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Risk Premium in Colombia Wholesale Electricity Market

David Esteban Rodriguez*, [1], Alfredo Trespalacios*, and Javier Orlando Pantoja[#]

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ABSTRACT

The FRP is the implicit payment received by the buyer or seller assuming the market risk used in the long-term transaction in electricity markets using forward contracts; however, the difficulties of long-term storage energy do not allow possible arbitrage opportunities over time when cost-of-carry techniques are applied. In these conditions, the spot price expectations determine the price of electricity contracts, which produce a Forward Risk Premium (FRP) in the transactions. This manuscript measures the ex-post FRP of the Colombian electricity market in a monthly time series to identify the risk hedging in the agent's contract. The FRP in Colombia presents two structural changes and seasonality and mean reversion patterns, showing the buyers of energy contracts are better paid concerning the spot price, showing an arbitrage problem in contracts. The paper results will do a tool for participants and policymakers to consider the risk involved in the energy transactions through FRP value.

1. INTRODUCTION

Electricity markets use the economic profit concept applied in microeconomics to explain the commodity transaction, where the buy and sell operations define the price and amount to be traded [1]. This operation is not regular because of the different types of products, troublesome transactions for geographic conditions, insufficient inventory for mitigating price fluctuations [2], and a closed market that can modify prices [3].

Electrical energy can be traded in multiple markets: short-term, spot, long-term contracts, or electricity-forward contracts. The forward contracts enable market agents to stabilise the prices for sale in the future considering two moments in the negotiation: (1) the deal, where the contract and the price are defined; and (2) the maturity delivery, who delivers the agreement profit [4]. As a result, the difficulties for storing energy make the contract price starts when the following expectations of the spot price for the second moment. If the negotiation is not systematically conducted at the expected spot price, the Forward Risk Premium (FRP) will reflect contango or backwardation conditions.

The FRP studies consider different approaches, resolutions, and markets worldwide. [5] make an empirical study with daily time-series data to find relationships between short-term volatilities and economic risk using a data panel and Vector Autoregressive (VAR) models, finding several patterns in variables. [6] use the same methodology to find evidence of the FRP in other types of energy markets, seeing similar results. On the other hand, [7] took 11 years' worth of weekly series about forward-energy contract prices in the Nord Pool market and used linear models to find the risk preferences of the agents change depending on the time of the year and the need for consumption. [8] report the commodities hedonic prices duplicate the market prices and, therefore, the perception of risk in the future.

Using advanced processes, [9] estimate an FRP value and set up the relationship between the deterministic component and volatility to get an unbiased linear model with seasonality and mean reversion. From the microeconomic perspective, [10] uses the imperfect market theory to estimate the FRP using the no-contract process (Allaz–Vila equation) and Strategic Premium to find possible arbitrage opportunities to obtain the maximum performance of the FRP. In the case of the Colombian electricity market, [1] uses linear and GARCH models to demonstrate that the FRP value presents a robust seasonal component due to characteristic climate events in the country (El Niño and La Niña phenomena). As a result, he built linear models and GARCH processes to capture the statistical characteristics of the spot price. As observed, the research about FRP adopts different approaches; none of the studies above mentioned the presence of seasonality and mean-reversion conditions, as in the case of the spot price.

As shown in [1], [5], [7], and [11], the FRP models have time series econometric developments (ARIMA or similar models that present memory effects), providing the tools to describe the risk perception of the agents for Colombian FRP value.

*Department of Finance, Instituto Tecnológico Metropolitano de Medellín (ITM), Colombia.

[#]EAFIT University, Colombia.

[1]Corresponding author:
Tel: +57 3104347629.
Email: davidrodriguez@itm.edu.co

By 2018 the Colombian electricity market has a supply nearby 17 GW to attend 8 GW of electricity demand. Hydraulic resources represent 68% of the market; this proportion has persisted since the market began in 1995. At the same time, the Colombian wholesale electricity market has a single-node price system with only one price reference for electricity generation; the result is a sealed-bid auction where the energy providers and market agents could hedge the risk using long-term contracts like hydroelectric projects and climate phenomena estimations.

Furthermore, the energy policy implemented in Colombia seeks an energy system with more competitive participation in non-conventional renewable technology. This paper contributes to the risk measure literature focusing on the Colombian electricity market to help market participants and policymakers consider the risk involved in the energy transactions through FRP value. In addition, this work tells which agents have been paying for risk hedging. This way, authorities could identify activities to accomplish sustainable development goals, bringing access to all populations in coverage and competitive prices.

