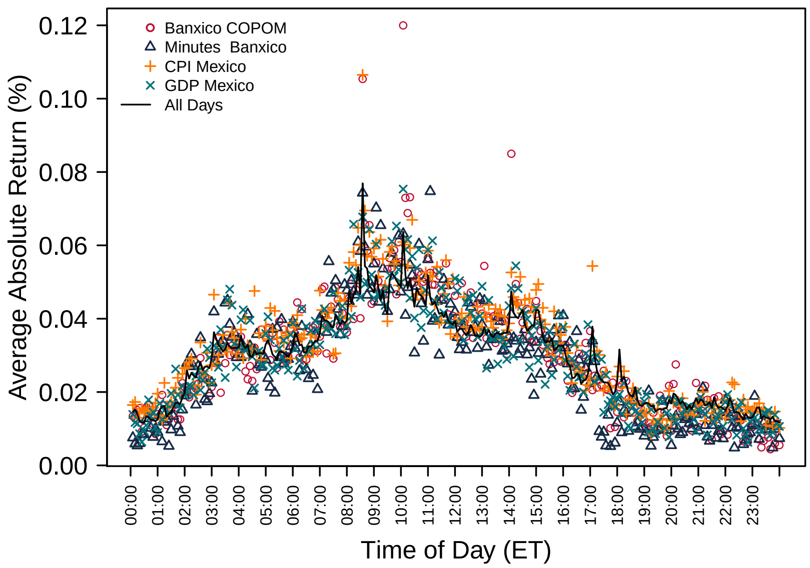

Figure 3: **Mexico macroeconomic announcement dates volatility.** It shows the average absolute five-minute USD/MXN return over the sample period, January 14, 2008, through November 8, 2017, for dates where at least one following Mexico's macroeconomic announcements is released: the Consumer Price Index and the revisions to the Gross Domestic Product at 9:00; at 14:00 the monetary policy decisions and minutes of Banxico. Sources: Own estimations with data from Bloomberg and Banco de México's website.

one release of scheduled announcements on Mexico macroeconomic data, monetary policy decisions and minutes of the Central Bank of Mexico (Banxico), where the red circles highlight some volatility spikes at 10:00, 13:00 and 14:00 ET, times when Banxico has released its monetary policy decision[15]. This suggests that these kind of announcements produce an effect in the intraday volatility. Macroeconomic data from Mexico, includes the Consumer Price Index (CPI), and quarterly Gross Domestic Product (GDP) estimates. A distinct important type of releases that will be also studied in this work are the announcements by Mexico's Foreign Exchange Rate Commission (MFXC).

Furthermore, it is also intuitive to analyze whether the macroeconomic announcements related to the U.S. economy, since it is directly linked to this exchange rate, and the economic relations between Mexico and U.S. suggests that the releases from this economy could have a significant impact in USD/MXN exchange rate parity. Figure (4) shows that U.S. announce-

[15]The monetary policy decision by the Central Bank of Mexico (Banxico) used to be released at 9:00 local time or 10:00 ET until 2015 when it decided to adopt 13:00 local time or 14:00 ET as its official release time, it is noteworthy to mention that this can differ by one hour because both countries adopt the daylight saving time in different days.

ments released at 8:30 ET are a source of volatility spikes, in particular when the Non-Farm Employment change and CPI data are released (series in yellow and blue at 8:30), a jump may also be observed at 8:15 (rhombus in green) associated with the release of the ADP Non-Farm Employment change. The figure also displays the intraday volatility pattern that contains other scheduled announcements on U.S. macroeconomic data, including the estimates to quarterly GDP, and the US Manufacturing PMI. Among other important source of volatility spikes are the announcements related to U.S. monetary policy decisions including the Federal Open Market Committee (FOMC) rate decision, the FOMC press conference and the publications of FOMC minutes, the FOMC decision and minutes are released at 14:00 ET by the Federal Reserve (FED), meanwhile the press conference stars at 14:30 [16]. In the figure can be observed that the series in dark cyan, orange and dark blue present volatility spikes at this time, it is apparent that these releases induce quite dramatic price adjustments, and after these announcements volatility decreases.

The Chinese economy is the second most important of the world and the first among emerging markets, therefore the release of its economic variables has become important worldwide. The announcements associated with this economy usually take place between 20:00 ET to 6:00 ET[17]. Figure (5) displays the average volatility of the dates when one of different macroeconomic Chinese announcements is released, this analysis accounts for the publication of the estimates of quarterly GDP, the services and manufacturing Caixin PMIs, the trade balance and the People's Bank of China monetary policy decision[18]. The volatility spikes related to these events can be identified in the figure during the Asian trading session, for instance, in the green triangles around 21:00-22:00, times when the GDP data has been published.

Similar announcements that are also analyzed in this work are the monetary policy decisions by Bank of Canada (BoC), Bank of England (BoE), the European Central Bank (ECB) and Bank of Japan (BoJ)[19]. It is also noteworthy that in contrast with scheduled events, seemingly with short-lived volatility bursts periods, unscheduled announcements/news produce more prolonged volatility episodes in the USD/MXN exchange rate, examples of these events are the different announcements released during the 2016 U.S. presidential race, but the effects

[16]The FED began to have a press conference after the FOMC decision since 2011, these conferences are every three months with release times, 14:15 from 2011 to 2012 and 14:30 from 2013.

[17]It is noteworthy to mention that although these announcements are not released always at the same time, these are controlled at the time they become public.

[18]This decision refers to the publication of the required deposit reserve ratio for major banks.

[19]Some of the coefficients related to these announcements are not presented in this work given that these are not significant.

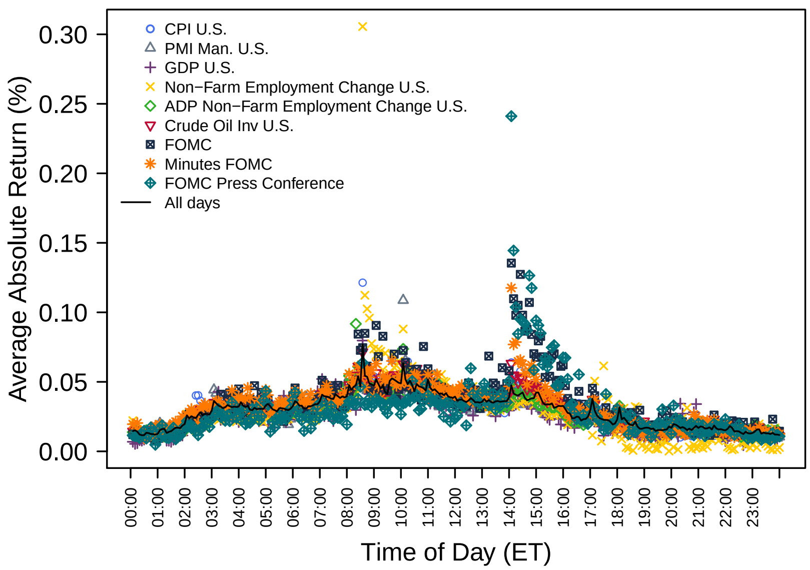

Figure 4: **U.S. macroeconomic announcement dates volatility.** It shows the average absolute five-minute USD/MXN return over the sample period, January 14, 2008, through November 8, 2017, for dates where at least one following U.S. macroeconomic announcements is released: the Consumer Price Index, the revisions to the Gross Domestic Product the Non-Farm Employment Change and its estimation (ADP) at 8:15; at 10:00 and 10:30 the Manufacturing PMI and Crude Oil Inventories respectively; at 9:00 and at 14:00 the monetary policy decisions by the FED, minutes and press conference from the FOMC. It can be observed that around the announcements' release time the volatility increases, the most noteworthy increments are linked to monetary policy announcements. Sources: Own estimations with data from Bloomberg.

