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Guillermo Benavides
Banco de México

Carlos Capistrán
Banco de México

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A Note on the Volatilities of the Interest Rate and the Exchange Rate Under Different Monetary Policy Instruments: Mexico 1998-2008*

Guillermo Benavides†
Banco de México

Carlos Capistrán‡
Banco de México

Abstract: To advance our understanding of the mechanisms through which monetary policy affect the economy, in this note we analyze the volatilities of the Mexican short-term interest rate and of the peso-dollar exchange rate under two monetary policy instruments: a non-borrowed reserves requirement target (the "Corto") and an interest rate target. Using tests for multiple structural changes, we document that both volatilities decreased around the time Banco de México started the transition from the former to the latter. With respect to the volatility transmission from interest rates to exchange rates and vice versa, we find, using a bivariate GARCH model and causality-in-variance tests, bi-causality during the period of the Corto, but no causal relation after the transition started.
Keywords: Corto, Granger causality, Multiple structural breaks, Multivariate volatility.
JEL Classification: C22, E43, E52, F31.

Resumen: Para avanzar nuestro entendimiento de los mecanismos a través de los cuales la política monetaria afecta a la economía, en esta nota analizamos las volatilidades de la tasa de interés de corto plazo y del tipo de cambio peso-dólar bajo dos instrumentos de política monetaria: el Corto y objetivos de tasa de interés. Usando pruebas para detectar múltiples cambios estructurales, documentamos que ambas volatilidades disminuyen alrededor de la fecha en que Banco de México comenzó la transición del primero hacia el segundo. Con respecto al impacto de la tasa de interés sobre el tipo de cambio y viceversa encontramos, usando un modelo GARCH bivariado y pruebas de causalidad en varianza, bi-causalidad durante el periodo del Corto, pero no encontramos ninguna relación causal después de que empezó la transición.
Palabras Clave: Corto, Causalidad a la Granger, Cambios estructurales multiples, Volatilidad multivariada.

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† Dirección General de Investigación Económica. Email: gbenavid@banxico.org.mx.
‡ Dirección General de Investigación Económica. Email: ccapistran@banxico.org.mx.

1 Introduction

The daily volatility of the Mexican short-term interest rate decreased substantially when Banco de México (Mexico's central bank) transited from a non-borrowed reserve requirements target, called the "Corto", to an interest rate target in April 2004.[1] This empirical fact could be considered the natural outcome of the actions taken by the central bank in order to achieve the desired interest rate target.

In contrast, the daily volatility of the peso-dollar exchange rate seems to have remained about the same after the transition to the new monetary policy instrument. However, there are reasons to believe that the exchange rate volatility should have increased with the introduction of interest rate targeting. For example, Schwartz et al. (2002) refer to the experience of New Zealand, where the volatility of the exchange rate clearly increased after the central bank switched from a non-borrowed reserves target, similar to the Corto, to interest rate targeting in March 1999. The explanation offered by Schwartz et al. (2002) is that under non-borrowed reserves targeting, external shocks hitting a small open economy are captured not only by the nominal exchange rate, but that part of the effect is captured by the nominal interest rates, "lowering" the volatility of the exchange rate. On the contrary, under interest rate targeting, the shocks can only affect the nominal exchange rate and hence its volatility should increase. A similar argument can be found in Martínez et al. (2001).

To advance our understanding of the mechanisms through which monetary policy affect the economy, in this note we analyze the dynamics of the volatilities of the interest rate and of the exchange rate. We find that each has a structural break around April 2004 in which the volatility decreases. This fall in the volatilities after the transition in the monetary policy instrument in Mexico is statistically significant. Hence, the exchange rate volatility not only not increased, but actually decreased. Moreover, the argument used to predict the increase in the volatility of the exchange rate implied that during the Corto the volatility of the interest rate responded to exogenous shocks and hence limited the role of the exchange rate as a buffer to these disturbances (Schwartz et al., 2002). To further investigate this issue, we analyze the volatility transmission between the interest rate and the exchange rate. We find that a causal relation existed during the period of the Corto, but not after the beginning of the transition. In particular, we find feedback in the volatilities during the Corto period.

[1] The non-borrowed reserves targeting regime or "Corto" was a monetary policy instrument used in Mexico between March 1995 and January 2008 (Banco de México, 1996; 2000; 2007; Gil, 1998). In April 2004, Banco the México started to send signals to the market about its desired level of interest rates, which for the purposes of this paper would be considered a *de facto* transition to the use of interest rates as the monetary policy instrument. The *de jure* switch was made in January 2008.

2 Interest rate and exchange rate volatility

2.1 The data

The interest rate data is the daily risk-free interest rate in the secondary market calculated from Mexican Government Bonds (CETES fondeo). The source is Bloomberg. The sample size is from November 4th, 1998 to August 29th, 2008. The beginning of the sample is given by data availability, since there is no other time series of CETES fondeo available with data before that date. The end of the sample corresponds to the last business day of August of 2008, in order to left aside the large volatility associated to the period when the global financial crisis intensified. The data for the spot exchange rate Mexican peso-US dollar consists of daily spot prices obtained from Banco de México's web page database.[2] These are daily averages of quotes offered by major Mexican banks and other financial intermediaries. The sample period for the exchange rate data is also from November 4th, 1998, to August 29th, 2008. The sample size for each financial series is 2,556 daily observations.