This study delves into the dynamics of the FRP from the perspective of time series, searching structural changes letting the agents handle future analyses about the compensation of risks in the market of forward-energy contracts. The authors measure two models for the forward risk premium (FRP) in the Colombian electricity market from 2006 to 2019. For the first case, the authors make a linear model for the Spot Price (PB) using the expected time (t), creating the FRP estimated data. Later the authors verify the structural change evidence in the FRP series to determine the most relevant changes events. For the second case, the authors recreate the expected model of FRP with an ARIMA model. For both cases, the residuals looking for heteroskedasticity are reviewed. As a final process, the authors compare the estimated values of both models to establish which are more tightly fitted in the expected series of FRP values, asking whether the risk premium is a non-distributable independent random variable for the memory process over time spot prices and risk.

The authors found FRP models in Colombia present two structural changes and seasonality and mean reversion patterns in the spot price. In addition, the study results are favourable for agents that participate in electricity negotiations doing market planning. As a result, sellers, and buyers, as regulators and organizations in charge of supervising the market, can improve their tools to support decision making.

For the development of the paper, the authors present an introductory task scheme about the FRP and the methodological procedure section; the authors developed the model to solve the problem described previously. The results have shown: 1) in the first case, the FRP presents structural changes explained by a climatic phenomenon, which coincide with the changes in the Oceanic Niño Index corresponding to the breakpoint's dates of the FRP series; in the second case, the model is like the spot price and does not determine a structural change; in both models, the authors did not find a heteroskedastic process. The following section describes the results and a discussion. Finally, the last section concludes and proposes future work.

2. METHODS

2.1 Expected Spot and Contract Prices

At the end time of T, the party that bought the electricity for the price of the contract at t_o time should pay F_{t_oT} and, in return, they will receive the value of the energy spot price SP_T. The contract seller, the party with a short position, will receive the same net benefit as the buyer but with an opposite sign. Equation (1) shows the profit for the forward contract seller, which corresponds to an income determined by the contract price. In return, the seller should deliver the energy agreed upon valued at spot price SP_T. [4] describe the long-term electricity contracts and the benefit for their parties.

$$\Pi_T = F_{t_oT} - SP_T \tag{1}$$

Under these conditions, it is easy to see an agent selling a forward contract finds it convenient if the spot price PB_T is systematically lower than the contract price. If the spot price is systematically above the contract price, an electricity generator suffers losses; showing generators are the ones who pay to stabilize the price in the contract market.

2.2 Forward Risk Premium (FRP)

To capture the phenomenon described previously, the Forward Risk Premium (FRP) is defined as the difference between the expected spot price and the contract price, as shown in Equation (2) [1].

$$FRP_{tT} = E(SP_T) - F_{tT} \tag{2}$$

Reference [12] explain the FRP process how: "*A positive value of FRP_{tT} indicates a contract price agreed below the expected market price and that the selling agent pays for the contract coverage; in turn, a negative value indicates that the contract price is greater than the market expectation and the purchasing agent pays for the coverage*".

This study analyzes two possibilities to calculate the expected Spot Price: (i) a linear trend model [13] and (ii) an ARIMA process (or SARIMA if needed). Equation (2) shows how to estimate the FRP with the estimate of Spot Price. Later, the authors check the model's goodness of fit with statistical analysis, structural changes tests and ARIMA-type patterns.

2.3 Structural Changes

A time series may alter its structure, such as changes in level, trend, or volatility structure. Such changes, which intervene in the series in the long term, are marked by socioeconomic, political, and environmental processes. In this case, structural changes may reflect the risk levels of the market or the valuation of such risks [5].

The authors carried out the analysis of the structural change of the FRP applying three tests: (i) Chow, (ii) Cumulative Sums or CUSUM, and (iii) Ordinary Least Squares-CUSUM or OLS-CUSUM. Those tests are complementary and aim to find different possible breakpoints [14]. The Chow test creates two model's types: 1) the original series that considers all the data, 2) the information breakpoint considering data before and after the structural change [15].