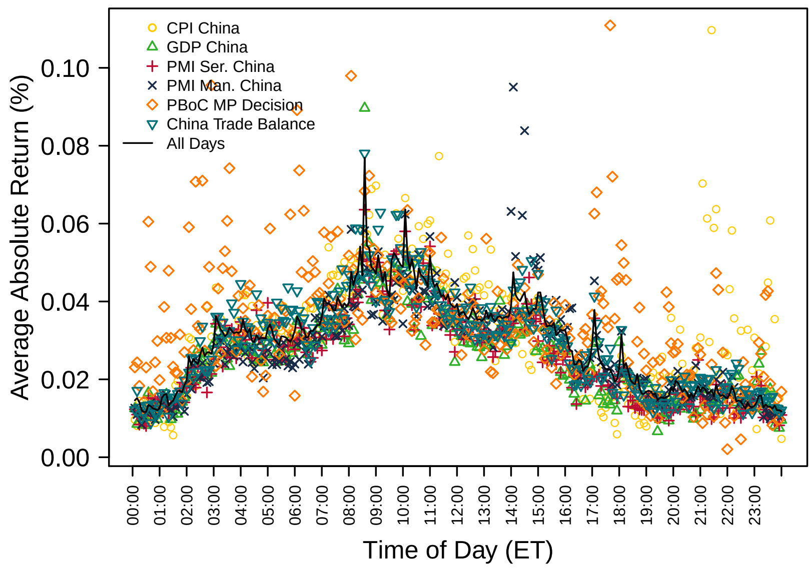

Figure 5: **China macroeconomic announcement dates volatility.** It shows the average absolute five-minute USD/MXN return over the sample period, January 14, 2008, through November 8, 2017, for dates where at least one following China's macroeconomic announcements is released: the Consumer Price Index, the revisions to the Gross Domestic Product, manufacturing and services Caixin Purchasing Managers' Indexes (PMI), Trade Balance and Monetary Policy decision by The PBoC, the times of these announcements variate from 20:00 ET to 6:00 ET. Sources: Own estimations with data from Bloomberg.

of these will not be studied in this work.

4 Results

This section documents the empirical results associated to the periodic/seasonal volatility patterns, macroeconomic announcement, and the volatility persistence implied in the intraday returns of the US Dollar–Mexican Peso exchange rate.

4.1 Periodic/Seasonal Volatility Patterns

As it was identified in section (3.3.1) the main events that cause significant jumps in the volatility process every trading day are the opening FX-trading times for London, New York and Tokyo, which are the trading sessions of the largest forex trading centers[20], these are captured by coefficients that allow for a linear decay of the associated one-hour volatility burst. This analysis also controls for different types of macroeconomic announcements. The first kind of announcements are related to monetary policy decisions, the most important being the decision of the FOMC meeting by the Federal Reserve, and its press conference, followed by the decision of the COPOM (Comité de Política Monetaria) meeting by the Mexican Central Bank (Banxico), the monetary decision by the Bank of England, and the press conference after the monetary policy decision by the ECB. The second kind include the releases of variables related to the real economy of particular countries, being the U.S. Non-Farm Employment Change the one that displays the strongest effects, followed by the quarterly Gross Domestic Product (GDP) and the Caixin Services and Manufacturing PMIs for China. Finally, the announcements related to the foreign exchange rate policy by Mexico's Foreign Exchange Rate Commission will be also considered to analyze their effects in the volatility process. The impact of the different announcements will be seized by the coefficients in Equation (3), in Section (4.2) the interpretation of these will be reviewed. The second column of Table (2) shows the results for the full system defined by Equation (4), where it can be observed that most of the coefficients associated with the periodic/seasonal intraday pattern are notably significant. The market openings effects are noteworthy; also it can be seen that there are significant day-of-the-week effects, being the largest on Thursday, this effect could be explained given that all Thursdays Jobless claims are released, this was not controlled in the regression. Table (2) column three displays the estimates of the coefficients without considering the day-of-the-week effect. Finally, in order to confirm that there is not a generated regressors problem in the two-step procedure, a constant daily volatility factor will be imposed, as in Andersen and Bollerslev (1998), represented by the average of Equation (5) over the sample period. The results in Table (2), column four, shows that the parameter estimates are unaffected, which confirms that using Equation (5) estimation does not induce a generated regressors problem.

The overall fit is for the intraday absolute returns are determined using the FFF patterns estimations and the following formula:

[20] According to the Triennial Central Bank Survey on Foreign exchange turnover in April 2016, BIS (2016), the largest trading centers of the foreign exchange market were United Kingdom with a share of the world's overall trading volume of 36.9%, followed by United States with 19.%5, Singapore with 7.9%, Hong Kong SAR with 6.7% and Japan with 6.1%.

$$|x_{t,n} - \mu| = N^{-1/2} \cdot \widehat{\sigma}_t \cdot \exp(FFF(\Theta, t, n)/2) \cdot \exp(\widehat{\epsilon}_{t,n}/2). \tag{7}$$

The economic significance of the periodic/seasonal intraday patterns are determined by the indicator variables associated with these events in Equation (3). The coefficient for the London Opening in Table (2) is 0.69 then from Equation (7), $\exp(0.69 \times .5) = 1.41$ implying that volatility jump for the corresponding interval is by about 41.2 percent. Consequently, the New York and Tokyo opening jumps by 16.8 and 25.9 percent respectively. For the day-of-the-week effect, it can be observed that Thursdays and Wednesday are the days that present the highest volatility levels during the sample period, in contrast, Mondays display the lowest levels.

In order to evaluate the remaining calendar effects, a decay-structure is imposed on the volatility response, Andersen and Bollerslev (1998) and Bollerslev et al (2000) suggest to use a third order polynomial $\gamma(i)$[21], which captures the average decay structure and forces the impact to zero after one hour, imposing $\lambda(k, i) = \lambda_k \cdot \gamma(i), \quad i = 0, \dots 12$. The intermediate response of the absolute returns will be represented by $\exp(\lambda_k \cdot \gamma(0)/2)$, meanwhile the effect at the $i-$th lag is $\exp(\lambda_k \cdot \gamma(i)/2)$. The associated cumulative response will be determined by $M(k) = \sum_{i=0}^{12} [\exp(\lambda_k \cdot \gamma(i)/2) - 1]$.