2.2 Interest rate volatility

The data on interest rates is transformed to daily returns, which we denote as y_{1t}, using the first difference of the variable in logarithms times 100. Figure 1 shows the original series in levels, whereas Figure 2 shows the returns. The volatility clustering effect (Engle, 1982) is clear.[3] Also clear is the significant reduction in volatility that occurred around the beginning of 2004. Figure 2 presents a vertical line, drawn in April 2004, which separates the periods when Banco de México used different monetary policy instruments. During the first part of the sample, the central bank used a non-borrowed reserve requirement, the Corto, whereas starting in April 2004 the central bank sent signals to the market about its desired level of the overnight interest rate.

In order to start with the analysis of the daily interest rate volatility, we calculate a proxy for it. This proxy is simply the returns squared. The top panel of Table 1 presents summary statistics of this time series for the full sample and for the periods before and after the beginning of the transition to the new monetary policy instrument. Most of the statistics change drastically from one sub-sample to the other. In particular, the mean of the volatility goes from 31.9 during the Corto to 0.58 afterwards. Also, during the period after the Corto the distribution of the volatility seems to have been less spread, less symmetric, and with

[2] Banco de México's web page is `http://www.banxico.org.mx`

[3] The p-value corresponding to Engle's (1982) LM test for ARCH effects is 0.0000 when applied to the interest rate returns, using 5 lags (the value of the statistic is 98.3), which rejects the null of homoscedasticity. Hence, the evidence is clearly in favor of time-varying volatility.

a larger kurtosis. These changes imply that for the sample under interest rate targeting, there is a larger proportion of small volatilities but that the larger volatilities extend over a considerable range (i.e.., the distribution is more skewed to the right), and that extreme values have a higher probability. These imply that under interest rate targeting more periods in the sample were calm, but that agitated times were relatively tougher.

To formally test if there is a structural break in the volatility around the time of the change in the monetary policy instrument, as well as to see if there are other possible breaks, we apply the test proposed by Lavielle and Moulines (2000). This is a test that can be applied to the mean and to the variance of a process and tests for the presence of multiple structural breaks. We use this test because most other tests for the presence of breaks proposed for linear processes assume conditions that are not satisfied by most GARCH process (Carrasco and Chen, 2001). However, the test proposed by Lavielle and Moulines can be applied to strongly dependent processes such as GARCH processes.[4] Among the break-point tests that can be applied to GARCH process, Andreou and Ghysels (2002) have shown that the test the we use has good power properties. The test of Lavielle and Moulines (2000) (LMT henceforth) sequentially searches for multiple breaks over a maximum number of possible segments pre-defined by the researcher, and uses a minimum penalized contrast to determine the number of breaks.[5]

We first applied the LMT to the returns, and find no structural breaks for the mean. Then we applied the LMT to the squared returns and obtained one break: May 12th, 2004. The break date is remarkably close to the start of the transition to interest rate targeting (April 2004). The time series of the volatility as well as the break date are presented in Figure 3, where is clear that the volatility decreased after the break.[6]

To account for the possible existence of a non-constant (conditional) mean, we also applied the LMT to the squared residuals of an $AR(p)$ model applied to the returns. We obtained three breaks in volatility: August 8th, 2000; May 16th, 2001, and May 12th, 2004. The last break date is identical to the one obtained without filtering with the autoregressive. The first two breaks do not seem to correspond to any particular event or institutional

[4] In particular, most break-point tests, such as those proposed by Bai and Perron (1998), assume uniform mixing conditions, which are not satisfied by GARCH process. In contrast, the tests developed by Lavielle and Moulines (2000) assume beta-mixing, which is satisfied by GARCH processes.

[5] In all our applications of the LMT test we used 15 as the maximum number of segments and 20 as the minimum length in each segment. We used the program dcpc.m available at M. Lavielle's web page.

[6] We also applied the Bai and Perron (1998) test to the volatility. Although the time series of the interest rate returns do not satisfy some of the assumptions needed to perform this test, it is widely used and allows certain degree of serial correlation and heteroskedasticity in the error term. This procedure also finds a structural break possibly associated with the change in the monetary policy instrument, in May 7th, 2004. Hence, the break that concern us appears to be robust to different testing procedures. Bai and Perron's test also finds other breaks, all before 2004.

change, to our knowledge. We decided not to include them in the results that we report in this note. However, all our conclusions are robust to considering these other breaks.

2.3 Exchange rate volatility

The exchange rate in levels and its returns, which we denote y_{2t}, are shown in Figures 4 and 5, respectively. In line with what happens with the interest rate, it appears to have time-varying volatility.[7] However, in contrast to what happens with the interest rate, there does not seem to be a dramatic change in the range in which the values of the returns are moving after the transition to the use of the interest rate as the monetary policy instrument.

The bottom panel of Table 1 presents the summary statistics of the exchange rate's volatility proxy, calculated in the same way as described above for the interest rate. The changes before and after April 2004 are smaller, proportionally, than those for the interest rate. The volatility of the exchange rate has a lower mean, standard deviation, skewness, and kurtosis during the sample after the Corto than when the Corto was used. This results imply that, in contrast to interest rate volatility, in the exchange rate sample agitated times were relatively milder after the Corto. Paired with the descriptive statistics of the interest rate volatility, there is some evidence that the change in monetary policy instrument reduced the overall risk in the variables analyzed here, but may have changed the relative tail risk, with interest rates now relatively riskier in this sense. We do not pursue this further, although it is certainly an interesting research topic.

We first applied the LMT to the exchange rate returns, y_{2t}, and find no structural breaks for the mean. Then we applied the LMT to the squared returns and obtained one break: February 13th, 2004. As with the volatility of the interest rate, the break date is remarkably close to the start of the transition to interest rate targeting. The time series of the volatility as well as the break date are presented in Figure 6. Although the change is not as marked as with the interest rate, it is clear that the volatility decreased after the break.[8]

The LMT was also applied to the squared residuals of an $AR(p)$ model of the returns. We obtained only one break date: February 11th, 2004. Again, the change in behavior of the volatility around April of 2004 is confirmed by this statistical test.