Such a test proposes a single representation for the three models as in the following linear model, in which the superscript m denotes the number of the model. In the case of the FRP, it assumes that the exogenous variable is time, as shown in Equation (3).

$$Y_t = \alpha^m + \varepsilon_t^m + \sum_{t=1}^{n} \beta_k^m X_{tk}\,; \quad m = \{1,2,3\} \tag{3}$$

For estimated models, the authors obtained the Square Sums of Errors SSE^m renamed as: SSE_R for the original model $(m = 1)$, and SSE_{NR} is the sum of the SSE of the break models $(m = 2,3)$. Afterwards the statistic that distributes a function F_{Chow} (4). There is evidence of structural change when the values of F_{Chow} are higher than a value $F_{critical}$, which is the function of the number of parameters in the model, the amount of observed data, and confidence level.

$$F_{Chow} = \frac{\dfrac{SSE_R - SSE_{NR}}{k}}{\dfrac{SSE_{NR}}{n-2k}} \tag{4}$$

The Chow test can fit only a critical breakpoint but not identify two or more breakpoints, even is not efficient to review the changes over time recursively in parameters. Therefore, other tests can describe more than one structural change [16].

The Ordinary Least Square-Cumulative Sums (OLS-CUSUM) is shown in Equation (5). Each recursive linear model is represented with the superscript "s", and k is the parameters model:

$$\varepsilon_t^s = Y_t^s - \alpha^s - \sum_{s=k+1}^{n} \beta_k^s X_{tk}^s\,; \quad s = k+1, k+2, \dots, n \tag{5}$$

$\varepsilon_t^{(s)}$ are the residuals obtained recursively to verify the structural change; their variance is compared to that of a standard Brownian process (6). When the evidence indicates that the residuals $\varepsilon_t^{(s)}$ exceed the confidence band of the Brownian process, a structural change is said to have happened [17].

$$B^{(s)} = \frac{1}{\hat{\sigma}\sqrt{n}\sum_{t=1}^{zn} \hat{\varepsilon}_t^{(s)}}\,; 0 \le z \le 1 \tag{6}$$

The Recursive Residuals-Cumulative Sums (Rec-CUSUM) Equation (7), where w_r is a series of residuals constructed with a standardization based on the root of the scalar matrix of variances and covariances of each recursive process.

$$w_r = \frac{\widehat{\left(\varepsilon_t^{(s)}\right)}}{\sqrt{1 + x_t'(X_{t-1}' X_{t-1})^{-1} x_t}} \sim N\left(0, \sigma_\mu^2\right) \tag{7}$$

Based on w_r, w_t is the standardized sum of w_r (8); under the confidence curves of $\left(k \pm a\sqrt{n-k}\right)$ as a minimum limit and $\left(n \pm 3a\sqrt{n-k}\right)$ as the maximum limit. Their analysis is like OLS-CUSUM, where limits are the confidence level of the hypothesis, and "a" is the significance level that comes from the distribution of [17].

$$w_t = \sum_{r=k+1}^{t} \frac{w_r}{\sigma_\mu}\,;\ \sigma_\mu = \frac{SSE}{n-k}\,;\ E(w_r) = 0; \alpha = 0.05 \tag{8}$$

To properly establish the breakpoints, the authors used statistical tools with the highest significance level in the series of information analyzed [16].

2.4 ARIMA – SARIMA Models

The ARIMA process decomposes a time series into three components (9), where φ_i is the coefficient of autoregressive (AR), Θ_i is the coefficient of moving average (MA), and d is the level of difference. SARIMA process complements the ARIMA process with a seasonal component. The representation of this model can be found in the paper by [18].

$$\Delta^d Y_t = \alpha + \sum_{i=1}^{p} \varphi_i y_{t-i} + \varepsilon_t + \sum_{i=1}^{q} \theta_i \varepsilon_{t-i} \tag{9}$$

According to the Box-Jenkins methodology, the first step is to review the stationarity process (unit root tests) using the KPSS (Kwiatkosky - Phillips - Schmit-Shin), ADF (Dickey - Augmented Fuller) and PP (Phillips - Perron) tests. As an additional process for Box-Jenkins to identify a SARIMA process, the Webell-Ollech test identifies the robustness of the seasonal data series, making the criterion of proving a model properly.[19]

Reference [20] says the ARIMA or SARIMA analyze the goodness-of-fit criteria using the AIC (Akaike Information Criterion), AICc Criteria (Akaike Information Criterion converted), the correlograms of the residuals and their normality. As a final analysis, the authors checked the residuals heteroskedastic process to establish if the FRP information series have ARCH or GARCH models and verify their parameters. [21] shows the hypotheses and tests for review of the process.

3. DATA DESCRIPTION

The authors considered information with monthly resolution from January 2006 to September 2019 from the operator of the Colombian electricity market about the spot price (SP) and average contract price (CP) of the contracts. Figure 1 shows the SP and CP dataset.