4.2 Macroeconomic Announcements

The effects in the volatility process related to macroeconomic announcements in Mexico, United States, China, and other economies are documented in this section. The results are summarized by point estimates of the announcement coefficients displayed in the third column of Table (2). Table (3) includes some of the releases that are highly significant. In order to clarify the economic impact of the different announcements, these are reported in columns

[21]The third-order polynomial representation of the volatility pattern following an announcement release is determined by $\gamma(i) = 1.737[1 - (i/13)^3] - 0.275[1 - (i/13)^2] + 0.012[1 - (i/13)]$ where $i = 0, 1, 2, \dots, 13$. These decay is calibrated by fitting all three parameters for the 26 announcements combined (this does not include the interventions mechanisms by the Mexican central bank, these announcements or policies are quantified in a daily basis), without the λ coefficient. For the rest of the k announcement effects, the response pattern is fixed and estimate the λ_k coefficient that loads onto this pattern. The analysis uses two time windows for testing the duration of the effects after the announcements, one-hour and two-hours windows, the results displayed in Figure (7) and Figure (6) suggest that the one-hour framework captures better the post effects of the announcements.

two and three in Table (3), the implied instantaneous jump in the volatility and the cumulative impact over the day respectively[22]. For illustration, consider the FOMC rate decision, which is highly significant. The estimate implies $\lambda_k \cdot \gamma(0) = 2.18 \times 1.35 = 2.96$, which is equivalent to a instantaneous jump in volatility of $\exp(2.96/2) - 1 = 337.25\%$, and a cumulative response of $M(k) = 21.54$. On the assumption that the average five-minute absolute return over the one hour response horizon from 2:00 PM to 3:00 PM ET equals 0.004%, the one-hour effect results in an increment in volatility of $21.54 \times 0.14\%$, which equals 3.19%. This translates into a 30.99% $(3.19/10.28)$ average increment in the cumulative absolute return for trading dates when the FOMC announces its monetary policy decision. It is noteworthy to mention that the size of the impact is not constant over the whole period. Table (8) in the Appendix shows that for the FOMC decision some of the times when this announcement is more impactful are 2008, the period when the Federal Reserve began to decrease its target rate, and 2013-2014, the time when the FED announced that it would be reducing the pace of its quantitative easing program, and tighten monetary policy (Taper Tantrum).

The announcement of monetary policy by Banco de México also has a significant coefficient but with a smaller contribution to the average volatility, its value is 1.34 resulting in an instantaneous jump of 145.02%, the contribution to daily volatility represents only 7.84% of the daily cumulative absolute return, smaller than the FOMC announcement. The ECB Press Conference and BoE monetary policy announcements have smaller and less significant jumps, 59.96% and 46.49% with impacts in cumulative daily absolute return of 5.17% and 5.79% respectively. The announcements related to monetary policy decisions of other central banks are not presented in these tables since they are not significant or have a smaller effect[23].

In terms of releases of macroeconomic variables related to the real economy, the regression shows that these are also significant for some economies. One surprising finding in this analysis, is the fact that the announcements related to the CPI and GDP of the Mexican economy do not produce jumps in the volatility, the coefficients associated with these announcements are small and not significant. Other works have shown that the releases of local macroeconomic variables are relevant for local assets, Andersen and Bollerslev (1998) showed that

[22]It is noteworthy to mention that the size of the jump could not be constant during the whole period, although the regression is controlled by the volatility regime that rules on the day of the announcement, the message released could not always have the same impact. Table (8) in the Appendix exhibits the coefficients for the regression in every year, where it can be observed that most of the significant announcements in each year have the same sign as the ones related for the whole-period regression.

[23]The regression was controlled by the monetary policy decisions of Bank of Canada, Bank of Japan, ECB and the People's Bank of China, as well as the publication of CPI and GDP of Germany, Euro zone, Canada, U.K. and Japan, and the Organization of the Petroleum Exporting Countries (OPEC) meetings.

Table 2: **Estimates for the Regression of the Five-Minute U.S. Dollar–Mexican Peso Absolute Returns Controlled by Periodic/Seasonal Patterns and Macroeconomic Announcement Effects** over the sample period from January 14, 2008, through November 8, 2017. The regression model used is described by Equation (4), the volatility components are estimated using Equation (5), and the results derived by the ARMA(0,1)+GARCH(1,1) model displayed in Table (1). The estimation in the third column uses $\widehat{\sigma}_{t,n}$ as the average of Equation (5) over the sample period. Robust t-statistics are given in parentheses, these are estimated using Newey and West (1987) considering 289 lags in order to account for intraday autocorrelation, regular OLS t-statistics are in brackets. Statistically significant coefficients at the 90%, 95% and 99% confidence levels have t-statistics with an absolute value greater than 1.645, 1.96 and 2.576, respectively. Sources: Own estimations with data from Bloomberg and Banco de México's website.

Parameter	Full System	Without controls for the Day-of-Week effects	Without controls for the Day-of-Week, and Daily Volatility effects
$\mu_0 + \widehat{c}$	-3.30	-2.86	-3.02
	[-204.32]	[-697.20]	[-729.48]
	(-52.40)	(-161.80)	(-147.68)
$\delta_{c,1}$	-1.60	-1.62	-1.60
	[-291.06]	[-302.66]	[-296.12]
	(-89.42)	(-94.83)	(-91.03)
$\delta_{c,2}$	-0.17	-0.16	-0.16
	[-30.99]	[-29.34]	[-30.13]
	(-17.16)	(-15.98)	(-16.60)
$\delta_{c,3}$	-0.09	-0.09	-0.10
	[-17.65]	[-17.06]	[-17.90]
	(-10.94)	(-10.67)	(-11.21)
$\delta_{c,4}$	-0.37	-0.37	-0.37
	[-68.41]	[-69.25]	[-68.19]
	(-45.33)	(-46.13)	(-45.78)
$\delta_{s,1}$	0.80	0.84	0.83
	[141.84]	[156.67]	[152.59]
	(62.79)	(69.41)	(69.10)
$\delta_{s,2}$	0.21	0.23	0.23
	[37.75]	[43.17]	[41.55]
	(19.16)	(23.75)	(23.17)
$\delta_{s,3}$	0.00	0.01	0.01
	[0.50]	[1.24]	[1.32]
	(0.31)	(0.79)	(0.84)
$\delta_{s,4}$	-0.14	-0.13	-0.14
	[-26.16]	[-24.97]	[-25.40]
	(-17.73)	(-16.83)	(-17.30)

Parameter	Full System	Without controls for the Day-of-Week effects	Without controls for the Day-of-Week, and Daily Volatility effects
Banxico COPOM	1.32	1.36	1.37
	[3.84]	[3.93]	[3.93]
	(5.32)	(5.45)	(5.19)
Minutes Banxico	-0.78	-0.72	-0.56
	[-1.23]	[-1.14]	[-0.87]
	(-1.51)	(-1.39)	(-1.08)
CPI Mexico	0.23	0.25	0.24
	[0.78]	[0.84]	[0.81]
	(0.84)	(0.90)	(0.89)
GDP Mexico	-0.14	-0.14	-0.12
	[-0.31]	[-0.29]	[-0.26]
	(-0.32)	(-0.30)	(-0.26)
Banxico Dollar Auctions	-0.59	-0.59	0.89
with Minimum Price	[-21.23]	[-21.03]	[31.57]
	(-5.35)	(-5.47)	(7.57)
Banxico Dollar Sales	-0.66	-0.64	-0.57
	[-7.88]	[-7.66]	[-6.80]
	(-1.48)	(-1.46)	(-1.28)
Banxico Dollar Auctions	-0.18	-0.15	-0.23
without Minimum Price	[-15.00]	[-12.47]	[-18.54]
	(-4.72)	(-3.97)	(-5.52)
CPI U.S.	0.74	0.78	0.81
	[2.54]	[2.67]	[2.76]
	(3.06)	(3.21)	(3.37)
PMI Man. U.S.	0.91	0.87	0.80
	[3.12]	[2.99]	[2.73]
	(4.33)	(4.15)	(3.87)
Non-Farm Employment Change U.S.	2.09	2.11	2.08
	[7.17]	[7.23]	[7.06]
	(9.82)	(9.91)	(9.69)
ADP Non-Farm Employment Change U.S.	0.82	0.87	0.82
	[2.81]	[2.99]	[2.80]
	(3.38)	(3.61)	(3.46)
FOMC	2.18	2.23	2.29
	[6.05]	[6.18]	[6.29]
	(7.45)	(7.66)	(7.52)
Minutes FOMC	1.34	1.39	1.30
	[3.70]	[3.83]	[3.54]
	(4.27)	(4.43)	(4.25)
FOMC Press Conference	1.96	2.02	2.07
	[3.16]	[3.26]	[3.31]
	(4.04)	(4.17)	(4.35)

