Dynamic hedging of prices of Natural Gas in Mexico

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Abstract

The first-hand sale prices of Natural Gas (NG) in Mexico had a dynamic lagged relationship with international NG futures prices during the period of January 2012 to June 2017. Based on a hedging strategy which includes NG futures and using an MGARCH VCC model, conditional variances were estimated with 20 and 40 days of lag between the prices of NG Futures. Dynamic hedges of NG were calculated assuming theoretical futures prices of the US dollar in Mexican pesos. With the use of backtesting, it was found that the forecasts of optimal hedge ratios improve with short prediction periods and proximate observed data. The dynamic hedging model proposed can be extended to other fuel markets. The importance of hedging NG prices derives from the size of the market and the extent of the risks to which the market participants are exposed.

JEL Classification: G13, G15, Q41, Q48
Keywords: Natural gas prices, first-hand sale prices, dynamic hedging, backtesting

Cobertura dinámica de precios del Gas Natural en México

Resumen

Los precios de venta de primera mano del gas natural (GN) en México tuvieron una relación dinámica, pero con retrasos, con los precios internacionales de los futuros de GN durante el periodo de enero de 2012 a junio de 2017. A partir de una estrategia de cobertura en la que se emplean futuros de GN y utilizando un modelo MGARCH VCC para estimar las variaciones condicionales con retrasos de 20 y 40 días de los precios de los futuros, se muestra cómo se comportan las coberturas dinámicas de GN, suponiendo precios teóricos futuros del dólar estadounidense en pesos mexicanos. A través de una prueba retrospectiva, se halló que las predicciones de las razones de cobertura óptima mejoran con períodos cortos de pronóstico y períodos cercanos de observación. El modelo de cobertura dinámica propuesto puede extenderse a otros mercados de combustibles. Se destaca la importancia de la cobertura de los precios del GN dado el tamaño del mercado y la magnitud del riesgo al que se encuentran expuestos los participantes.

Clasificación JEL: G13, G15, Q41, Q48
Palabras clave: precios del gas natural, precios de venta de primera mano, cobertura dinámica, pruebas retrospectivas

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1 Introduction

The structure of energy markets usually requires price regulation as in the Natural Gas (NG) markets in which there are natural monopolies. In these cases, governments regulate prices by imposing limits on them as a defense measure in favor of the other market participants.

In Mexico, the Energy Regulatory Commission (CRE) is the regulatory body that, until June 2017, limited the prices of the NG that Petróleos Mexicanos (PEMEX), the state oil and gas company, used in its first sales to the other participants in the distribution chain. These prices are known as First-hand Sale Prices (PVPM, for its initials in Spanish). These prices typically set for a one-month period were denominated in pesos, and initially referred to two strategic geographical points: the main gas import gate (Reynosa) and the main production point (Pemex city) in the country. See CRE (2016).

The other prices in the distribution chain were determined from the PVPM, considering transportation costs, taxes, and investment recovery, among others. The PVPM remained fixed for a month and was denominated in Mexican pesos. The NG prices in the US market changed frequently and were quoted in dollars. Hence, there was a possibility that the importer, the distributor, or the consumer would use hedges to manage the risk that was assumed when selling or consuming at a constant price in one currency (Mexican pesos) and eventually buying the product in the future at another price, which was set according to floating prices (prices in the South of the United States) in another currency (US dollar).

After June 2017, the CRE stopped the releasing of PVPM. The risk management problem was transformed because the NG distributor or consumer continued to face an environment of fixed prices in pesos for sale to the public versus permanently changing dollar prices of the commodity. The problem of NG price hedging becomes increasingly important internationally due to the growing demand for hydrocarbons, which is driven by the also greater generation of electricity using NG, and the gap between NG exporting and importing countries. In countries that import NG with a weak regulatory scheme, the wholesale prices of the NG are set by independent contracts in which the international price component is the most critical factor.

Since the transport and distribution of NG are natural monopolies, the authorities regulate prices in such a way that the consumer is not deprecated. Given the necessary investment in transportation and distribution networks by a provider to serve an area, the overlapping of networks of different providers will result in significant additional costs. For this reason, regulators usually set maximum selling prices that allow the regulated parties to recover their investments and costs at a reasonable capital rate. This asymmetric regulation applies to other elements of the production chain, for example, a single producer or a preponderant storage facility.

In addition to the limits on prices and tariffs, regulators employ other measures, such as allowing the use of facilities and equipment of the monopolist, ordering disintegrations, and limiting concentrations. It is important to notice that, in the absence of an appropriate regulatory system, price fluctuations and risks are (at least in part) transferred to the final consumer. The NG price regulation model is widely used, even in market economies. The following section includes a revision of some relevant work.

The main objectives of this investigation are the following two:

(1) To introduce a dynamic hedging approach based on a GARCH-VCC (GARCH stands for Generalized Autoregressive Conditional Heteroskedasticity and VCC for Variable Conditional Correlation) model to predict the values of the best hedges for an immediate future period, and

(2) To evaluate the predictions obtained through backtesting and make recommendations to improve these predictions.

The importance of the study is based on the considerable size of the NG import market in Mexico, the

possibility of a resurgence of NG regulated prices in Mexico, and the existence of regulation in the energy sector in many countries of the world, for which the Mexican experience in first-hand NG prices can be relevant.

The organization of the paper is as follows. In this section, we include the introduction. The following section briefly discusses relevant Mexican NG price regulation. The third section is a bibliographical review. The fourth section analyzes the data and the results. Finally, we make concluding remarks in the last section.

2   The Mexican NG regulation.

In Mexico, the NG price regulation methodology evolved since its first publication in 1996. In February 2016, CRE (2016) published its latest methodology, which explains the calculation of the PVPM at two points: Reynosa and Pemex city, with two different frequencies: daily and monthly. The considered factors are: (1) the estimation of the price of NG in South Texas; (2) the existence of a net import or export of NG in the country; (3) the cost of transportation between Reynosa and South Texas; (4) the Sintragás system transportation fee from Reynosa to Pemex city, and (5) the peso-dollar exchange rate. In turn, the estimate of the price of NG in South Texas considers the following price indexes: (1) Henry Hub; (2) Houston Ship Channel published by Platts, and (3) other local Texas indexes. For the estimation of the tariffs of transport in the United States, the rates of the systems were used: (1) Tennessee Gas Pipeline Company, L.L.C.; (2) El Paso Natural Gas Company, L.L.C., and (3) Texas Eastern Transmission, LP, published by the Federal Energy Regulatory Commission of the United States.

3   State of the Art

Tse & Tsui (2002) propose a GARCH model for multiple variables (MGARCH) in which the correlations vary over time; the conditional variance follows a single variable GARCH formulation, and the conditional correlation matrix adopts a self-regressive average behavior. Tolmasky & Hindanov (2002) present a family of term structure models to evaluate contingent obligations of contingency goods and seasonal markets, in particular the oil market. Pindyck (2003) examines the behavior of volatility in the prices of natural gas and crude oil futures since 1990 and finds that there is a short-term trend of volatility due to shocks and that, during these, the interrelation between volatilities of both hydrocarbons increases. Jin & Jorion (2006) study the hedging activities in 109 oil and gas producing companies in the United States and analyze the effects that these activities have on the value of the companies. They found that the hedges reduce the price sensitivity of the companies' shares to variations in the prices of hydrocarbons.