The average spot price is 132 COP/kWh, with a linear trend and marked seasonality. The price increase in 2015 for the El Niño phenomenon is notable with a relative scarcity of natural gas in the country and the subsequent energy generation from liquid fuels. The average price of contracts in the regulated market (CP) shows the growing trend and seasonal effects. It also presents a rise in price between 2015 and 2017, but not at the same level SP. Some contracts that expired between 2015 and 2017 may be signed considering the expectations of the El Niño phenomenon some months before it started.

Table 1 presents the descriptive statistics of the series under analysis and their logarithms. Only the CP series meets the assumption of normality according to the Jarque-Bera test, which is coherent with the center interquartile distances. The spot price (SP) presents more data dispersion toward the right side of the mean, which reflects positive skewness also for the natural logarithm of the series. The time series (Figure 2) was also decomposed into its (i) trend, (ii) seasonal, and (iii) random components.

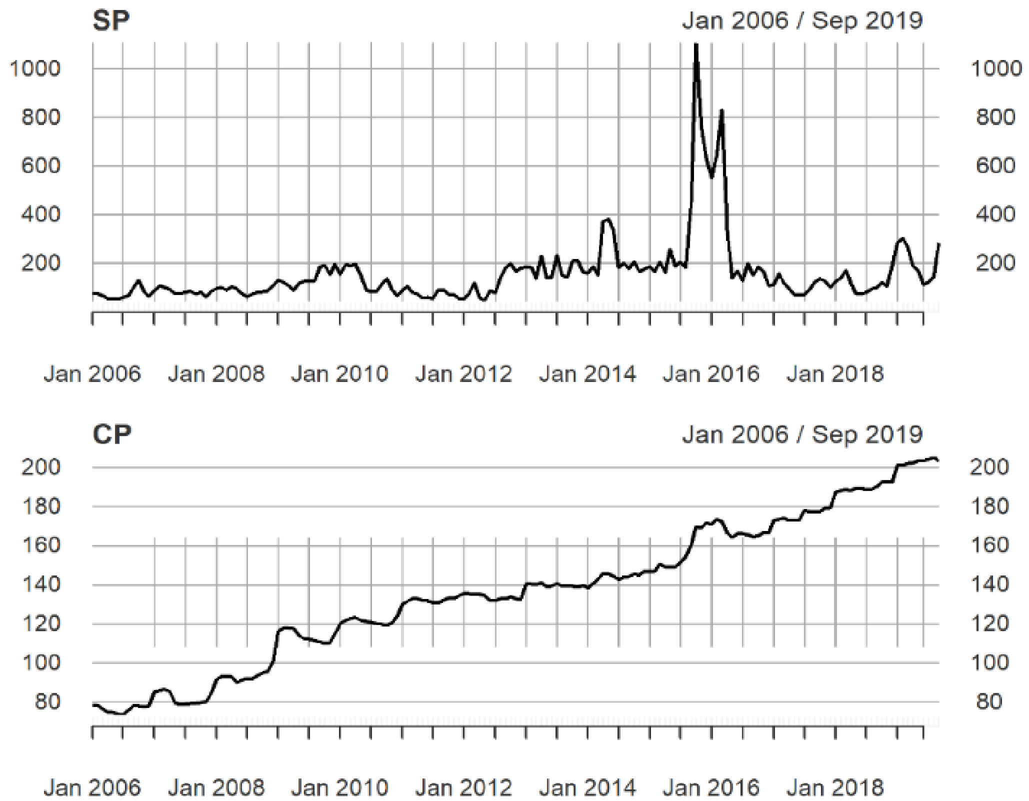

Fig. 1. Spot price (SP) and average contract price (CP). Both series are measured in COP/kWh.
Source: www.xm.com.co

Table 1. Basic document specifications.