[7] This is confirmed by a LM test for the presence of ARCH effects. Using 5 lags, the test statistic is 98.3, for a p-value of 0.0000, which clearly rejects the null of homoscedasticity.

[8] The Bai and Perron (1998) test identifies a break around the same dates: May 27th, 2002. Hence, this appears to be a robust finding. Bai and Perron's test also finds another break before 2004.

2.4 Empirical facts from univariate analysis

From the analysis of the individual volatilities, there are two empirical facts that can be highlighted:

1. The volatility of the interest rate appears to have a structural break around the time the central bank started to send signals about its interest rate target. It decreased substantially after the break. The volatility may have other breaks around 2000 and 2001, but the empirical evidence is not as strong.

2. The volatility of the exchange rate also seems to present a structural break in which the volatility decreases, and it coincides with the change of monetary policy instrument around April 2004. There is some evidence of another break at the beginning of 2002, but the empirical evidence is very weak.

3 Interaction between interest rate and exchange rate volatility

3.1 Multivariate ARCH model

A multivariate model for the variances is used in order to investigate the interaction between interest rate and exchange rate volatilities. The model applied here is the BEKK model, which estimates the conditional variances and covariances of the series under analysis using a multivariate ARCH method (Engle and Kroner, 1995).[9] The BEKK model is a special case of an earlier model postulated in a paper by Bollerslev et al. (1988). The latter proposed the VEC Model, in which each element in the variance matrix depends only on their past values and on past values of the cross product of the residuals (represented by ε_t in the equation below). In other words, the variances depend on their own past squared residuals and the covariances depend on their own past cross products of the relevant residuals. An important limitation of Bollerslev et al.'s (1988) model is that there is a possibility of estimating a negative variance, which is inconsistent with statistical theory. On the other hand, the proposed BEKK model has sufficient conditions to obtain a positive definite conditional variance matrix in the optimization process.

The procedure to obtain the estimates of the BEKK model is as follows. Let y_t be a vector of returns at time t,

$$y_t = \mu_t + \varepsilon_t,$$

[9]The acronym BEKK refers to Baba, Engle, Kraft and Kroner, which are the surnames of the authors who originally proposed the method in 1992.

where μ_t is a mean vector which may change over time (e.g., a vector autoregression), and the heteroskedastic errors ε_t are conditionally multivariate normally distributed. If I_{t-1} represents the information set up to time t-1, then

$$\varepsilon_t \mid I_{t-1} \sim N\left(0, H_t\right).$$

Each of the elements of H_t depends on q lagged values of squares and cross products of ε_t as well as on the p lagged values of H_t. This model representation is:

$$H_t = \omega\omega' + \sum_{i=1}^{q} \alpha(\varepsilon_{t-i}\varepsilon_{t-i}')\alpha' + \sum_{i=1}^{p} \beta H_{t-i}\beta',$$

where ω is upper triangular and $\omega\omega'$ is symmetric and positive definite and the second and third terms in the right-hand-side of this equation are expressed in quadratic forms. This quadratic form ensures that H_t is positive definite and that no constraints are necessary on the α and β parameter matrices. As a result, the eigenvalues of the variance-covariance matrix have positive real parts, which satisfy the condition for a positive definite matrix that estimates positive variances.

For an empirical implementation, the BEKK model can be estimated for the bivariate case. The bivariate-BEKK model from Engle and Kroner (1995), henceforth, BVBEKK, can be expressed in the following manner (suppressing the time subscripts for convenience):

$$\begin{aligned}
H_{11} &= \omega_{11}^2 + \alpha_{11}^2\varepsilon_1^2 + 2\alpha_{11}\alpha_{21}\varepsilon_1\varepsilon_2 + \alpha_{21}^2\varepsilon_2^2 + \beta_{11}^2 H_{11} + 2\beta_{11}\beta_{21}H_{12} + \beta_{21}^2 H_{22}, \\
H_{12} &= H_{21} = \omega_{11}\omega_{12} + \alpha_{11}\alpha_{12}\varepsilon_1^2 + (\alpha_{12}\alpha_{21} + \alpha_{11}\alpha_{22})\varepsilon_1\varepsilon_2 + \alpha_{21}\alpha_{22}\varepsilon_2^2 + \beta_{11}\beta_{12}H_{11} \\
&\quad + (\beta_{12}\beta_{21} + \beta_{11}\beta_{22})H_{12} + \beta_{21}\beta_{22}H_{22}, \\
H_{22} &= \omega_{21}^2 + \omega_{22}^2 + \alpha_{12}^2\varepsilon_1^2 + 2\alpha_{12}\alpha_{22}\varepsilon_1\varepsilon_2 + \alpha_{22}^2\varepsilon_2^2 + \beta_{12}^2 H_{11} + 2\beta_{12}\beta_{22}H_{12} + \beta_{22}^2 H_{22}.
\end{aligned}$$

As can be seen, the advantage of this specification is that it is possible to estimate volatility spillovers between the variables in the model.[10]

3.2 Empirical results from the BEKK model

The variables used in the bivariate model are the Mexican risk-free interest rate returns (y_{1t}) and the exchange rate returns (y_{2t}). The specification of the models was selected by applying

[10] The BEKK model that we present here is in its general form, also known as the unrestricted BEKK model. A more popular restricted BEKK model will not allow for estimation of cross-volatilities (Bauwens et al., 2006).

the Akaike Information Criterion (AIC).[11] For the mean, a vector autoregressive (VAR) was estimated. We use a VAR as recommended by Pantelidis and Pittis (2004) to take into account the presence of causality in mean, since Granger causality tests applied to the mean can not reject causality from the exchange rate returns to the interest rate returns during the Corto period. For the variance, the parsimonious first order specification was found to have the smallest AIC. The maximum likelihood methodology and the BHHH (Berndtand et al., 1974) algorithm are used in the estimation procedure. Test for asymmetries were also conducted. These asymmetry tests show no evidence of asymmetries present in the data.[12] According to the BVBEKK specification the cross-volatilities coefficients are α_{12}, α_{21} and β_{12}, β_{21}. The advantage of applying this general form is that it allows us to estimate the parameters for volatility spillovers (cross-volatilities) from one series to the other (Bauwens et al., 2006).