Woo, Olson & Horowitz (2006) prove, through a partial regression model, that California NG users in the United States can take advantage of the opportunity to cross-cover with the Henry Hub index and can even predict the behavior of the index in the future and, thereby, improve risk management through futures contracts or swaps. Wong-Parodi, Dale & Lekov (2006) compare the NG price forecasts published by the Energy Information Administration (EIA) with those of the New York Mercantile Exchange (NYMEX) market and found that the futures market prices are a better forecast than the forecasts released by the government agency.

Roussillon (2008) highlights the work of the CRE since 1996 for adopting an NG pricing methodology that links them to the prices of this same substance in the South of the United States. The author points out that, in setting a reference price, it is appropriate to use two geographical points: the one of importation and the one of domestic production, and to adopt an intermediate point that presumably reduces the arbitration between the option of importing and buying gas from domestic production. Brown & Yücel (2008) study the

separation between the prices of NG and those of crude oil. They develop a vector error correction (VEC) model, with which they demonstrate that the prices of the crude affect those of the NG. So, both goods can be considered substitutes. Suenaga, Smith & Williams (2008) examine the volatility of the prices of the NG futures in NYMEX and conclude that the prices show seasonality in the winter. Besides, the effect of price shocks is persistent. Therefore, hedging strategies that do not consider these factors are sub-optimal.

Agnolucci (2009) compares the predictive capacity of GARCH models and that of implied volatility to estimate the volatility in the prices of West Texas intermediate (WTI) futures contracts in the NYMEX based on statistical and regression results. Kaufmann & Ullmann (2009) study the effect of innovation on hydrocarbon prices and how these effects are propagated to other prices in the spot and futures markets, they also analyze the long-term relationship between spot and futures prices. Wei, Wang & Huang (2010) use different models of the GARCH type to estimate the price volatility of the Brent and WTI crude markers. They found that non-linear models are better for capturing long-term effects and asymmetric volatility.

Laurent, Rombouts & Violante (2012) investigate the selection of different MGARCH models in large-scale portfolios and find that the models are inaccurate in periods of instability. Nomikos & Andriosopoulos (2012) investigate the behavior of the prices of eight energy products listed on the NYMEX, both in the spot market and in the futures market, and conclude that there is a leverage effect on the WTI and heating oil, while in the rest of the markets the effect is inverse. Wang & Wu (2012) forecast energy market volatility using uni and multivariate GARCH models. They propose hedging strategies based on multivariate models. Lv & Shan (2013) model the volatility of the NG market using GARCH models with long memory distributions and fat tails. Gannon & Liu (2013) propose a dynamic method of rebalancing asset hedges extending the GARCH-BEKK (BEKK are the initials of the authors Baba, Engle, Kraft and Kroner) approach to one MGARCH DCC (DCC stands for Dynamic Conditional Correlation). Scholtens & Van Goor (2014) analyze the volatility in NG prices in the United Kingdom and conclude that GARCH models based on supply and demand and theoretical assumptions of an economic nature are good predictors.

Blazsek & Villatoro (2015) compare GARCH and EGARCH (Exponential GARCH) Beta-t models and conclude that the EGARCH Beta-t models had a higher forecasting capacity in the period after the 2008 financial crisis in the United States. Asche, Oglend & Osmundsen (2017) find that when NG prices are decoupled from crude oil prices due to short-term effects. So, models such as VEC ones lead to erroneous conclusions about the nature of the cointegration relationship. Ghodussi & Emamzadehfard (2017) experiment with hedging alternatives in the US NG market. They contrast the use of a single type of futures contract with the use of futures contracts that exceed the maturities of the obligations to cover six different physical positions. They found that extending the term of future contracts can increase the effectiveness of the hedging. Gulay & Emec (2018) compare the variance normalization and stabilization method (NoVaS) with different GARCH methods in forecasting the volatility of different financial series and find that the NoVaS method has a higher forecasting capacity for values that are out of the sample.

Few studies analyze energy hedging in Mexico or even Latin America. For example, Barrera-Rivera & Valencia-Herrera (2019) describe a regulatory price model for NG in Mexico, propose an NG price hedging model, estimate optimal hedge ratios, and evaluate positions with some suitable future contracts. They propose two price hedging strategies: the first one through futures contracts and the other one using swaps. Based on the methodology of the PVPM, the optimal hedging with futures considers NG futures contracted one and two months earlier, plus contemporary exchange rate futures. Another study is Gutiérrez (2016) that focuses on cross hedging in the Mexican oil market with a multivariate GARCH model. Also, Díaz Contreras et al. (2014) analyze hedging strategies for the Colombian energy market. Related literature analyzes the use of international agricultural derivatives for hedging agricultural commodities in Latin America, see, for example, Troncoso-Sepúlveda & Cabas-Monje (2019), Ortiz Arango & Montiel Guzmán (2017), Ortiz

Alvarado & Girón (2015), Guízar Mateos, et al. (2012), and Godínez Placencia (2007).

The present work proposes a dynamic hedging approach that considers conditional variances and covariances within an MGARCH VCC model and a larger sample than in Barrera-Rivera & Valencia-Herrera (2019). With this approach, we can predict optimal hedge ratios that can be used in immediate periods beyond the sample. In the following section, we give an overview of the methodology followed in this paper, the single hedging strategy and the main proposal in this paper, a dynamic hedging approach based on an MGARCH VCC model.

4   Methodology

4.1   Use of future contracts as hedging

For purpose of explanation, lets introduce the following case: A NG distributor of an urban area acquires the fuel that it will subsequently sell to domestic or industrial users from PEMEX or an importer. The price of the NG is acquired at a fixed price at the entrance of the urban area (city gate), once the gas has been transported from the point of importation or from a processing terminal. For a month, the purchase price of the gas will be fixed in pesos and the distributor, in turn, must sell it at a fixed price to its users. The next month, the distributor will buy the NG at another price, which will depend on fuel prices in South Texas and the peso-dollar exchange rate, among others. To manage the risk represented by the variation of the NG in dollars and the exchange rate, the distributor may take positions of futures contracts for the gas and for the exchange rate. As was stated, the price volatility of NG in dollars may be higher than the volatility of the exchange rate so that the two hedging strategies, one for the price of NG in dollars and the other for the exchange rate in pesos, could be independent and intermittent.

The NYMEX market offers NG futures contracts with monthly maturities that span a decade ahead. For example, the December 2016 contract was last listed on November 28, had physical delivery on December 31, 2016 and each contract covers 10,000 MMBtu (ten billion Btu). The pulse (tick) of quotation prices is 0.001 US dollars. On the other hand, the contract of future peso-dollars in the Chicago Mercantile Exchange (MCE) covers Mx Ps 500,000, with a minimum fluctuation in the price of USD 0.00001 per peso, equivalent to 5 dollars per contract. The contracts have monthly maturities and cover a period of 18 months.