Variable	SP	Log_SP	CP	Log_CP
Min	46.88	3.85	73.65	4.3
1st Q	83.25	4.42	112.6	4.72
Median	122.33	4.81	135.33	4.91
Mean	157.39	4.86	136.54	4.88
3rd Q	181.81	5.2	166.43	5.11
Max	1107.4	7.01	205.44	5.33
Std. Dev	139.58	0.57	36.7	0.29
Coeff. Var	0.89	0.12	0.27	0.06
JB	2668.06	44.52	5.25	9.66

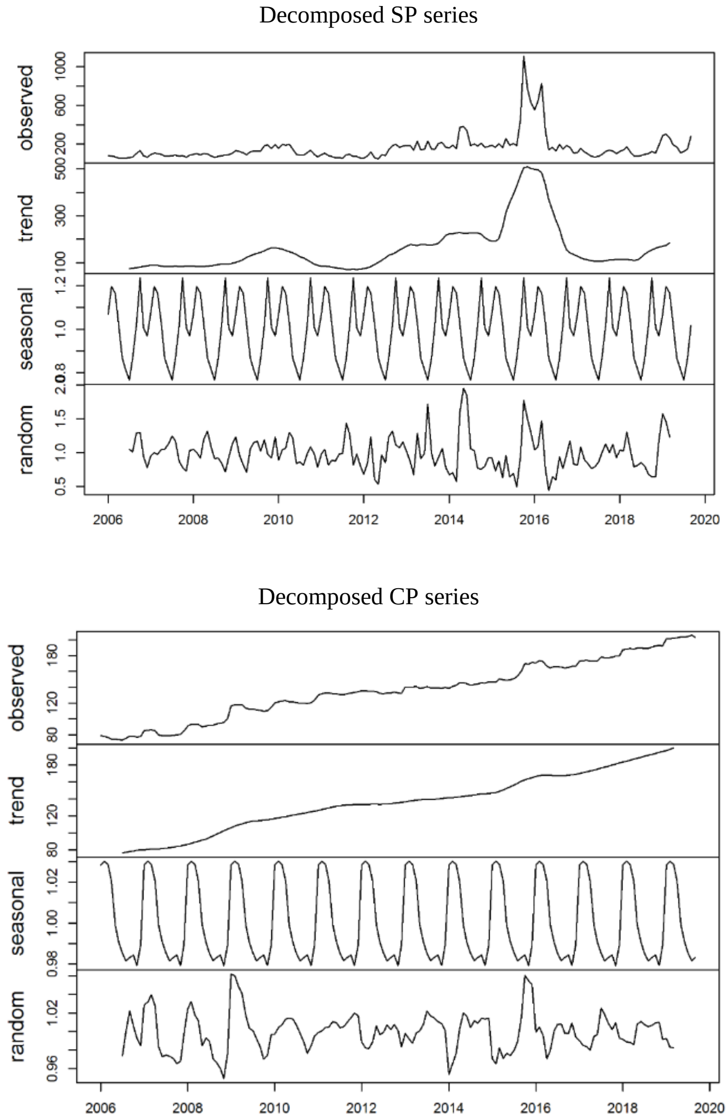

Fig. 2. Decomposed SP and CP series.

The trend component of CP is positive with a change in 2015 but did not have a reaction to the level change, meaning a stabilization of market risks avoiding short-time deviations. The SP series presents a cyclical trend component as a function of the availability of primary energy sources and the medium-term macroclimatic conditions that can influence the price because electricity poses technical and economic limitations for long-term storage. The seasonal component reflects the economic and fluvial dynamics, and the random component is an example of the effect of conditions for which there is no forecasting capacity. (Which could be related to failures in the generation equipment, modification of the topology of the transmission network, and electricity demand peaks, among others).

4. RESULTS

This study considers two possibilities to calculate the expected spot price: (i) a linear trend model and (ii) a SARIMA process. The FRP has a positive trend and two structural changes, one in December 2008 and one in August 2015. Additionally, the authors found that electricity generators pay the risk premium.

4.1 Case 1: Expected Spot Price (SP) toward FRP

The following is the calculation of the expected spot price considering a linear trend model. The parameters in this model are estimated by employing the Ordinary Least Squares (OLS) method and following the procedure proposed by [13]. The obtained parameters present an individual significance level of 5% seen in Table 2.

Subsequently, the FRP is calculated using (2), considering the trend model of the spot price $\widehat{PB}_t$ and the historical values of MC_t.

Figure 3 shows positive values of FRP_t and compose a growing series; therefore, the buyers of energy contracts are, on average, better paid concerning the spot price. There were negative values in only four months of 2009, maybe due to sales during a strong La Niña phenomenon.