Parameter	Full System	Without controls for the Day-of-Week effects	Without controls for the Day-of-Week, and Daily Volatility effects
GDP China	1.23	1.26	1.12
	[3.21]	[3.28]	[2.89]
	(3.39)	(3.42)	(3.02)
PMI Ser. China	0.71	0.73	0.60
	[1.87]	[1.91]	[1.57]
	(1.96)	(2.02)	(1.63)
PMI Man. China	0.76	0.72	0.68
	[3.02]	[2.83]	[2.65]
	(2.68)	(2.49)	(2.35)
China Trade Balance	0.60	0.61	0.71
	[1.70]	[1.72]	[1.98]
	(1.59)	(1.60)	(1.88)
ECB Press Conference	0.69	0.76	0.71
	[2.24]	[2.46]	[2.26]
	(2.83)	(3.12)	(2.82)
BoE Rate Decision	0.56	0.63	0.61
	[1.85]	[2.07]	[1.98]
	(2.59)	(2.91)	(2.61)
Tokyo Core CPI	-1.25	-1.09	-1.13
	[-3.97]	[-3.45]	[-3.55]
	(-3.23)	(-2.79)	(-2.95)
New York	0.31	0.30	0.31
	[4.83]	[4.76]	[4.76]
	(6.02)	(5.93)	(5.99)
Tokyo	0.46	0.47	0.47
	[7.02]	[7.10]	[7.00]
	(6.69)	(6.78)	(6.74)
London	0.69	0.68	0.68
	[10.52]	[10.36]	[10.29]
	(11.15)	(10.99)	(11.01)
Monday	0.32	–	–
	[17.41]	–	–
	(4.87)	–	–
Tuesday	0.48	–	–
	[26.23]	–	–
	(6.80)	–	–
Wednesday	0.53	–	–
	[29.17]	–	–
	(7.44)	–	–
Thursday	0.55	–	–
	[30.08]	–	–
	(7.56)	–	–
Friday	0.50	–	–
	[25.23]	–	–
	(6.85)	–	–

German GDP publication has a significant effect in the Deutsche mark–U.S. dollar exchange rate, meanwhile Bollerslev et al (2000) found significant effects of American CPI and GDP publications in the U.S. treasury bond market. In contrast, the announcement related to the U.S. and China's economy are pretty significant, being the Non-Farm Employment Change in U.S. the most important[24], it has a coefficient of 2.09 producing a jump of 311.27%, impacting in 13.76% the daily cumulative absolute return on dates of this announcement. Andersen and Bollerslev (1998) also found significant effects associated with the releases of economic variables of other economies in the DM/USD parity, primarily the related to the U.S. economy, in particular the employment report, which also yields to be most significant macroeconomic announcement related to U.S. in this work. The following most relevant for the U.S. economy are the manufacturing PMI with a coefficient of 0.91 producing a jump of 85.02% and impacting in 0.34%, ADP Non-Farm Employment Change and CPI have instantaneous jumps of 74.19% and 64.96% and impacts of 0.09% and 3.1% respectively. Chinese announcements also have significant impacts in USD/MXN exchange rate, the GDP of China produces an instantaneous jump in volatility of 130.57%, and an impact in daily cumulative return of 2.06%, Chinese manufacturing and service PMIs, and Trade Balance also present positive significant effects but with smaller significance, these are presented in Table (3). It is important to mention that the fact that the release of U.S. data has a bigger impact on the exchange rate rather than Mexican data could be supported by the size of the American economy, who is the biggest among these two countries. In the case of the Chinese announcements, the correlation of the USD/MXN exchange rate with emerging markets (EM) assets, the liquidity of the Mexican currency in the Asian trading session, and the economic importance of the Chinese economy among the emerging economies have made that when there are relevant news/announcements about this economy, market participants use the Peso as a proxy to hedge risk related to this announcements and EM assets. Furthermore, the fact that the USD dollar has been seen as a safe haven currency and that the Mexican currency has become one of the most liquid during all day have made that it reacts to risk-on and risk-off episodes induced by worldwide relevant announcements, usually related to the largest economies, the American and Chinese.

Additionally, Figure (6) and Figure (7) display the effects of some announcements during one hour and two hours after they were released using the decay-structure assumed, Figure (7) shows that the effects disappear before the two-hour window, suggesting that a better adjust-

[24]Since the U.S. dollar remains as the dominant currency for international trade and investment, tracking the U.S. economy strength is relevant in the forex world in particular for emerging market currencies.

ment is achieved by using a one-hour window, which is consistent with the time window used in Andersen and Bollerslev (1998). Another fact that can support these results is, as it was mentioned before, that the Mexican Peso is one of the most traded currencies in the world, the increase of its market liquidity and deepness has contributed to faster news digestion from market participants.

The MFXC has implemented several tools in order to provide liquidity, to promote orderly market conditions and to reduce volatility in the foreign exchange market. In this paper, three of the different mechanisms are studied[25], dollar auctions with minimum price[26], dollar auctions without minimum price, and direct dollar sales. The results show that, these three mechanisms accomplish the objective of stabilizing the volatility of the USD/MXN exchange rate in the period they are assessed[27]. The direct sales of dollars generate a coefficient of -0.66, resulting in a reduction in volatility of 28.09% in dates when the central bank makes direct sales, meanwhile dollar auctions with minimum price reduce volatility in 25.57%, and the dollar auctions without minimum price produce an effect of -8.66%. It is noteworthy that this framework only evaluates the short-lived effects in the volatility[28].

Summarizing, most of the macroeconomic announcements studied in this work produce considerable average jumps in the U.S. Dollar–Mexican Peso exchange rate intraday volatility, albeit these volatility burst are short-lived. There were two kind of macroeconomic announcements tested, the first type related to monetary policy decisions, highlighting that the largest jumps are linked to the FED's announcements. The second kind are the related to releases of economic variables, the results in the study show that for this type,

[25]Further details about the different intervention mechanism implemented by the MFXC could be consulted at "On central bank interventions in the U.S. Dollar–Mexican Peso foreign exchange market" by García-Verdú, Zerecero (2013)

[26]This includes only the auctions with minimum price from October 9th, 2009 through April 9th, 2010, the first time that this mechanism was implemented, and a second period from November 30th, 2011 through April 8th, 2013. In both episodes the auction's minimum price was equivalent to the previous working day's FIX exchange rate published by *Banco de México* plus 2%. Posterior auctions are not considered since the minimum price are not totally comparable, the trigger price rule for the auction was reduce in 0.5% (FIX exchange rate plus 1.5%) from December 9th 2015, through July 30th, 2015, and an extra decrease of 0.5% (FIX exchange rate plus 1%) through February 17th, 2016 when this mechanism was suspended. The two last minimum price rules suggest that the mechanism was targeted to a less volatility environment.

[27]In order to make all mechanisms comparable -since the information of the particular time of the intervention of some mechanisms is not known- the dummy variables are considered for the 24 hr of the intervention's date of each mechanism, for instance if the intervention day were on May 20th, 2017, the dummy variables will imposed from May 20th 00:00 ET to May 20th, 2017 23:55 ET.

[28]Since the effects of the mechanisms are controlled during all day, at most the effects assessed could be for one day.

the announcements of the U.S. and Chinese economies have a greater average impact in the intraday volatility rather than the ones associated with the Mexican economy.