A distributor that estimates that the prices of NG in dollars will be on the rise and that the peso will depreciate in the coming weeks or months can buy NG futures in the NYMEX and buy dollar futures in the CME. To allow these operations, the distributor will need to open contracts and provide guarantees, and before the expiration of the contracts, he or she must revert them, unless the distributor wishes to reach the "physical delivery" of the goods. In case of the reversal, the distributor will take his or her profit or loss, and with it he or she will go to the spot exchange market to convert the dollars to pesos. With the possible benefit, the distributor can acquire NG from the new PVPM. If the hedging strategy was successful, the distributor will have the ability to acquire the same or a higher volume of NG as a result of good risk management. The operation would be contrary if the price expectation were down: Futures would be sold in the NYMEX and, if necessary, peso futures would be bought in the CME. In any case, the resulting dollar would be expected to be positive. Figure 1 shows the use of futures contracts as a hedging tool.
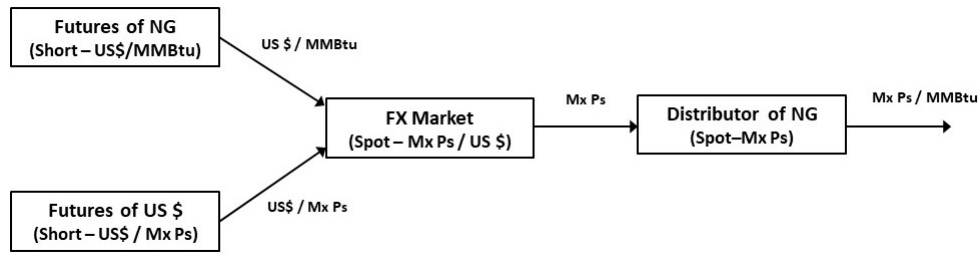
Figure 1. Employment diagram of NG and dollar futures hedge.
Source: Own elaboration

The classic theory of hedging with futures, see for example Hull (2009) and Ghoddusi & Emamzadehfard (2017), consists of reducing or nullifying the price volatility of a spot position with the inclusion of a certain number of futures contracts in the portfolio. If we have a P portfolio with n_S long asset positions and n_F short futures positions, the hedge ratio is defined as the number of futures positions that are occupied to cover a unit of the spot position, that is, $h = n_F/n_S$.

The value of the portfolio, considering n_S units of assets to be covered and n_F units of futures, would be given by equation (1),

$$P = n_S\ S\ -\ n_F\ F \tag{1}$$

Therefore, changes in the covered portfolio are given by equation (2),

$$\Delta P = n_S\ \Delta S - n_F\ \Delta F \tag{2}$$

The minimum variance hedge ratio is estimated by selecting the number of futures contracts that minimizes the conditional variance of changes in the value of the portfolio. The optimal hedging ratio is given by equation (3),

$$h^* = \frac{n_F}{n_S} = \frac{Cov(\Delta S, \Delta F|I)}{Var(\Delta F|I)} \tag{3}$$

where I is the set of information in time t and h^* and is the optimal hedging ratio. The hedge ratio h* can be easily estimated using ordinary least squares (OLS), as in equation (4), where ΔP_t is the PVPM monthly growth rate and $\Delta F_{l,t}$ is the monthly growth rate of an NG Futures Contract with l lags,

$$\Delta P_t = a_0 + a_1\ \Delta F_{l,t}\ +\ \mathcal{E}_t \tag{4}$$

and thus, the optimal hedge ratio would be applicable to the hedging instrument F_j, as shown in equation (5),

$$h_j{}^* = \frac{n_F}{n_S} = \frac{Cov(\Delta S, \Delta F_j|I)}{Var(\Delta F_j|I)} \tag{5}$$

The historical data can not only serve to determine an optimal hedging up to the last date of the data, it can also contribute to estimating the hedge that must be taken to face a risk that is expected in the immediate future through the prediction of conditional variances. Additionally, the initial strategy may change as new data is known that makes it necessary to rebalance the portfolio. In summary, in cases where there is a certain seasonality, historical data can be used to estimate future parameters, and it is convenient to update the information with newly available data that, in turn, will result in new estimates. Let us introduce the VCC multivariate GARCH model proposed to replicate the volatility of the underlying and suitable hedging instruments.

4.2   Multivariate GARCH VCC model

GARCH models are those in which the conditional variance of the errors can be explained through the variance of the previous errors and, usually, they are used together with the ARCH (Autoregressive Conditional Heteroscedasticity) models in which the conditional variance of the errors is explained through the behavior of the errors of the past periods. See Engle (1982) and Bollerslev (1986).

Different authors have used and evaluated the use of GARCH models as predictive tools to estimate price volatility, particularly in energy. See Agnolucci (2009), Wei, Wang & Huang (2010), Wang & Wu (2012), Lv & Shan (2013), Gannon & Liu (2013), Scholtens & Van Goor (2014), and Blazsek & Villatoro (2015).

The multivariate GARCH models (MGARCH), following the notation of Orskaug (2009), are defined as:

$$r_t = \mu_t + a_t \tag{6}$$

$$a_t = H_t^{1/2} z_t \tag{7}$$

where:

r_t: $n \times 1$ vector of the logarithmic returns of n assets in time t,

a_t: $n \times 1$ vector of mean-corrected returns of n assets in time t, so that $E[a_t] = 0$, $Cov[a_t] = H_t$.

μ_t; $n \times 1$ vector of the expected conditional values of r_t. H_t: $n \times n$ matrix of conditional variances - covariances of at in time t.

$H_t^{1/2}$: any $n \times n$ matrix in time t as H_t is the matrix of conditional variances of a_t. $H_t^{1/2}$ may be obtained by a Cholesky factorization of H_t.

z_t: $n \times 1$ vector of errors iid such that $E[z_t] = 0$ and $E[z_t z_t^T] = I$.

μ_t in equation (6) can be modeled as a constant vector or as a time series; at is not correlated in time, which does not mean that it does not have a serial dependency, but that the dependency can be non-linear. On the other hand, H_t in equation (7) is a matrix of conditional variances, which needs to be inverted every period t. Besides, for Cholesky factorization to be possible, H_t must be positive and defined.

In the VCC multivariate GARCH model, conditional variances are modeled as univariate GARCH models and conditional covariances are modeled as non-linear functions of conditional variances. The parameters of the quasi-correlations involved in the non-linear functions of the conditional variances follow a GARCH model specified by Engel (2002). In the MGARCH VCC there is a revolving estimator of the covariance matrix of standardized residues, following the development of Tse & Tsui (2002).

The optimal hedge ratios $h_j{}^*$ of equation (5) can be calculated with the conditional variances and covariances obtained through the MGARCH VCC model. These optimal hedge ratios can correspond to the whole period of data or they can be estimated for subperiods, even on a daily basis, as conditional variances and covariances can be obtained dynamically, that is, the newest estimates considers the last historical data available, as new information arrives, a new set of conditional variances and covariances can be calculated, and thus, new optimal hedge ratios. This can be performed with in-sample or out-of- sample data.