Although the series presents an upward movement, it seems to have different trend levels in some periods. For that reason, the authors decided to conduct parametric stability tests to identify possible breakpoints for structural change in the FRP_t series. Table 3 shows the statistics of the Chow, OLS-CUSUM, and Rec-CUSUM tests. The second column presents the calculated statistic of each test; the third column the p-value of the null hypothesis of structural change. According to the three tests, there is a structural change with a 99% confidence level. For the Chow test, the residuals must be homoscedastic; to test this assumption, [14] recommend the White and BGP tests; the results show possibly homoscedastic residuals using a White test (5%), but the calculated and theoretical values are similar; to review this hypothesis the authors have done the BGP test finding homoscedastic residuals.

Table 2. Linear model by OLS.

Coefficients	Estimate	Std. Error	P-value
Intercept	77.57	20.67	0.000
$\widehat{\beta_2}$	0.961	0.21	0.000

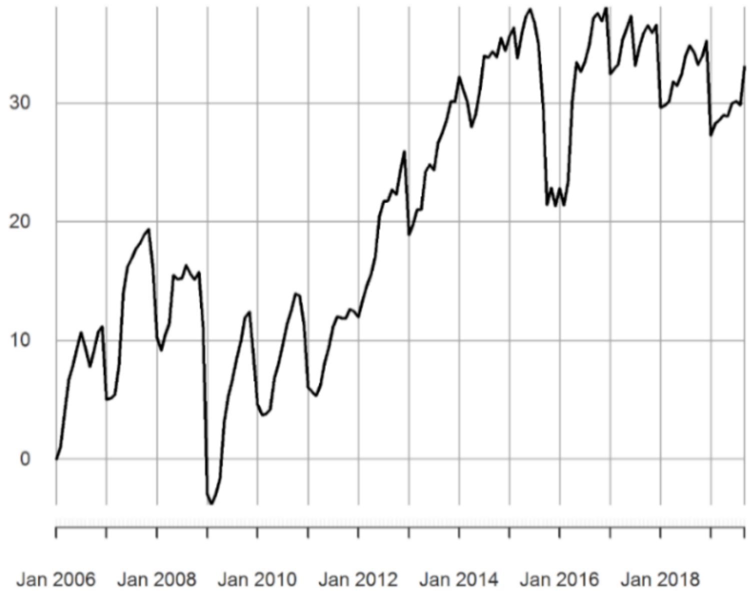

Fig. 3. Time series of FRP (COP/kWh) based on the estimated value of SP.

Table 3. Tests of structural changes applied to the FRP in Case 1.

Test	Value	P-value
Chow (F-distribution)	15.66	0.000
OLS-CUSUM (chi distribution)	1.937	0.001
Rec-CUSUM (chi distribution)	1.174	0.007
Heteroskedastic Tests		
Test	Calc Value	P- Value
White	5.991	0.049
BGP	3.841	0.247

Next, Table 4 provide the most relevant breakpoints in the data series. The first event occurred in December 2008 in the La Niña phenomenon when the hydrological contributions grew significantly; as a result, the market supply increased, the prices decreased and the predictability toward relatively low spot prices, which reduced the risk levels and increased the cost of the risk premium. The second event occurred in August 2015 due to the El Niño phenomenon, when the FRP reached its highest point to later stabilize as its rate of change decreased, these results are shown in the ONI dataset [22]. See the Figure 4.

Reference [23] demonstrates in his article that the risks are more significant in "El Niño" phenomenon than La Niña phenomenon, doing the spot prices rise because of scarcity of water resources. As evidenced in the previous paragraph, there are two events of "El Niño" phenomenon. However, the risk is not evident when the climatic effect is the opposite (La Niña phenomenon) keeping reservoirs capacity.

The authors found that the FRP trend changed between January 2006 and December 2008 (P1) increasing the risk premium at an average speed of 0.33 COP/kWh per month. The premium fastest-growing period was between 2009 and 2015 (P2), when it increased 0.48 COP/kWh per month and even exceeded 30 COP/kWh after 2014. In turn, the FRP decelerated in the most recent period (P3), *i.e.*, from September 2015 until the end of the data in September 2019 FRP increased by 0.065 COP/kWh and stayed around 32 COP/kWh. It seems that, after the most recent strong El Niño phenomenon, the market agents found the maximum risk market valuation. Figure 4 presents the graph of the FRP with the breakpoints of structural change marked with dashed lines and the slope of the series in the three periods in blue.

Table 4. Linear model fitted with structural changes.