Given the structural breaks identified in the previous section, the whole sample was divided into two different subsamples.[13] These are as follows: November 4th 1998 until February 10th 2004 and May 13th 2004 until August 29th, 2008. For each subsample estimations were carried out applying the BEKK model presented above. The results are presented in Tables 2-3. In each Table, panel (a) presents the results corresponding to the equation for the mean and panel (b) presents the results for the variance equation. A description of the estimated results in each subsample is presented next.

Table 2 considers the subsample that is part of the Corto period i.e. November 4th 1998 until February 10th 2004. The equation for the mean in panel (a) shows that, apart from the autoregressive terms, there was a clear effect from the exchange rate to the interest rate. Panel (b), in column 2, shows the impact of interest rate volatility (r) on exchange rate volatility (xr) whereas the opposite impact can be seen in column 3. It can be observed that for the case of r impacts xr the coefficients α_{21} and β_{21} are statistically significant. Neither coefficient α_{12} or β_{12} are statistically significant. In the other direction, the coefficients that could show volatility spillover effects from the volatility of the exchange rate to volatility of the interest rates (column 3), with the exception of α_{12}, are not significantly different from zero (α_{21} and β_{12}, β_{21}).

Table 3 is for the period May 13th, 2004 to August 29th, 2008. By that time Banco de México started the transition from the Corto to interest rates as a monetary policy instru-

[11] Our conclusions are robust to the use of other information criteria (e.g., BIC).

[12] The asymmetry tests conducted were the estimation of a correlation coefficient between the squared returns and the lagged returns. The estimated correlation coefficient was positive showing no asymmetries. Also a view of a cross correlogram between the squared standardized residuals and the standardized residuals corroborated no asymmetric effects by having very few statistically significant estimated coefficients. For more details about these type of tests see Zivot (2009).

[13] See van Dijk et al. (2005) for the possible effects of structural breaks on causality-in-variance tests.

ment. According to the results in panel (a), only autoregressive terms seem to be relevant for the mean. In panel (b), there appears to be no evidence of any volatility spillover between interest rate and exchange rate volatilities in this subsample, since the cross-volatilities coefficients (the interaction coefficients) are not statistically significant. Apparently, once the Corto started to be abandoned as a monetary policy tool the volatility spillover observed before, between the volatility series under analysis, disappeared.

3.3 Causality-in-variance tests

There are several tests of (Granger) causality-in-variance in the literature. Two approaches have been followed. One is to use the residual cross-correlation function (e.g., Cheung and Ng, 1996; Hong, 2001; and, van Dijk et al., 2005). The other is to use bi-variate models for the conditional volatilities, and then perform exclusion tests on the relevant conditional variance parameters (e.g., Caporale et al., 2002). The latter is the approach that we follow.[14]

We apply joint tests of significance of the relevant parameters, α_{12}, α_{21} and β_{12}, β_{21}, in each equation. The results of the Wald tests are presented in Table 4. The estimations were carried out for each subsample. It is clear that interest rate volatility Granger-causes exchange rate volatility and vice versa for the subsample in which monetary policy was conducted using the Corto. For this time frame the Wald tests show p-values that clearly reject the null hypothesis that the four coefficients of interest are jointly zero at usual significance levels. For the last subsample, which relates to the period after the transition started, there is no statistical evidence of any causal relationship between the volatility series under study (p-values well above 0.10).

3.4 Empirical facts from bivariate analysis

From the analysis of the volatilities in the bivariate framework, there are two empirical facts that can be highlighted:

1. There appears to be Granger causality-in-volatility between the exchange rate and the interest rate, running in both directions, for the sample corresponding to the period when the Corto was used as monetary policy instrument.

2. There is no evidence of volatility spillovers between the exchange rate and the interest rate for the sample of the transition to the use of interest rates as the monetary policy instrument started.

[14] Hafner and Herwartz (2004) compare both approaches and conclude that the one we follow has better power properties and that it is robust to misspecification of the model.

4 Conclusions

In this note we study the volatilities of the risk-free interest rate and the exchange rate in Mexico using daily data from November 4th, 1998 to August 29th, 2008, as well as the interactions between the two. We document that the volatility of the interest rate has a structural break at the beginning of 2004, when it decreased substantially. This coincides with the beginning of the transition to a new monetary policy instrument. For the exchange rate volatility we also find a break around the same date, and the volatility also decreases, although the change is smaller. In addition, we provide empirical evidence on the causal relationship between these volatilities. We show that a causal relation existed during the period of the Corto, with volatility spillovers going in both directions, but that no causal relation can be found afterwards.