In the following section, we discuss the data, the results from a single hedging strategy, the optimal hedging strategy from a MGARCH VCC model, and the suitability of the dynamic hedging proposal with the use of a backtesting tool.

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5 Data y Results

5.1 Data

The data sample is from the beginning of 2012, until June 30, 2017 when CRE ended the publication of the PVPM. The NG price series in the United States are from the US Energy Information Administration (EIA) website; spot and futures market prices correspond to those of NYMEX; the PVPMs in Reynosa and Pemex City are those published by the CRE, and the exchange rates of the peso-dollar are those published by Banco de México (BANXICO). In its first part, as was stated, this study follows the methodology of Barrera-Rivera & Valencia-Herrera (2019) for an extended study period.

Figure 2 shows the graph of the daily and monthly PVPM in Reynosa during the study period. Notice that the monthly values do not correspond to the average of the daily values. The reason is that monthly PVPMs were determined one day before the beginning of the month and sustained throughout the period. However, daily prices were also calculated one day in advance and modified daily, which allowed them to reflect information more up to date on international prices. It should be noted that the PVPMs correspond only to business days, they exclude weekends and holidays.
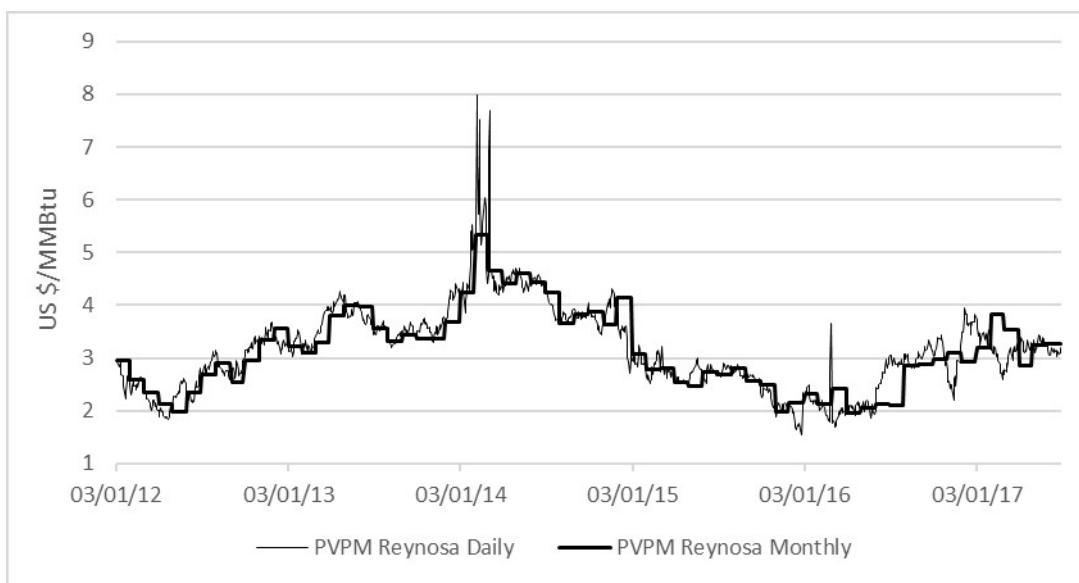

Figure 2. Daily and monthly PVPM in Reynosa in the period of study.
Source: Own elaboration with data of the CRE

Table 1 shows the statistics of the continuous growth rates of the Reynosa's daily PVPM in dollars (USD PVPM), of the NG Spot Price at NYMEX (Spot NYMEX) and the Mexico United States exchange rate (Mx Ps – USD XR). The value of the skewness in the PVPM (-0.63395) indicates that the distribution is moderately biased and the value of kurtosis (57.51959) shows that the distribution is sharply leptokurtic; therefore, it is not normal. However, the elements of greatest interest for this work are those of volatilities: the standard deviation for the logarithmic variation of the daily PVPM was 0.04421 and the standard deviation of the logarithmic variations of the NG Spot Price in NYMEX was 0.03920, which means that, during the study period, the PVPM in Reynosa was more volatile than the NG spot price in NYMEX.

Table 1 also shows the statistics of the logarithmic exchange rate variations (Mex Ps - USD). During the study period, the standard deviation of the continuous daily growth rate was 0.0058. It should be noted that, although the prices and quotations of this study refer to the same period of analysis, the observations of the

exchange rate include dates of weekends and others in addition to those of NG prices. During the period considered, the volatility of NG dollar spot prices (NYMEX), measured through the standard deviation of the logarithmic variation, was 6.7 times the volatility of the peso-dollar exchange rate.

Table 1. Statistics of selective series in the study period.

	Mean	Standard Deviation	Kurtosis	Skewness	Observations
USD PVPM	5.05045E-05	0.04421	57.51959	-0.63395	1,364
Spot NYMEX	2.46433E-06	0.03920	20.55434	1.03573	1,364
Mx Ps – USD XR	0.00012	0.00588	15.82514	1.12651	2,007

Source: Own elaboration with data of the CRE

Figure 3 shows graphically the peso-dollar exchange rate in the study period. As can be seen in the figure, the exchange rate experienced significant volatility from 2015 until the last date of the analyzed period.

Figure 3. Daily exchange peso-dollar rate during the study period.
Source: Own elaboration with BANXICO data

Table 2 depicts numerically the differences in the standard deviations of the prices during two subperiods: from January 2012 to December 2014 and from January 2015 to the end of the sample period. Standard deviations of the second subperiod are larger than those of the first subperiod in the domestic markets. The opposite happens with the NG spot prices of NYMEX where the volatility is greater in the first subperiod. This shows that the local market had its own sources of variations. Notice that in both subperiods, the volatility of the NG spot price in the NYMEX was several times greater than the volatility of the peso-dollar exchange rate.

Table 2. Standard deviations observed in sub periods during the study period

	Standard Deviation Whole Period	Standard Deviation 2012-2014	Standard Deviation 2015-Jun 2017
USD PVPM	0.04421	0.04006	0.04879
Spot NYMEX	0.03920	0.04139	0.03641
Mx Ps – USD XR	0.00588	0.00499	0.00779