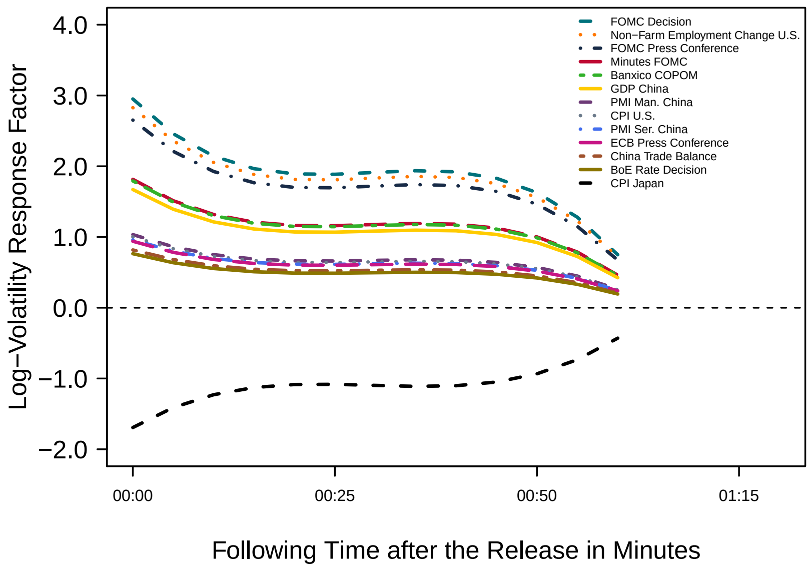

Figure 6: **After announcement 1 hour effect.** The figure shows the effects an hour after selected macroeconomic announcements for the five-minute USD/MXN absolute returns over the sample period, January 14, 2008 through November 8, 2017. Sources: Own estimations with data from Bloomberg and Banco de México's website.

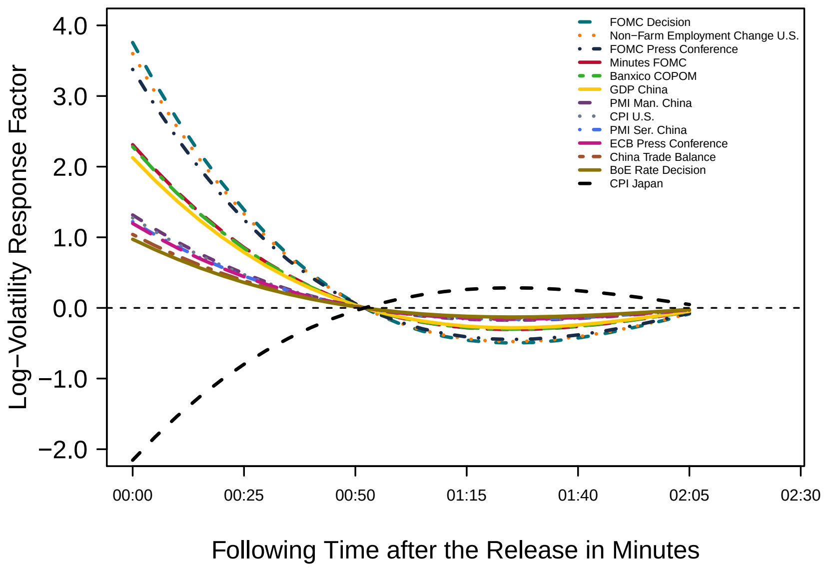

Figure 7: **After announcement 2 hours effect.** The figure shows the effects two hours after selected macroeconomic announcements for the five-minute USD/MXN absolute returns over the sample period, January 14, 2008 through November 8, 2017. Sources: Own estimations with data from Bloomberg and Banco de México's website.

4.3 Volatility Persistence in the U.S. Dollar–Mexican Peso Exchange Rate Using High Frequency Returns

Volatility persistence in exchange rates has been studied by several researchers. Baillie and Bollerslev (1989), Bollerslev (1987), McCurdy and Morgan (1988), Hsieh (1989), Baillie and Bollerslev (1989), Harvey (1994) and Baillie, Bollerslev and Mikkelsen (1996) are some works that have documented this phenomena using interday data, some of these have concluded that the volatility process is persistent and could be estimated by IGARCH processes. Andersen and Bollerslev (1997A), Andersen and Bollerslev (1998), and Andersen et al (2001) have also examined this hypothesis but using intraday returns. In particular for the U.S. Dollar–Mexican Peso exchange rate, it will be important to document whether this parity's intraday returns provide information about the long-memory characteristic that defines its volatility process. In order to address such hypothesis, the USD/MXN intraday returns will be filtered from the estimates of the calendar and announcement effects, $\frac{\mid x_{t,n} - \mu \mid}{\widehat{s}_{t,n}}$. Figure (8) shows the correlogram of the absolute and filtered-absolute returns, the plot related to the filtered-absolute returns displays a strictly positive and slowly declining correlogram, suggesting the success of modeling the systematic calendar and announcement effects by

Table 3: **Estimates of Selected Announcements Effects Obtained from the Regression of the Five-Minute U.S. Dollar–Mexican Peso Absolute Returns Controlled by Periodic/Seasonal Patterns and Other Macroeconomic Announcements** over the sample period form January 14, 2008, through November 8, 2017. The linear model used is described by Equation (4), the volatility components are estimated using Equation (5), and the results derived by the ARMA(0,1)+GARCH(1,1) model displayed in Table (1). Robust t-statistics are given in parentheses, these are estimated using Newey and West (1987) considering 289 lags in order to account for intraday autocorrelation. Sources: Own estimations with data from Bloomberg and Banco de México's website.

Selected Macroeconomic Announcement Effects			
Announcement	Coefficient (Robust t-stat)	Instantaneous Jump in Volatility (%)	Impact of Daily Cum. Abs. Return (%)
FOMC	2.18	337.25	30.99
	(-7.45)		
Non-Farm Employment Change U.S.	2.09 (-9.82)	311.27	13.76
FOMC Press Conference	1.96	276.67	31
	(-4.04)		
Minutes FOMC	1.34	147.82	17.18
	(-4.27)		
Banxico COPOM	1.32	145.02	7.84
	(-5.32)		
GDP China	1.23	130.57	2.06
	(-3.39)		
PMI Man. U.S.	0.91	85.02	0.34
	(-4.33)		
ADP Non-Farm Employment Change U.S.	0.82 (-3.38)	74.19	0.09
PMI Man. China	0.76	67.66	1.12
	(-2.68)		
CPI U.S.	0.74	64.96	3.1
	(-3.06)		

Important Announcement Effects			
Announcement	Coefficient (Robust t-stat)	Instantaneous Jump in Volatility (%)	Impact of Daily Cum. Abs. Return (%)
PMI Ser. China	0.71	61.55	5.17
	(-1.96)		
ECB Press Conference	0.69	59.96	0.06
	(-2.83)		
China Trade Balance	0.6	50.44	7.15
	(-1.59)		
BoE Rate Decision	0.56	46.49	5.79
	(-2.59)		
CPI Japan	-1.25	-57.11	-3.18
	(-3.23)		
Banxico Dollar Sales	-0.66	-28.09	–
	(-1.48)		
Banxico Dollar Auctions with Minimum Price	-0.59 (-5.35)	-25.57	–
Banxico Dollar Auctions without Minimum Price	-0.18 (-4.72)	-8.66	–

$s_{t,n}$[29]. On the contrary, the plot related to the absolute five-minute returns, $|x_{t,n} - \mu|$, exhibits a strong periodicity over every one-day cycle.