Overall, this is a first step into the analysis of the determinants of the volatilities of the interest rate and the exchange rate in Mexico. In particular, with respect to the impact of monetary policy on them. Although we only document empirical regularities of these volatilities and their interaction, future studies should try to explain these regularities. Special emphasis should be put on explaining why the volatility of the exchange rate decreased and the volatility spillover ceased after the Corto started to be abandoned as the main monetary policy instrument. One possible explanation for the former is that the signal to noise ratio of the interest rate as a monetary policy instrument is higher than that of the Corto. Insights to rationalize these facts are fundamental to advance our understanding of the monetary transmission mechanism.

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Table 1. Summary Statistics

Interest rate volatility

	Full sample	"Corto"	Interest Rate Targeting
Mean	18.08	31.90	0.58
Median	0.48	3.76	0.02
Maximum	1275.10	1275.10	82.91
Minimum	0	0	0
Std. Dev.	68.41	89.09	3.19
Skewness	9.02	6.85	18.08
Kurtosis	115.86	67.73	422.74
Observations	2556	1428	1128

Exchange rate volatility

	Full sample	"Corto"	Interest Rate Targeting
Mean	0.20	0.25	0.14
Median	0.07	0.09	0.06
Maximum	24.83	24.83	3.16
Minimum	0	0	0
Std. Dev.	0.62	0.80	0.23
Skewness	26.33	21.70	4.81
Kurtosis	996.80	639.03	41.44
Observations	2556	1428	1128

The sample size consists of 2,556 daily observations from November 4th, 1998 to August 29th, 2008. ‘Corto’ refers to non-borrowed reserves requirement target (monetary policy tool) that ended on April 2004.

Table 2. BEKK (General form) Estimates.
November 4th 1998 – February 10th 2004
(a) Mean equation

	y_{1t}	y_{2t}
y_{1t-1}	-0.3967***	-0.0020
	(0.0272)	(0.0026)
	[-14.5782]	[-0.7701]
y_{1t-2}	-0.1583***	-0.0033
	(0.02874)	(0.00274)
	[-5.5062]	[-1.1875]
y_{1t-3}	-0.0546**	-0.0014
	(0.0269)	(0.0025)
	[-2.0233]	[-0.5553]
y_{2t-1}	1.6134***	0.0862***
	(0.2861)	(0.0273)
	[5.6381]	[3.1569]
y_{2t-2}	1.1355***	-0.0129
	(0.2897)	(0.0276)
	[3.9188]	[-0.4670]
y_{2t-3}	0.8194***	-0.0273
	(0.2907)	(0.0277)
	[2.8181]	[-0.9839]
c	-0.0024*	0.0001
	(0.0014)	(0.0001)
	[-1.6589]	[0.4700]

(b) Variance Equation.

Underlying Coefficient	*r* impacts *xr*	*xr* impacts *r*
ω_{11}	0.0320***	0.0019***
	(0.0012)	(0.0002)
	25.9770	*8.2017*
ω_{12}	0.0004	0.0087
	(0.0003)	(0.0063)
	1.2993	*1.3812*
ω_{22}	0.0021***	0.0357***
	(0.0002)	(0.0012)
	9.5456	*29.1886*
α_{11}	0.7434***	0.3860***
	(0.0310)	(0.0202)
	23.9822	*19.1366*
α_{22}	0.4622***	0.7172***
	(0.0252)	(0.0307)
	18.3521	*23.3775*
α_{12}	0.0012	-1.9056***
	(0.0027)	(0.2679)
	0.4554	*-7.1140*
α_{21}	-0.3265***	-0.0037
	(0.0516)	(0.0028)
	-6.3334	*-1.3286*
β_{11}	0.4203***	0.8417***
	(0.0434)	(0.0266)
	9.6940	*31.6321*
β_{22}	0.7865***	0.2885***
	(0.0350)	(0.0553)
	22.4815	*5.2135*
β_{12}	-0.0050	0.8607
	(0.0049)	(0.5896)
	-1.0252	*1.4598*
β_{21}	0.9402*	0.0028
	(0.5345)	(0.0050)
	1.7590	*0.5600*
L	7606.3150	7588.1210
AIC	-11.0851	-11.0586
N	1370	1370

Notes: Standard errors are shown in parenthesis. (***), (**), (*) indicate statistical significance at the 1%, 5% and 10% level, respectively. t-statistics are shown in brackets. Italics show the *z*-statistic. *L* = Log-likelihood estimate. *AIC* = Akaike information criterion. *N*= Sample size. *r* represents interest rate volatility and *xr* represents exchange rate volatility.

Table 3. BEKK (General form) Estimates.
May 13th 2004 – August 29th 2008
(a) Mean Equation.

	y_{1t}	y_{2t}
y_{1t-1}	-0.1140***	0.0053
	(0.0297)	(0.0159)
	[-3.8307]	[0.3313]
y_{2t-1}	-0.0527	0.0783***
	(0.0560)	(0.0299)
	[-0.9407]	[2.6111]
c	0.0002	-0.0001
	(0.0002)	(0.0001)
	[1.1930]	[-0.9210]

(b) Variance Equation.

Underlying Coefficient	***r* impacts *xr***	***xr* impacts *r***
ω_{11}	0.0055	0.0006
	(0.0094)	(0.0016)
	0.5899	*0.3891*
ω_{12}	-0.0012	-0.0062
	(0.0097)	(0.0196)
	-0.1219	*-0.3161*
ω_{22}	0.0001	0.0011
	(0.0824)	(0.1127)
	0.0016	*0.0096*
α_{11}	0.3399***	0.0448
	(0.0649)	(0.0620)
	5.2392	*0.7222*
α_{22}	0.0114	0.2839***
	(0.0751)	(0.0690)
	0.1519	*4.1116*
α_{12}	-0.0122	0.0033
	(0.0343)	(0.1383)
	-0.3556	*0.0242*
α_{21}	0.0053	-0.0250
	(0.1364)	(0.0578)
	0.0390	*-0.4333*
β_{11}	0.4249	0.9904***
	(0.2804)	(0.0752)
	1.5151	*13.1673*
β_{22}	0.9357***	0.5044**
	(0.3567)	(0.2454)
	2.6231	*2.0556*
β_{12}	-0.0025	0.3721
	(0.0989)	(0.4062)
	-0.0251	*0.9159*
β_{21}	0.8619	-0.0123
	(4.0883)	(0.1025)
	0.2108	*-0.1196*
L	8658.5380	8653.4410
AIC	-15.4247	-15.4156
N	1121	1121

Notes: As in Table 2.