		Estimate	Std. Error	t value	P value
P1: Jan 2006–Dec 2008	α^s	5.294	1.245	4.251	0.00
	β^s	0.329	0.058	5.606	0.00
	95%	Lower	(3.125 – 14.642)	Upper	(8.121–19.638)
P2: Jan 2009–Sept 2015	α^s	-18.625	1.245	-14.954	0.00
	β^s	0.484	0.015	31.105	0.00
	95%	Lower	(-2.125 – 36.175)	Upper	(0.750 – 39.050)
P3: Sept 2015–Sept 2019	α^s	22.431	6.286	3.568	0.00
	β^s	0.065	0.044	1.482	0.14
	95%	Lower	(27.586 – 30.743)	Upper	(32.663 – 35.819)

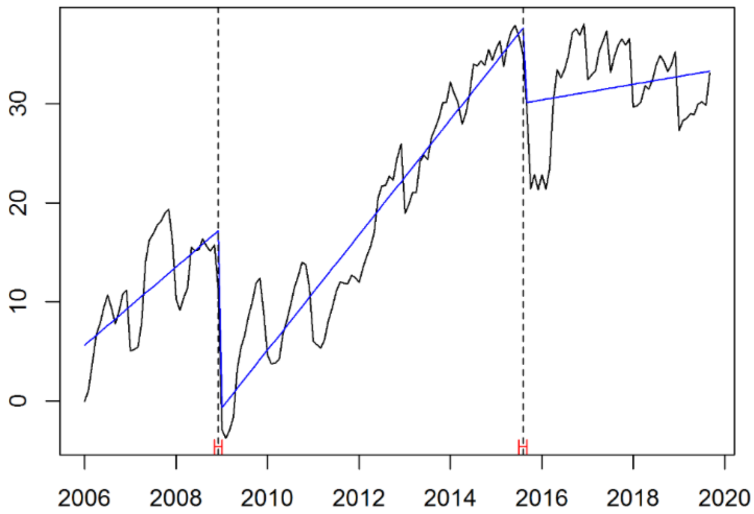

Fig. 4. Linear model adjusted with structural changes

In these conditions, the lowest FRP (-3.2 COP/kWh) occurs at the setup of Period 2. P1 also presents the lowest expected spot price: 78.5 COP/kWh. The higher change rate of premium is 38.1 COP/kWh in P3, also showing the higher spot price: 236.3 COP/kWh. For the change rate, P3 show the higher FRP standard deviation due to the positive skewness identified in the distance between the third quartile and the mean. Table 5 presents the descriptive statistics of the FRP and the expected spot price in the three periods.

For the estimated FRP data series, the authors used Box–Jenkins's method (Table 6), adding a seasonal component as suggested by [24], to determine if exist a SARIMA model. Figure 5 shows the FRP have a second-order process (regarding the autoregressive price) and a moving average component of the delay.

Contemplating the possibility of heteroskedastic innovations in the model (Figure 6), the authors evaluated the non-seasonal variance and found empirical evidence of several information peaks. However, the conditioned variance process is not applicable because its implementation only revealed two high values in the innovations given the conditions of the structural events previously described.

Table 5. Descriptive statistics of the forward risk prime and expected spot price in the three periods of structural change of the FRP.

Period	P1		P2		P3	
Variable	FRP	Est SP	FRP	Est SP	FRP	Est SP
Min	-0.08	78.5	-3.8	113.2	21.3	190.1
1st Q	7.9	87	9.28	132.2	29.6	201.6
Median	10.9	95.4	16.3	151.1	32.9	213.2
Mean	11.3	95.4	18.4	95.4	31.7	213.2
3rd Q	15.6	103.8	29.3	170.1	34.9	224.7
Max	19.3	112.2	37.9	189.1	38.0	236.3
Std.Dev	5.08	10.13	11.7	22.35	4.54	13.74
Coef.Var	0.45	0.11	0.63	0.15	0.14	0.06

Table 6. Results of the SARIMA model for Case 1 of the FRP.

Coefficients	Estimate	P-value	Other test	
MA1	0.165	0.027	KPSS, ADF, PP	1
SAR1	1.211	0.000	AIC	727.23
SAR2	-0.219	0.015	AICc	727.76
SMA1	-0.980	0.000	Seasonality test (p-value)	0