Source: Own elaboration with data of the CRE and BANXICO

Since there is an open market to import NG to Mexico, the PVPM in Reynosa was the reference for the other local market prices, even for the PVPM in Pemex city, the main production center. Therefore, we will focus on the PVPM of Reynosa and, first, on its monthly version. During the study period, the monthly PVPM in Reynosa in dollars is highly correlated with the daily one-month future prices 'Future # 1' of the NYMEX NG. Figure 4 shows graphically the proximity of the monthly PVPM and the daily prices of the future contract.
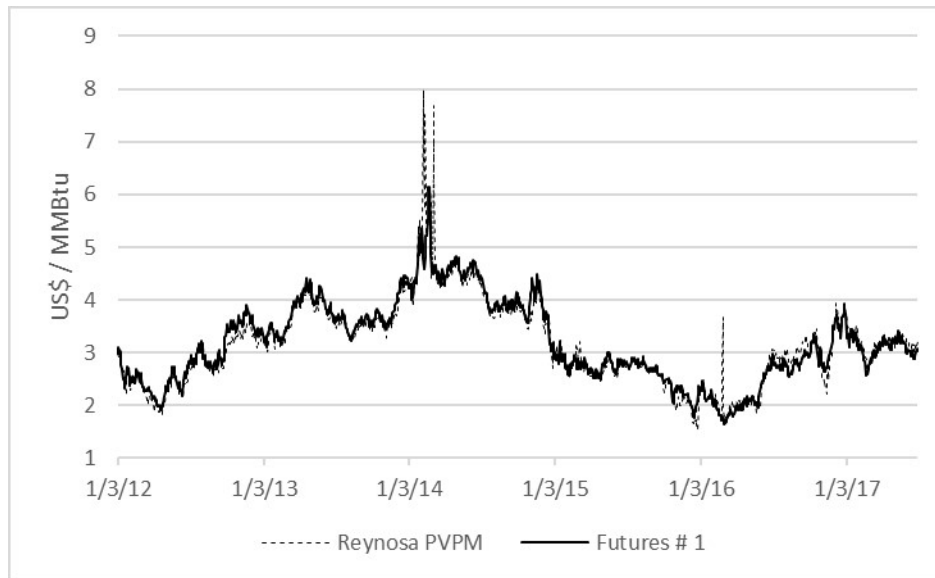

Figure 4. Daily PVPM of Reynosa in dollars vs. prices of NYMEX Futures Contract # 1 in study period.
Source: Own elaboration with data from CRE and NYMEX.

5.2   The simple hedging strategy

In the case of an urban NG distributor and that of an industrial user of the product. We consider the CME lists NG futures contracts that take Henry Hub index prices as a reference. These futures contracts have a very close relationship with their underlying. Also, gas prices in Henry Hub have a very close relationship with those of Texas Eastern STX, Tennessee Zone 0 and Houston Ship Channel, as can be seen in Barrera-Rivera & Valencia-Herrera (2019). Therefore, the hedge ratios consider PVPMs in Reynosa as spot prices and the CME NG Henry Hub futures.

In order to estimate the hedge ratios, we use equation (4), where ΔP_t the monthly growth of the PVPM in Reynosa at month t and $\Delta F_{1,t}$ is the one-month growth of the one-month Henry Hub gas future price at month t. Note that, due to the solution of the OLS method, the coefficient a1 in equation (4) is the same as the optimal hedge ratio h* in equation (3).

Since the estimation of PVPMs considers international NG previous prices, futures from previous periods can be useful for making PVPM hedges. Figure 5 shows the growth in the prices of the three-month futures and the growth of the PVPM prices in Reynosa in dollars. Notice that PVPM of Reynosa with one and two months of advance and delay have a statistically significant relationship with the futures at three months.
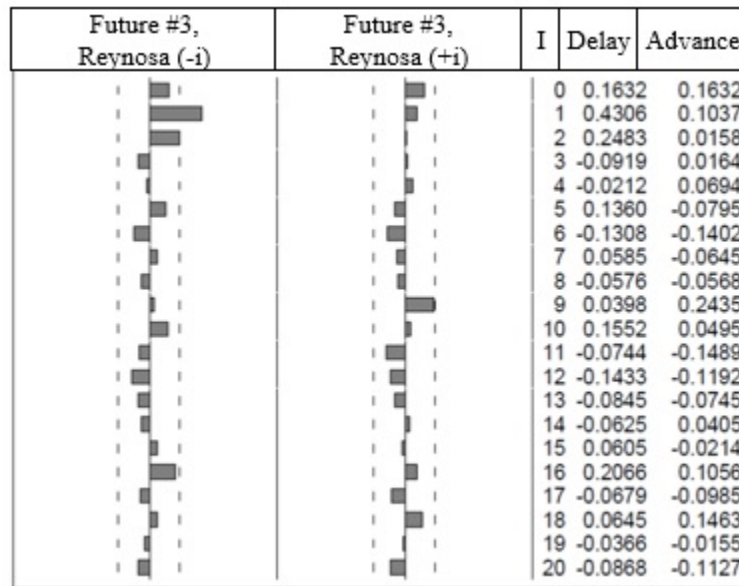
Future #3, Reynosa (-i)	Future #3, Reynosa (+i)	I	Delay	Advance
		0	0.1632	0.1632
		1	0.4306	0.1037
		2	0.2483	0.0158
		3	-0.0919	0.0164
		4	-0.0212	0.0694
		5	0.1360	-0.0795
		6	-0.1308	-0.1402
		7	0.0585	-0.0645
		8	-0.0576	-0.0568
		9	0.0398	0.2435
		10	0.1552	0.0495
		11	-0.0744	-0.1489
		12	-0.1433	-0.1192
		13	-0.0845	-0.0745
		14	-0.0625	0.0405
		15	0.0605	-0.0214
		16	0.2066	0.1056
		17	-0.0679	-0.0985
		18	0.0645	0.1463
		19	-0.0366	-0.0155
		20	-0.0868	-0.1127

Figure 5. Correlation between the growth of the Henry Hub three-month futures and those of the PVPM in Reynosa in dollars during the study period.

Source: Own elaboration with data of the NYMEX and CRE

From Figure 5, it could also be stated that there may be more than one hedging instrument, for example, the Future # 3 with zero and one month of offset, so that equation (3) could be extended to more than one hedging instrument.

Table 3 shows the hedge ratios with NG futures of the CME for the period and previous periods. From the table, only the futures of one and two delayed periods to the PVPM offer hedging possibilities, since only in these cases $h_j{}^*$ are statistically significant. The optimal hedging of a natural gas seller in the Mexican market could be structured with the instrument lagged one month by taking a short futures position for 54.7082% of the value of the position to be filled a month before the natural gas is sold to PVPM. The R^2 is an indicator of the potential risk reduction using hedging, here 14.0259%. Since the optimal hedging ratio for futures with two months of delay is statistically significant, it could be hedged, for example, the purchase of PVPM buying futures for 36.4429% of the value of the position to be filled two months before it was made the purchase.

Table 3. Optimal hedge ratios of PVPM of Reynosa with three-month futures with delay.

Delayed months of Future #3	h_j*	Standard Error	T Statistics	R^2
0	0.211115	0.17927	1.177642	0.018822
1	0.547082	0.167063	3.274710**	0.140259
2	0.364429	0.1748	2.084838**	0.057112

**, statistically significant at 95%.

Source: Own elaboration with data of the NYMEX and CRE.