Table 4. Granger Causality Tests in Volatility.

Dependent Variable	Excluded	Chi-sq	Prob
November 4th 1998 - February 10th 2004			
Exchange Rate Vol	Interest Rate Vol	42.6463***	0.0000
Interest Rate Vol	Exchange Rate Vol	50.7400***	0.0000
May 13th 2004 – August 29th 2008			
Exchange Rate Vol	Interest Rate Vol	0.2646	0.9920
Interest Rate Vol	Exchange Rate Vol	2.5166	0.6417

This table presents Granger Causality tests for the BEKK model (general form) estimations. The null hypothesis is that the cross-correlation coefficients α_{12}, α_{21} and β_{12}, β_{21} are jointly zero. Chi-square statistic and respective *p*-values (prob.) are reported. The number of observations for the first subsample is 1,370, and for the second is 1,121.

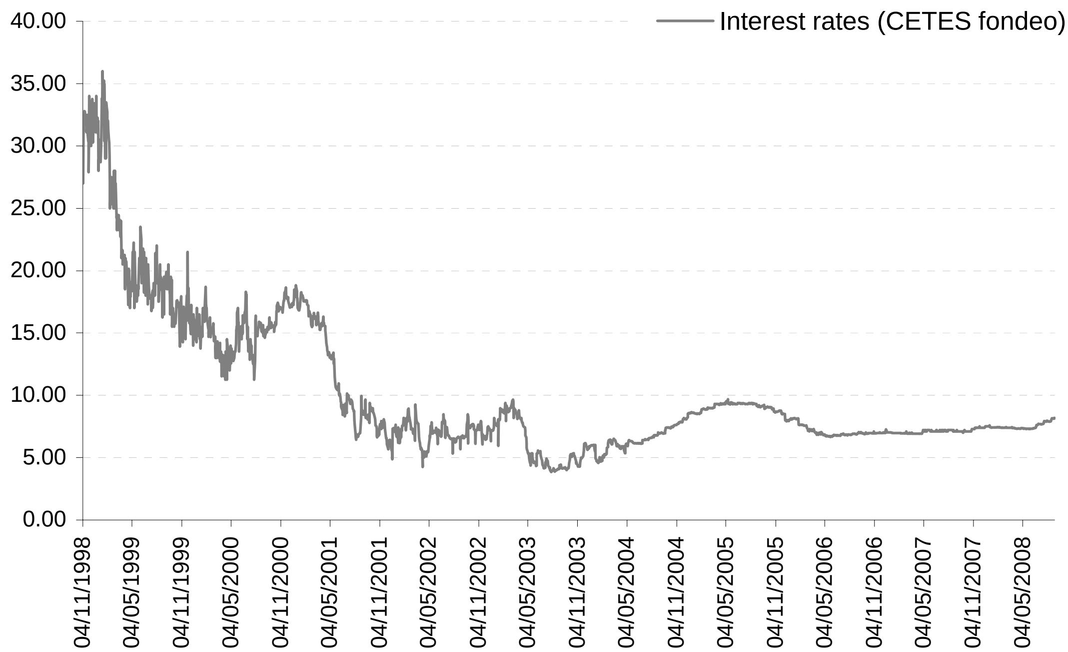

Figure 1: Interest rates (CETES fondeo).
Sample: November 4th, 1998 to August 29th, 2008.
Source: Bloomberg.