The degree of volatility persistence, or the fractional integration d can be derived from Equation(8), according to Andersen and Bollerslev (1997A)

$$\log(\widehat{\rho}_j) = c + (2d - 1)\log(j) + u_j \tag{8}$$

where $\widehat{\rho}_j$ denotes the sample autocorrelation for the intraday absolute returns; applying this formula to the sample autocorrelations of the filtered intraday absolute returns results in $\widehat{d} = 0.405$, which is consistent with the estimates of d obtained for other currencies, Andersen and Bollerslev (1998) and Andersen et al (2001). The implied hyperbolic rate of decay, in Figure (8), derived from d and $\widehat{\rho}_j \approx c * j^{2d-1}$, shows a good fit for the shape of the autocorrelogram, showing that once discounted the intraday dependencies, the long-memory characteristic of the U.S. Dollar–Mexican Peso exchange rate volatility process is evident.

[29]The shape of the information plotted in Figure (8) exhibits the same patterns presented in Andersen and Bollerslev (1998) and Bollerslev et al (2000), this supports the argument of the success of modeling $s_{t,n}$ for this asset.

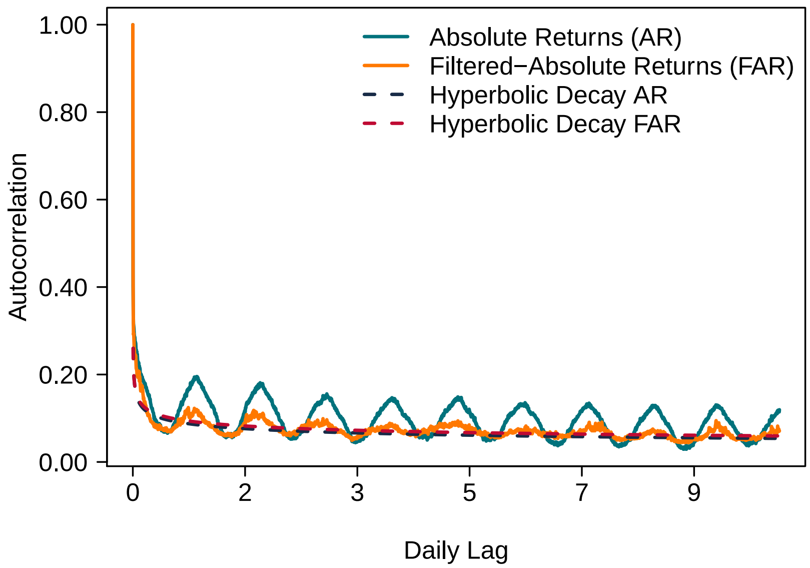

Figure 8: **Absolute and filtered-absolute returns correlograms.** It shows the autocorrelations for the five-minute USD/MXN absolute and filtered-absolute returns over the sample period, January 14, 2008, through November 8, 2017. The filtered returns are obtained by using the following equation $\frac{\mid x_{t,n} - \mu \mid}{\widehat{s}_{t,n}}$. Sources: Own estimations with data from Bloomberg and Banco de México's website.

5 Conclusion

The volatility process of the MXN/USD spot exchange rate is partly defined by the disclosure of new information, not only at the level of daily returns but also high-frequency intraday returns. This work contributes to the literature that documents the dynamics of the U.S. Dollar–Mexican Peso volatility process from a high-frequency perspective. The main results of this study are on the empirical identification of the macroeconomic announcements effects at different frequencies. The results display strong but short-lived announcement effects that are prevalent at the highest frequencies, their effects disappear around one hour after they are released, with the most significant effects at the intraday level linked to monetary policy announcements released by different central banks, being the FOMC (Federal Open Market Committee) monetary policy decision the most considerable, followed by Banco de México monetary policy decision. Additionally, other significant announcements include the release of economic variables from different economies; being the publication of U.S. economic data the most impactful among this class, followed by the associated with the Chinese economy. In contrast, the release of the different economic variables of Mexico do not present significant effects in the intraday volatility. The results also show that the policies executed by Mexico's Foreign Exchange Commission accomplish their objective of stabilizing the volatility of the U.S. Dollar–Mexican Peso exchange rate when these are performed. In addition, the results documented in this article confirm the different characteristics that define the systematic features of the process identified in other works and other financial assets.

Additionally, it is noteworthy to mention that one of the main goals of this analysis was to identify and assesses the effects induced by the release of macroeconomic data on the exchange rate. In this context, there are possible lines of future research in terms of forecasting performance. For instance, albeit this work controls for the interday volatility using GARCH models, the current framework assumes that this factor is constant over the day and it does not consider the different regimes that could affect volatility. Then a more general Stochastic Volatility Model (SVM) may be considered to relax some of these assumptions. In addition, having a SVM that permits to estimate non-constant jumps influenced by the macroeconomic announcements simultaneously with the rest of the parameters and states –interday volatility factors and seasonal components– could contribute to avoid the potential inefficiencies produced by the actual two-stage procedure. A general approach, that could be a starting point for addressing these issues and improving the forecasting performance of volatility for this exchange rate process, is the multiplicative specification framework developed by Stroud and Johannes (2014) that leverages MCMC techniques for efficiently estimating the different factors that characterize the intraday volatility processes.

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Appendix

Table 4: **GARCH Model Selection**. The models are estimated with data over the sample period from January 14, 2008, through November 8, 2017. Sources: Own estimations with data from Bloomberg.

Model	Log-likelihood	AIC	BIC	SIC	HQIC
GARCH(1,1)	-8598.2450	-6.9477	-6.9383	-6.9477	-6.9442
ARMA(0,1) + GARCH(1,1)	-8610.5682	-6.9568	-6.9451	-6.9568	-6.9525

Table 5: **Estimates of ARMA(0,1) + GARCH(1,1) Model with Daily USD/MXN Returns beginning at at 8:00 AM ET**. The model is estimated with data over the sample period from January 14, 2008, through November 8, 2017. The log returns are calculated using the following formula: $x_t = logP_{t,107}/P_{t-1,107}$. μ and θ are the parameters of the ARMA model and ω, α and β are the parameters of the GARCH model. Sources: Own estimations with data from Bloomberg.

Summary	Estimate	Std. Error	$t-$value	$Pr(>\|t\|)$
μ	-0.00004	0.00011	-0.32616	0.74430
θ	-0.11309	0.02131	-5.30669	0.00000
ω	0.00000	0.00000	3.43288	0.00060
α	0.13248	0.01580	8.38371	0.00000
β	0.86200	0.01594	54.07759	0.00000

Table 6: **Standardised Residuals Tests for the ARMA(0,1)+ GARCH(1,1) model:**. The model is estimated with data over the sample period from January 14, 2008, through November 8, 2017. Sources: Own estimations with data from Bloomberg.

Test		Lag	Statistic	p-Value
Ljung-Box Test	R	Q(10)	20.37	0.026
Ljung-Box Test	R	Q(15)	27.32	0.026
Ljung-Box Test	R	Q(20)	28.17	0.11
Ljung-Box Test	R^2	Q(10)	19.50	0.034
Ljung-Box Test	R^2	Q(15)	22.19	0.103
Ljung-Box Test	R^2	Q(20)	26.07	0.163
LM Arch Test	R	TR^2	19.00	0.088

Table 7: **Durbin-Watson Test for Autocorrelation of the Standardised Residuals of the the ARMA(0,1)+ GARCH(1,1) model:**. The model is estimated with data over the sample period from January 14, 2008, through November 8, 2017. Sources: Own estimations with data from Bloomberg.