The hedging can be structured by acquiring multiple futures during several previous periods. Because the autocorrelation in the growth of futures with months of lag is very small and not statistically significant, it is possible to consider futures with arrears of one and two months as independent instruments. Therefore, the coefficients that are obtained when making a linear regression of the growth in PVPM with respect to the growth of futures with one and two months of lag can be considered as optimal hedge ratios with each

instrument, in a multiple hedging. From Table 4, a position of gas subject to PVPM could be filled with futures of different maturities with one and two months of lag, acquiring futures at two months, with a value of 56.0542% of the position, one month before and 31.11712% of the value to cover two months before, for a risk reduction of 23.3381% (R^2).

Table 4. PVPM hedging in dollars with two Henry Hub futures instruments with one- and two-month lag.

	h_j*	**Standard Error**	**T Statistics**
Future # 2 (-1)	0.560542	0.149673	3.745105**
Future # 3 (-2)	0.311712	0.159525	1.95399**

and*, statistically significant at 99% and 94%, respectively.

$$R^2 = 0.233381$$

Source: Own elaboration with data of the CRE and NYMEX

To analyze the hedge with exchange rate futures for the purpose of analysis, synthetic futures prices were estimated using the interest rate parity $F_t = S_t \left(1 + r_d\right)^t / \left(1 + r_f\right)^t$, where F_t the price of the future quoted at period t, S_t is the exchange rate spot in direct quotation and r_d y r_f are the effective domestic and foreign rates at the future term in period t, respectively. In this case, the rates of the 91-day Cetes and the 90-day Treasury Bills were considered, adjusted for a period of one month. In a similar exercise, the PVPM in Reynosa can be covered with two- and three-month NG futures with one and two lags and one-month MXN-USD exchange rate futures, see Table 5.

Table 5. PVPM hedging models in pesos in the study period with Henry Hub futures and Mex Ps-USD exchange rate futures in the study period.

Instrument	h_j*	**Standard Error**	**T Statistics**
Mex Ps-USD (1)	1.420590	0.392058	3.623420**
Future # 2 (-1)	0.609386	0.137362	4.436364**
Future # 3 (-2)	0.278413	0.145986	1.907120**

$$R^2 = 0.371015$$

Source: Own elaboration with data of the CRE, NYMEX, BANXICO and Bloomberg.

5.3   Hedging under the MGARCH VCC model

In Barrera-Rivera & Valencia-Herrera (2019), optimal hedging ratios h_j^* are estimated for a PVPM spot position with the exchange rate and one month and two months lagged NG futures. Once the hedge is determined, it is can be necessary to rebalance the hedge based on estimates of conditional variance forecasts and correlations, both variations in the PVPM in Reynosa and of the NG futures used, since these elements concentrate the risk.

Table 5 shows the results of the MGARCH VCC for the daily series of the variations of the PVPM in dollars ('reynosavpm') and the two-month futures of the NG Henry Hub, with 20 and 40 days of lag ('lag20' and 'lag40', respectively). The 20 and 40 days of lag are equivalent, in the daily series of prices, to 1 and 2 months of lag in the monthly series used in section 3.4.1. For the model, 1,324 daily observations were used, distributed in a t-student manner and a Newton-Raphson optimization method. From the results of Table 6 it follows that the ARCH and GARCH coefficients are statistically significant at more than 99%; in the estimation of correlations, an acceptable statistical security was not achieved.

Table 6. MGARCH VCC model of the daily variations of the PVPM Reynosa in dollars and the Henry Hub two-month futures, with lags of 20 and 40 days in the study period.

		Coefficient	Standard Error	Z
ARCH_reynosavpm				
		.172906	.026373	6.56**
Arch L1.				
Garch L1.		.7638289	.0314717	24.27**
_cons		.0000642	.0000165	3.89**
ARCH_lag20				
		.0391612	.0107685	3. 64**
Arch L1.				
Garch LI.		.9315916	.0188782	49. 35**
_cons		.0000201	8.47e-06	2.37**
ARCH_lag40				
		.0508818	.0120538	4 .22**
Arch L1.				
Garch L1.		.9248127	.0177219	52.18**
_cons		.0000178	7 .52e-06	2.36*
corr(reynosavpm,lag20)		.0060658	.0308313	0.20
corr(reynoaavpm,lag40)		.0408179	.0307444	1.33
corr(lag20,lag40)		-.0016276	.0310237	-0.05
		.0130937	.039S099	0.33
Adjustment	lambda1 lambda2			
		.7153054	1.327244	0.54
Degree of Freedom	_cons	9.492002	1.001048	8.77**

**,* statistically significant at 99% and 95%, respectively.

Source: Own elaboration with data of CRE and NYMEX.

In the case of daily variations in Reynosa PVPM in dollars, the two-month futures with 20 days lag, and the two-month futures with 40 days lag, the conditional variance is estimated as in equations (8) to (10), respectively,

$$\sigma_{1,t}^2 = 0.0000642 + 0.172906\varepsilon_{1,t-1}^2 + 0.7638289\sigma_{1,t-1}^2 \tag{8}$$

$$_{2,t-20}^2 = -0.0000201 + 0.0391612\varepsilon_{2,t-21}^2 + 0.9315916\sigma_{2,t-21}^2 \tag{9}$$

$$\sigma_{3,t-40}^2 = -0.0000178 + 0.0508818\varepsilon_{3,t-41}^2 + 0.9248127\sigma_{3,t-41}^2 \tag{10}$$

With these values of conditional variances, the new optimal hedge ratios $h_j{}^*$ can be estimated and done on a recurring basis, as new information is obtained, in the manner of Gannon and Liu (2013). The model in Table 6 and equations (8), (9) and (10) can be used both to forecast conditional variances of future periods, and to estimate conditional variances for the historical data period itself and, with conditional variances, calculate the optimal hedge ratios $h_j{}^*$ by applying equation (5).

Figure 6 graphically shows the conditional covariances estimated in the study period obtained using the

MGARCH VCC model. The estimation of conditional variances is dynamic, that is, even if the determined coefficients are applied to current data, the value of these coefficients is updated as new information is received and these new values are applied to the following current data.
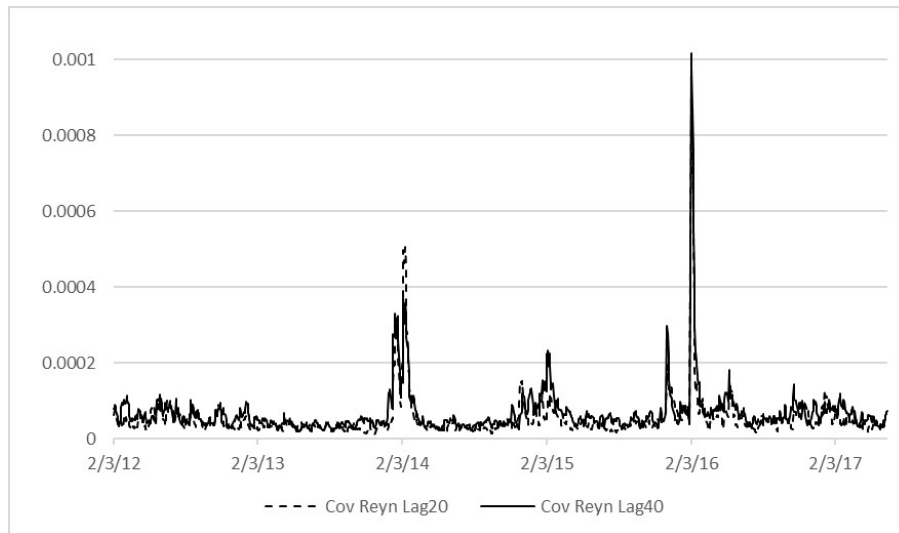

Figure 6. Estimated conditional covariances between the daily growth of the PVPM in Reynosa in dollars and the daily growth of the two-month Henry Hub futures with lags of 20 and 40 days in the study period. Source: Own elaboration with data from CRE and NYMEX.