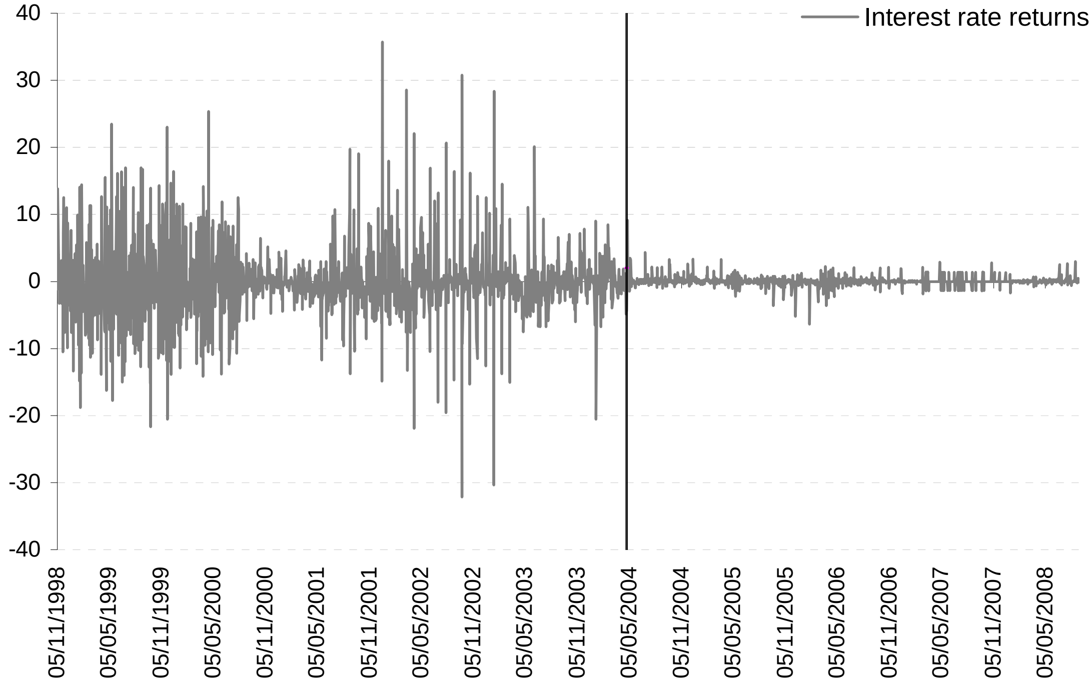

Figure 2: Interest rate daily returns, y_{1t}. The vertical line corresponds to April 26th, 2004.
Sample: November 5th, 1998 to August 29th, 2008.
Source: Own calculations with data from Bloomberg.

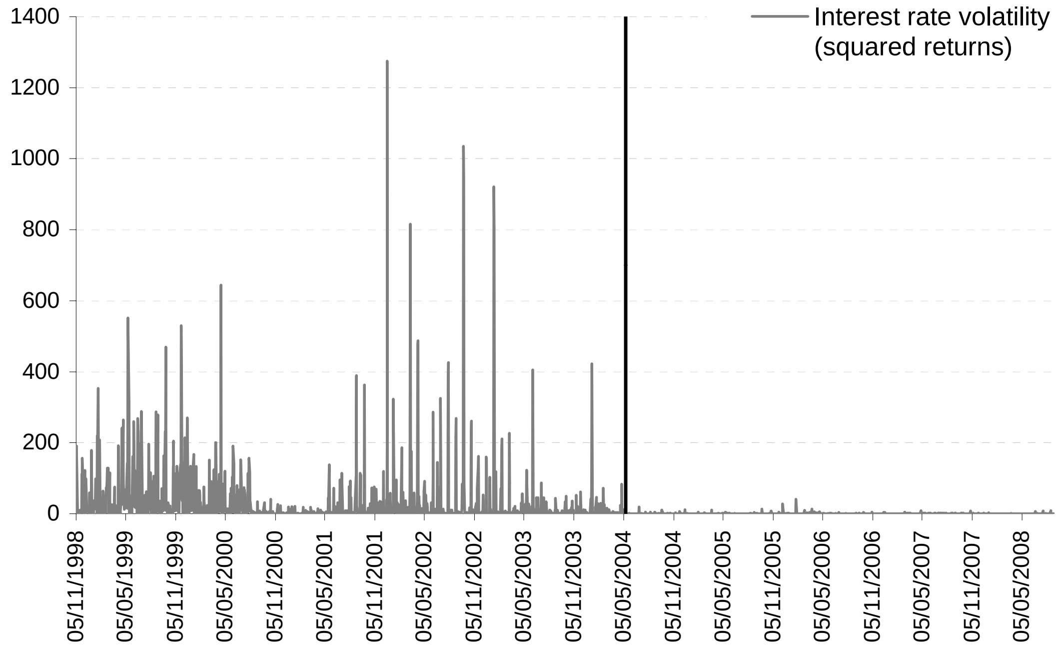

Figure 3: Interest rate volatility calculated as $(y_{1t})^2$, where y_{1t} is the daily return, and the bold vertical line shows the estimated break-date. Breaks estimated using Lavielle and Moulines' (2000) procedure.
Sample: November 5th, 1998 to August 29th, 2008.
Source: Own calculations with data from Bloomberg.

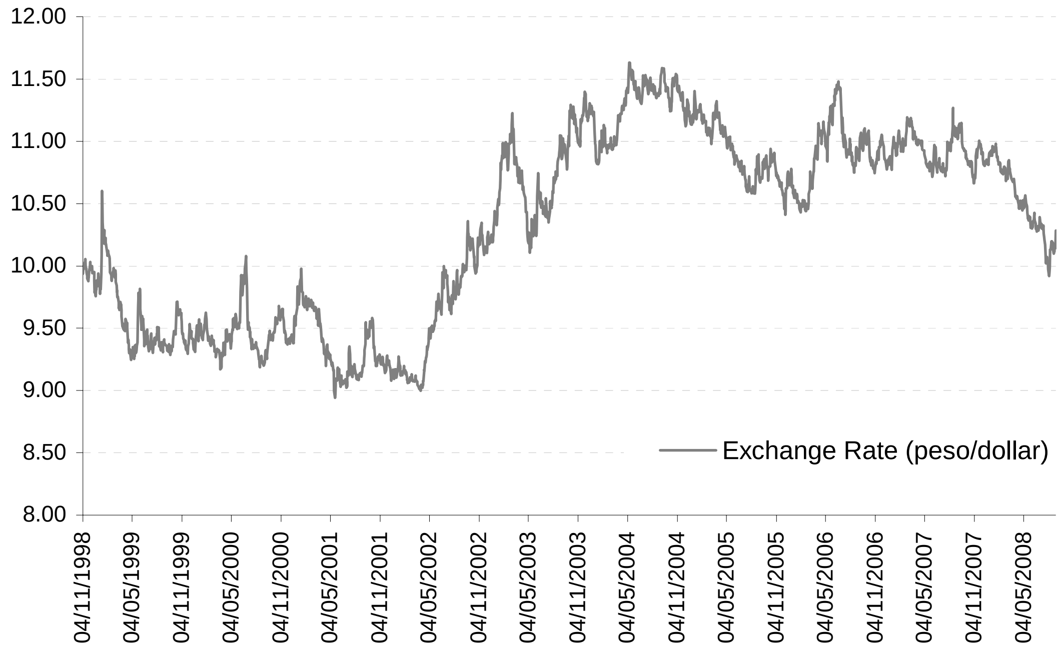

Figure 4: Mexican peso- U.S. dollar daily exchange rate.
Sample: November 4th, 1998 to August 29th, 2008.
Source: Banco de México.