Residual	Lag	Autocorrelation	DW Statistic	p-Value
R	5	-0.026	2.05	0.196
R	10	0.0002	1.99	0.956
R	15	-0.007	2.01	0.544
R^2	5	0.06	1.870	0.022
R^2	10	-0.02	2.04	0.136
R^2	15	-0.008	2.01	0.548

Table 8: **Estimates for the Regression of the Five-Minute U.S. Dollar–Mexican Peso Absolute Returns Controlled by Periodic/Seasonal Patterns and Macroeconomic Announcement Effects** for every year from 2007-2017. The regression model used is described by Equation (4), the volatility components are estimated using Equation (5), and the results derived by the ARMA(0,1)+GARCH(1,1) model displayed in Table (1). Robust t-statistics are given in parentheses, these are estimated using Newey and West (1987) considering 289 lags in order to account for intraday autocorrelation. Sources: Own estimations with data from Bloomberg and Banco de México's website.

Announcement	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
$\delta_{c,1}$	-2.57	-2.38	-1.73	-1.34	-1.09	-1.69	-1.71	-1.84	-1.38	-1.55
	(-62.04)	(-43.12)	(-41.18)	(-22.49)	(-32.12)	(-47.27)	(-110.48)	(-50.5)	(-91.04)	(-47.85)
$\delta_{c,2}$	-0.53	-0.15	-0.07	-0.18	-0.13	-0.01	-0.21	-0.15	-0.01	-0.22
	(-13.54)	(-3.77)	(-2.18)	(-5.76)	(-5.49)	(-0.28)	(-13.97)	(-6.02)	(-0.92)	(-8.85)
$\delta_{c,3}$	-0.07	0.02	0.05	-0.03	-0.1	-0.08	-0.11	-0.14	-0.25	-0.23
	(-1.74)	(0.66)	(2.04)	(-1.18)	(-4.5)	(-3.35)	(-7.05)	(-7.01)	(-16.77)	(-9.31)
$\delta_{c,4}$	-0.24	-0.39	-0.29	-0.18	-0.27	-0.42	-0.41	-0.44	-0.54	-0.5
	(-7.69)	(-12.76)	(-12.08)	(-6.55)	(-12.38)	(-19.88)	(-27.34)	(-20.31)	(-36.79)	(-23.53)
$\delta_{s,1}$	0.93	0.64	0.69	0.6	0.62	0.86	0.84	1.12	1.1	0.95
	(24.19)	(15.1)	(18.55)	(11.72)	(19.36)	(27.82)	(53.74)	(39.41)	(72.32)	(34.15)
$\delta_{s,2}$	0.55	0.16	0.12	0.08	0.06	0.25	0.21	0.26	0.13	0.12
	(14.12)	(3.74)	(3.78)	(2.05)	(2.42)	(9.72)	(13.45)	(10.46)	(8.66)	(4.81)
$\delta_{s,3}$	0.35	0.13	0	0.09	0.01	-0.08	-0.01	-0.02	-0.14	-0.06
	(9.25)	(3.62)	(0.16)	(3.05)	(0.51)	(-3.53)	(-0.68)	(-0.96)	(-9.5)	(-3)
$\delta_{s,4}$	0	-0.04	-0.16	-0.11	-0.16	-0.24	-0.17	-0.21	-0.2	-0.17
	(0.09)	(-1.33)	(-6.16)	(-4.58)	(-8.29)	(-11.2)	(-11.6)	(-9.6)	(-13.72)	(-7.75)
BdM COPOM	1.46	2.09	0.22	0.07	1.93	2.16	0.84	1.31	1.62	0.29
	(2.65)	(4.61)	(0.36)	(0.12)	(2.92)	(3.71)	(1.16)	(1.17)	(2.03)	(0.09)
Minutes BdM	–	–	–	–	–	0.56	-3.03	-1.64	-1.88	0.21
	–	–	–	–	–	(1.59)	(-80.39)	(-1.84)	(-1.85)	(0.25)
CPI Mexico	0.56	0.3	0.44	0.12	-1.73	1.78	-0.02	-0.04	-0.78	0.23
	(0.69)	(0.6)	(0.65)	(0.14)	(-1.34)	(3.27)	(-0.02)	(-0.09)	(-0.82)	(0.44)
GDP Mexico	0.31	-0.27	-1.48	0.2	0.09	-2.23	-1.51	0.36	0.33	0.24
	(0.24)	(-0.27)	(-0.92)	(0.29)	(0.1)	(-0.9)	(-0.97)	(0.4)	(0.28)	(0.2)
BdM USD Auct.	0.1	-0.13	–	–	–	–	–	–	–	–
with Min. Pr.	(1.01)	(-1.18)	–	–	–	–	–	–	–	–
BdM USD Sales	–	-0.61	–	–	–	–	–	–	0.09	0.74
	–	(-1.48)	–	–	–	–	–	–	(0.41)	(3.54)
BdM USD Auct.	–	-0.28	–	–	–	–	–	0.14	–	–
w/o Min. Pr.	–	(-3.26)	–	–	–	–	–	(1.73)	–	–
CPI U.S.	-0.81	0.19	1.23	1.74	-0.06	1.2	0.4	1.64	1.23	-0.53
	(-0.69)	(0.33)	(2.76)	(5.11)	(-0.08)	(2.05)	(0.61)	(3.39)	(1.77)	(-0.53)
PMI Man. U.S.	-0.59	0.31	0.32	0.72	1.11	2.3	1.33	0.63	0.82	0.51
	(-0.82)	(0.57)	(0.62)	(1.08)	(1.56)	(5.2)	(2.65)	(0.92)	(1.2)	(0.7)
GDP U.S.	-0.34	0.08	0.9	-1.58	-0.51	-1.83	1.58	1.43	-0.36	2.76
	(-0.18)	(0.08)	(0.9)	(-2.87)	(-0.66)	(-0.75)	(4.51)	(2.4)	(-0.2)	(5.84)
NF Emp.	1.44	1.4	1.73	2.19	2.61	3.16	2.35	2.03	1.45	1.35
Chang. U.S.	(1.65)	(1.93)	(4.03)	(2.74)	(5.94)	(7.65)	(2.83)	(3.51)	(2.54)	(2.29)
ADP NF Emp.	1.04	1.12	1.66	0.86	-1.04	1.1	1.74	0.77	-0.15	-0.39
Chang. U.S.	(2.03)	(1.79)	(3.35)	(1.45)	(-0.94)	(1.85)	(2.84)	(1.02)	(-0.19)	(-0.42)
FOMC	2.39	1.58	2.14	2.26	1.23	2.45	3.57	0.77	2.67	2.61
	(3.51)	(1.24)	(2.33)	(2.65)	(1.62)	(2.88)	(5.54)	(1.06)	(2.36)	(3.2)
Minutes FOMC	0.52	0.92	-0.17	1.54	1.75	2.19	2.32	1.08	0.9	1.58
	(0.44)	(1.43)	(-0.17)	(2.49)	(1.85)	(2.57)	(2.58)	(0.82)	(0.99)	(1.63)
FOMC Press	–	–	–	1.27	1.55	3.05	3.45	-0.09	1.76	1.91
Conference	–	–	–	(0.93)	(1.28)	(4.16)	(4.57)	(-0.09)	(1.04)	(3.07)