Figure 7 shows the estimates of the conditional covariances between the variations of the PVPM in Reynosa and those of the two-month Henry Hub futures, with lags of 20 and 40 days, for the last 100 days of the series, which include 10 forecasted days. The predicted conditional covariances are those that appear after the vertical line. The covariances of the last 100 days are shown in Figure 8, however, the data of the 1,384 days of the study period were used to obtain them. The purpose of Figure 8 is to depict in greater detail the last part of the estimated conditional covariances.
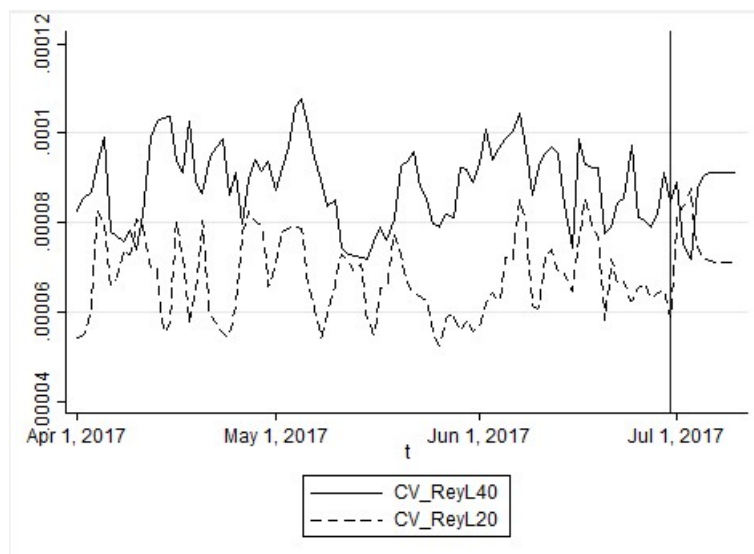

Figure 7. Estimated conditional covariances between the daily growth of the PVPM in Reynosa in dollars and the daily growths of the two-month Henry Hub futures, with lags of 20 and 40 days in the period of the last 90 days of the historical series and the first 10 days forecast.

Source: Own elaboration with data from CRE and NYMEX.

As already stated from the data of the conditional variance matrix, the optimal hedge ratios h_j obtained using equation (5). Figure 8 shows the graph of the hedge ratios between the spot position and the futures with lags of 20 and 40 days in the study period.
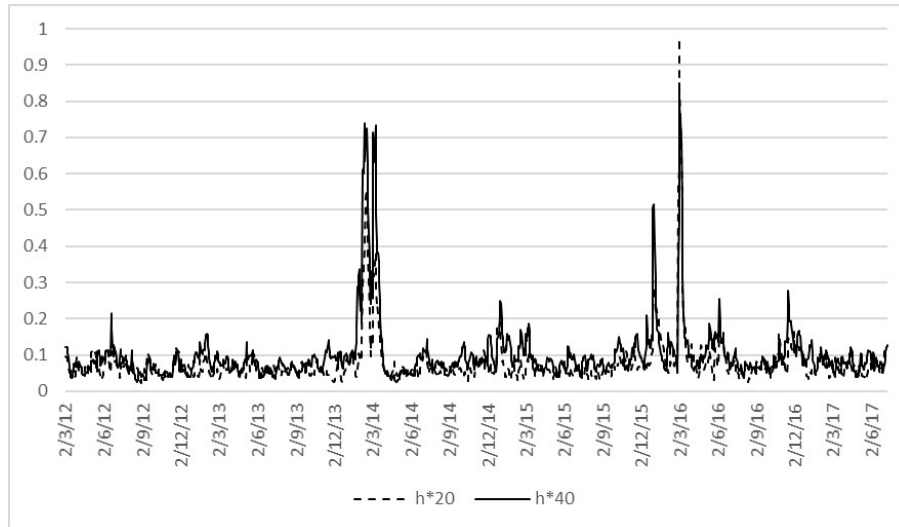

Figure 8. Optimal hedge ratios $h_j{}^*$ between the daily growth of the PVPM in Reynosa in dollars and the daily growth of the two-month Henry Hub futures, with lags of 20 and 40 days in the study period.
Source: Own elaboration with data from CRE and NYMEX.

Table 7 lists the optimal hedge ratios $h_j{}^*$ predicted for the 10 days following the last date with historical data and, as support, the conditional covariances between the spot position and the futures are detailed.

Table 7. Relationship of conditional covariances and optimal hedge ratios $h_j{}^*$ predicted for 10 days with the two-month Henry Hub futures, with lags of 20 and 40 days.

Day Forecast	Cov Reyn Lag20	Cov Reyn Lag40	h*20	h*40
1	0.000032	0.000032	0.060609	0.074616
2	0.000047	0.000034	0.086592	0.075478
3	0.000060	0.000033	0.109885	0.071314
4	0.000061	0.000043	0.109619	0.088827
5	0.000061	0.000051	0.108659	0.101764
6	0.000062	0.000057	0.107585	0.111066
7	0.000062	0.000062	0.106600	0.117609
8	0.000062	0.000066	0.105759	0.122111
9	0.000062	0.000069	0.105057	0.125129
10	0.000062	0.000072	0.104472	0.127080

Source: Own elaboration with data of the CRE and NYMEX

5.4 Backtesting in the VCC model

Forecasts of conditional variances and optimal hedge ratios $h_j{}^*$ say little about the goodness of the estimate. Figure 8 above shows the conditional covariances predicted for a period of 10 days, however, how much do the out-of-sample covariances forecasts approximate the estimated in-sample covariances? In order to resolve this uncertainty, we performed a backtesting; first, we used the first 90% of historical data (in-sample) to

forecast the last 10% of the information (out-of-sample). Figure 9 graphically shows the results in the forecast period; in that figure, the first current and forecast optimal hedge ratios appear within the ellipse.
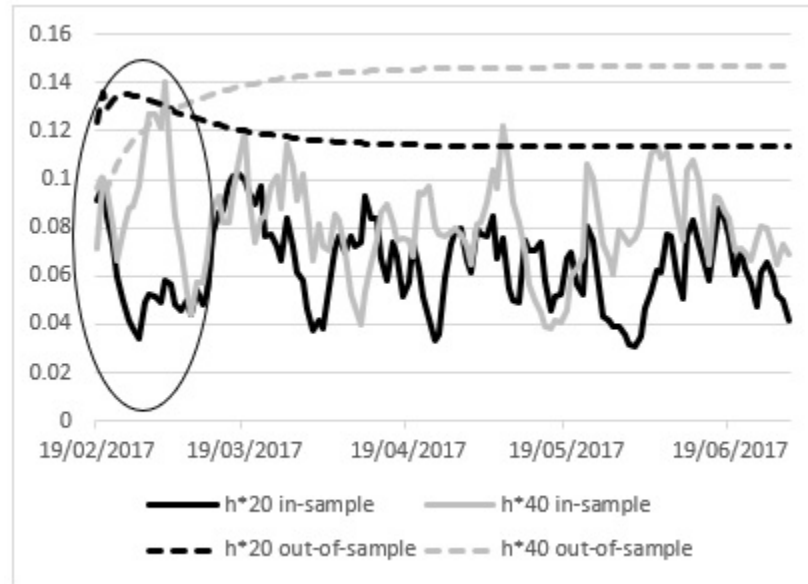