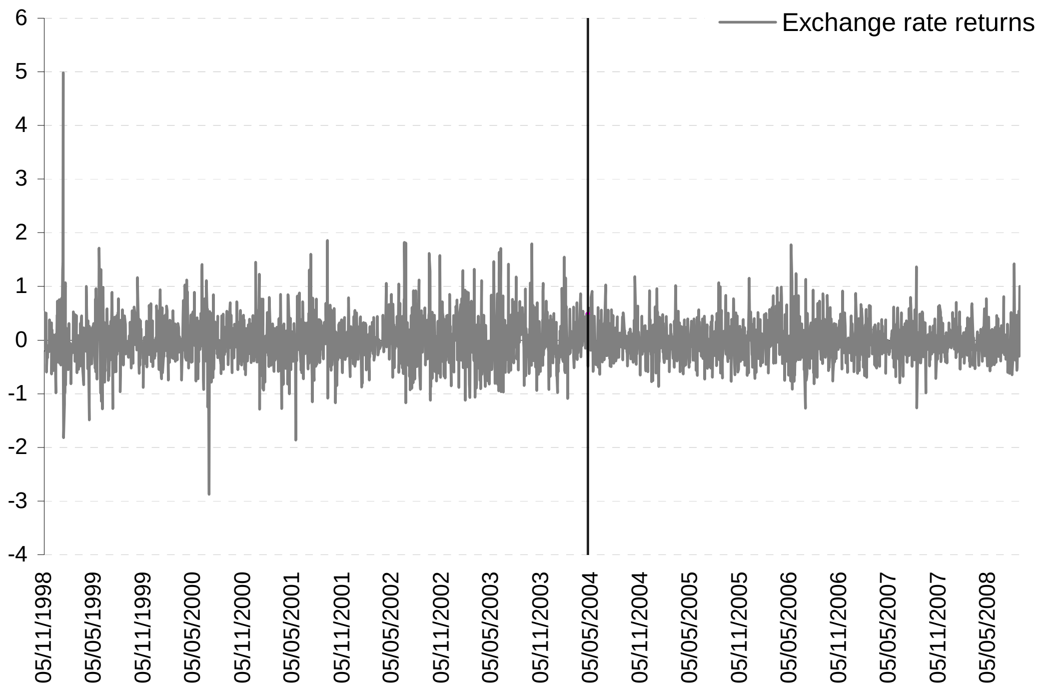

Figure 5: Exchange rate daily returns, y_{2t}. The vertical line corresponds to April 26^{th}, 2004.
Sample: November 5th, 1998 to August 29th, 2008.
Source: Own calculations with data from Banco de México.

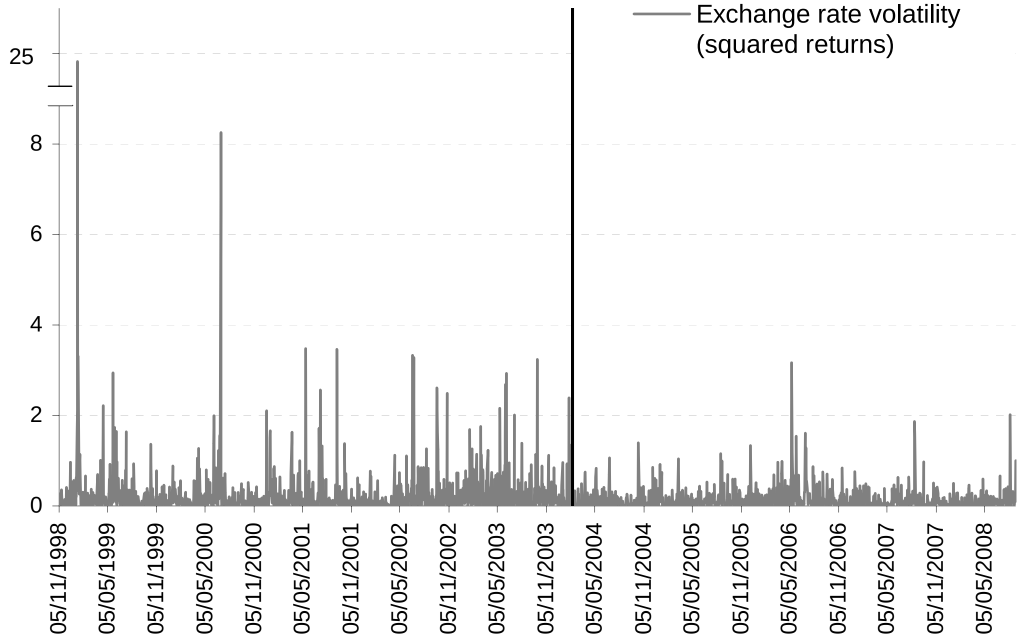

Figure 6: Exchange rate volatility calculated as $(y_{2t})^2$, where y_{2t} is the daily return, and the bold vertical line shows the estimated break-date. Breaks estimated using Lavielle and Moulines' (2000) procedure.
Sample: November 5th, 1998 to August 29th, 2008.
Source: Own calculations with data from Banco de México.