	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
ECB Rate Decision	-0.41	0.39	-0.3	-0.25	0.45	1.21	0.82	1.1	0.86	-0.36
	(-0.66)	(0.81)	(-0.27)	(-0.36)	(0.98)	(1.79)	(0.77)	(1.7)	(1.31)	(-0.4)
ECB Press Conference	-0.66	1.28	0.83	-0.04	2.23	1.2	-0.01	0.49	-0.11	0.64
	(-0.59)	(2.76)	(1.55)	(-0.06)	(4.66)	(3.1)	(-0.01)	(0.71)	(-0.14)	(0.49)
BoC Rate Decision	0.1	-1.11	0	1.28	1.03	-0.22	-0.63	0.55	-0.02	0.23
	(0.13)	(-1.04)	(0)	(2.99)	(2.12)	(-0.29)	(-0.48)	(0.71)	(-0.02)	(0.35)
BoJ Rate Decision	2.04	-0.11	0.25	-0.93	-0.07	1.35	0.83	-1.36	3.36	2.95
	(1)	(-0.07)	(0.27)	(-1.08)	(-0.09)	(1.48)	(1.44)	(-1.49)	(5.13)	(5.98)
BoJ Minutes	-3.66	0.42	1.83	1.05	-0.89	0.5	-0.72	0.57	0.64	-1.97
	(-1.72)	(0.4)	(3.52)	(1.13)	(-1.25)	(0.55)	(-0.68)	(0.88)	(0.43)	(-1.33)
BoE Rate Decision	0.29	0.86	0.81	0.71	-0.17	-0.27	-0.68	1.69	1.42	1.35
	(0.32)	(1.58)	(1.23)	(1.47)	(-0.3)	(-0.5)	(-0.97)	(3.41)	(2.55)	(7.74)
CPI China	7.2	1.65	-0.11	1.32	-0.55	0.07	0.02	0.05	0.93	-2.36
	(11.89)	(1.27)	(-0.08)	(1.77)	(-0.41)	(0.08)	(0.02)	(0.07)	(1.2)	(-1.72)
GDP China	-12.19	0.76	2.18	0.51	2.62	0.11	1.26	1.25	1.4	0.2
	(-19.59)	(0.35)	(1.31)	(0.38)	(6.03)	(0.12)	(1.33)	(1.81)	(1.37)	(0.19)
PMI Ser. China	–	–	1.03	1.94	0.3	-0.79	-1.09	1.49	0.82	1.83
	–	–	(0.87)	(3.19)	(0.31)	(-0.98)	(-0.93)	(1.92)	(0.71)	(1.01)
PMI Man. China	2.09	0.24	0.09	0.65	1.62	1.14	1.06	-1.17	-0.01	-0.18
	(0.73)	(0.15)	(0.07)	(0.92)	(3.07)	(1.9)	(1.84)	(-1.67)	(-0.02)	(-0.15)
PBoC Rate Decision	2.3	–	1.65	-0.39	–	–	–	2.07	2.83	–
	(1.13)	–	(1.45)	(-0.28)	–	–	–	(6.79)	(81.32)	–
China Trade Balance	3.15	-0.32	-0.25	-1.23	0.9	1.27	1.23	0.81	1.76	-0.46
	(1.56)	(-0.26)	(-0.21)	(-1.14)	(0.93)	(1.13)	(1.46)	(1.17)	(2.23)	(-0.38)
GDP Germany	4.26	-4.78	0.64	0.1	-1.68	1.06	0.9	-1.32	0.74	0.98
	(36.62)	(-2.69)	(0.41)	(0.11)	(-1.34)	(0.85)	(0.75)	(-0.6)	(0.77)	(13.2)
GDP UK	2.57	0.95	2.1	-0.84	1.25	-2.95	-1.32	-0.65	0.21	-2.82
	(19.22)	(1.52)	(3.15)	(-1.56)	(4.32)	(-1.65)	(-1.06)	(-0.48)	(0.72)	(-1.92)
GDP Japan	1.49	2.95	2.04	-2.19	2.29	1.41	-1.06	-0.4	0.6	-1.63
	(0.68)	(3.74)	(1.75)	(-2.33)	(2.19)	(1.17)	(-0.55)	(-0.14)	(0.56)	(-1.93)
GDP Canada	0.79	0.82	0.23	-1.15	-0.05	-0.65	0.07	0.87	1.22	1.24
	(1.39)	(1.54)	(0.28)	(-1.07)	(-0.11)	(-0.8)	(0.11)	(1.29)	(3.86)	(1.99)
CPI Canada	-0.22	1.05	-0.48	-0.19	0.2	-1.17	0.3	-0.95	-0.2	0.19
	(-0.19)	(1.74)	(-0.41)	(-0.26)	(0.25)	(-2)	(0.74)	(-1)	(-0.22)	(0.24)
CPI Eurozone	2.89	0.49	-0.51	0.65	0.23	0.32	-0.26	-0.89	0.01	-1.5
	(3.71)	(0.54)	(-0.53)	(0.91)	(0.24)	(0.36)	(-0.32)	(-2.04)	(0.01)	(-1.21)
CPI Japan	-5.65	0.58	-0.85	-2.1	-0.73	-1.14	-1.35	-0.74	-2.4	-0.51
	(-4.88)	(0.61)	(-0.64)	(-1.57)	(-0.81)	(-1.01)	(-1.35)	(-0.75)	(-2.05)	(-0.51)
CPI UK	0.42	-0.3	-0.05	0.83	0.33	-0.08	0.51	-0.34	0.32	0.27
	(0.56)	(-0.24)	(-0.08)	(1.38)	(0.69)	(-0.1)	(0.51)	(-0.61)	(0.5)	(0.39)
London	0.6	0.2	0.32	0.51	1.01	1.01	0.7	1.03	0.92	0.52
	(1.2)	(0.71)	(1.61)	(2.65)	(5.93)	(6.16)	(4.27)	(7.14)	(6.63)	(3.2)
New York	0.09	0.18	0.04	0.2	0.62	0.33	0.51	0.32	0.16	0.5
	(0.48)	(1.17)	(0.23)	(1.3)	(4.39)	(2.04)	(2.97)	(2.24)	(0.9)	(3)
Tokyo	2.15	0.44	-0.29	0.29	0.25	0.75	0.66	0.41	1.17	0.62
	(3.46)	(1.51)	(-1.31)	(1.43)	(1.4)	(4.28)	(3.59)	(2.24)	(7.13)	(3.46)
Monday	-0.67	0.35	0.13	1.47	0.83	-0.28	0.6	-0.29	-0.32	0.08
	(-3.53)	(1.16)	(0.64)	(6.35)	(6.21)	(-2.5)	(10.66)	(-2.11)	(-5.35)	(0.65)
Tuesday	-0.55	0.36	0.33	1.77	1.12	-0.08	0.76	-0.18	-0.11	0.28
	(-2.89)	(1.12)	(1.52)	(7.16)	(7.59)	(-0.63)	(13.51)	(-1.32)	(-1.86)	(2.11)
Wednesday	-0.74	0.27	0.43	1.91	1.28	0.03	0.85	-0.08	0.09	0.51
	(-3.93)	(0.84)	(1.91)	(7.72)	(8.56)	(0.27)	(14.87)	(-0.56)	(1.53)	(3.54)
Thursday	-0.83	0.22	0.42	1.9	1.28	0.19	0.93	-0.1	-0.05	0.53
	(-4.42)	(0.69)	(1.89)	(7.81)	(8.59)	(1.56)	(16.43)	(-0.61)	(-0.79)	(3.83)
Friday	-0.48	0.16	0.32	1.71	1.19	0.06	0.88	-0.06	-0.1	0.29
	(-2.51)	(0.44)	(1.44)	(7.05)	(7.41)	(0.46)	(14.57)	(-0.44)	(-1.56)	(1.88)