Figure 9. Optimal hedge ratios $h_j{}^*$ in-sample and forecasted out-of-sample in the last 10% period of the data observed through backtesting.
Source: Own elaboration with data of the CRE and NYMEX

Notice that the out-of-sample predicted hedge ratios $h_j{}^*$ do not closely follow short-term changes in the in-sample ratios; however, the order of the predicted ratios is the same as that of the current ones, that is, the in-sample and out-of-sample $h_{20}{}^*$ predicted hedge ratios are lower than the in-sample and out-of-sample $h_{40}{}^*$ predicted ratios. Table 8 shows the backtesting statistics, both for in-sample data and in the out-of-sample forecast period.

Table 8. Statistics of the optimal $h_{20}{}^*$ and $h_{40}{}^*$ in-sample ratios and out-of-sample forecasts in the entire period and the estimation period in the backtesting.

	First 1,192 days (90%) (In-sample)		Remaining 132 days (10%) (Out-of-sample)			
	h*20 actual	h*40 actual	h*20 actual	h*40 actual	h*20 predict	h*40 predict
Mean	0.082095	0.112268	0.063728	0.081820	0.117371	0.140759
Std Dev	0.076295	0.103794	0.017128	0.020148	0.006357	0.010954
Kurtosis	83.675187	25.423120	-0.689331	0.100092	1.587913	5.993851
Skewness	7.824266	4.612342	0.158550	0.129760	1.683808	-2.502337

Source: Own elaboration with data of the CRE and NYMEX

The absolute differences between the optimal $h_{20}{}^*$ and $h_{40}{}^*$ in-sample and the forecasted out-of-sample hedge ratios are 0.05364 and 0.05894, respectively. Table 9 shows the "memory" that the estimated hedge ratios retain, since they do not fully reflect the decline in actual hedge ratios in the forecast period, within the backtesting.

In order to reduce this "memory" period in the estimated hedge ratios, we reduced the period of actual data to a minimum in which the MGARCH VCC estimates were convergent with the Newton-Raphson

method and we sought to make forecasts for a shorter period (10 days). Table 8 shows the results for this shorter backtesting period.

Table 9. Statistics of the optimal $h_{20}{}^*$ and $h_{40}{}^*$ in-sample ratios and out-of-sample forecasts for the period of the last 252 days in the backtesting.

	First 242 days (In-sample)		Remaining 10 days (Out-of- sample)			
	h*20 actual	h*40 actual	h*20 actual	h*40 actual	h*20 predict	h*40 predict
Mean	0.012957	-0.049824	-0.01765	-0.075207	0.019034	-0.073572
Std Dev	0.039929	0.036346	0.010531	0.014862	0.014705	0.023248
Kurtosis	-0.602354	0.613126	0.507476	2.186578	5.099191	-0.442972
Skewness	0.279302	-0.558116	0.214191	1.365924	2.206246	-0.968940

Source: Own elaboration with data of the CRE and NYMEX

The absolute differences between the optimal $h_{20}{}^*$ and $h_{40}{}^*$ in-sample hedge ratios and the out-of-sample forecasts in the 252 days period are 0.036685 and 0.001635, respectively, which implies reductions in the differences of the estimates of 31.61% and 97.23% for hedge ratios of 20 and 40 days. That is, the proximity of the actual data and the shortage of the predicted period result in better predictions if the historical data is enough for a convergent solution.

6   Conclusions and final considerations

This study focuses on the study of the dynamic hedging of NG, in particular of PVPM in Mexico. It is paradoxical that being NG a fuel of such broad use, it has attracted so little attention among researchers in the field. This study confirms, at least during the study period, that volatility in the prices of NG usually exceeds exchange rate volatilities. During the study period, the volatility of the NG prices in NYMEX was 6.7 times the volatility in the peso-dollar exchange rate; however, the correlation between variations in the price of NG and the exchange rate is close to zero. This was also true for two subperiods of the sample which show different volatility patterns.

The optimal hedging of NG first-hand sale prices (PVPMs) proposed considers the purchase of futures, months before the hedging date, which may allow arbitration. Considering the opening of the oil and gas market in Mexico, if PVPMs are re-established, the pricing schemes must be reviewed to reflect in a timelier manner the international price levels and avoid arbitration. A similar recommendation applies wherever PVPMs are used.

Dynamic hedging is a necessary tool for exposures to changing levels of risk, so that hedging is updated as new information is obtained. In order to obtain more reliable forecasts of variances, it is necessary to "filter" historical price information, so that the importance of some abrupt changes can be properly assessed and whether they are matched in other markets.

The MGARCH VCC method of forecasting conditional variances was an adequate tool for estimating optimal hedge ratios for the case analyzed. This tool improves its efficiency when the predicted period is short and the actual sample data is close and they result in a convergent solution in the estimation method.

The proposed hedging analysis and scheme is extensible to other fuels and other international markets, with little effort, since the regulation of NG prices is an international regulatory practice and many countries are net importers of hydrocarbons. An immediate case is the gasoline market where gasolines spot positions can be hedged with crude oil or RBOB (reformulated blendstock for oxygenate blending) futures. Another

case of great importance is the generation of electricity from NG where both markets, the power market and the NG's have their own intricacies.

The hedging strategy adopted in this investigation minimizes the variance of the hedge portfolio which it is not necessarily the most adequate approach for an investor, especially when he or she has an opinion on the price trends, in the presence of transaction costs or with a more rational attitude towards risk. In these cases, the optimal hedge solution should consider the expectations of the returns and risk measures as well as a function to deliver the investor's preferences under such expectations.

Finally, the field looks promising; NG pricing for a period, even without the PVPM scheme, implies costs and risks that someone must bear: the final consumer, the distributor, the importer, and/or the local gas producer. Hedging strategies allow the distribution of this risk and cost among other participants with capital structures and market views that may be different. Having a different view of the risk as a result of a forecast and, at the same time, having the hedging a cost, it is convenient to evaluate whether it is appropriate to rebalance the hedging, however, this would be subject to further study.

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