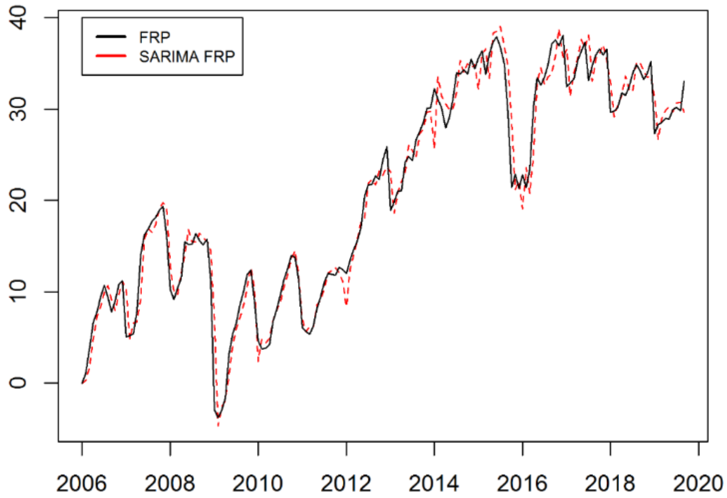

Fig. 5. SARIMA estimation of FRP in Case 1

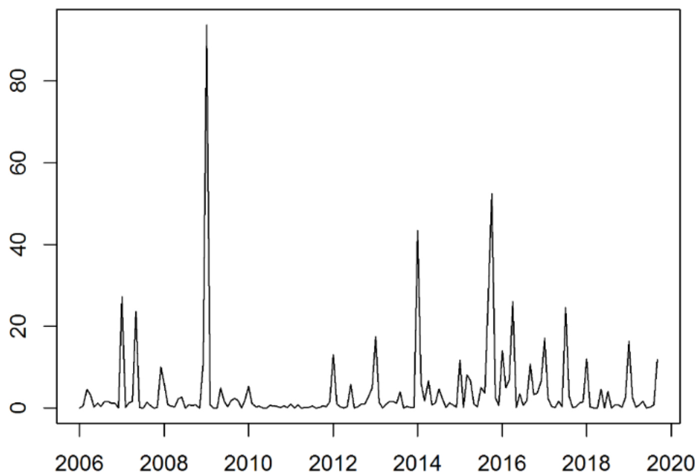

Fig. 6. Squared innovations to estimate the spot price in Case 1.

4.2 Case 2: Expected Spot Price (SP) based on ARIMA/SARIMA models toward the FRP

In this case, the authors used Equation (7) to determine the ARIMA/SARIMA model of the spot price (SP) and take the value of FRP from it. Therefore, the authors applied the following model in Table 7.

Figure 7 presents the historical spot price (solid black line) and the process fitted to the time series (dashed red line), which has two autoregressive components of moving averages; all of them are significant at a confidence level of 95%. This way of calculating expected spot prices uses the spot price and the innovations of the electricity series in the two previous periods; as a result, the model price expectations require the past period. As in Case 1, the authors did not find conditioned heteroskedasticity in the model's residuals. The errors of the ARIMA model (1,0,1) of the spot price (SP) only exhibit one variance peak and no volatility clusters.

Figure 8 presents the FRP estimated in Case 1 (solid black line) and Case 2 (dashed red line). In Case 1, the FRP is smoother, possibly since the expectations of spot price are less volatile, although the risk estimation of the price forecast is higher. Spot price expectations based on short-term information increase the volatility of the risk premium. The model in Case 1 explains a short-term expectation. However, in the market, the CP is agreed one, two, or three years in advance, which shows the effect of actual short-term decisions and decision changes due to climate phenomena. Nevertheless, the spot price forecasting that uses $t-1$ periods is not sufficient to make market decisions because the long-term effects have behaviour like the spot price SP, see Case 2.

Table 8 summarizes the estimated spot prices (SP) and risk premia (FRP) obtained in the two cases. The average value of the FRP over the entire time horizon is 21 COP/kWh in Case 1 and 18.9 COP/kWh in Case 2. This situation indicates that the forward risk premium is positive on average whether the authors use a long-term trend modeling (Case 1) or a short-term estimation (Case 2). In Case 2, there be more years with a negative risk premium, more volatility and an annual variation coefficient that exceeds even that of the contract prices CP.

The results also show in [23], [25]–[27] take VAR, VEC or ARDL methodologies to study the Free risk premium for explaining the exogenous variables' impact. This paper is an exploratory start of those procedures providing a source of univariate analysis; in fact, this paper revisited [28]. The advice for management spot prices and FRP is to apply this methodology for agents' preference risk, behavior, and how institutions can control the bid-ask expectations.

Table 7. Results of the SARIMA model of the FRP in Case 2.

Coefficients	Estimated	P-value	Other test	
AR1	0.823	0.000	KPSS, ADF, PP	1
MA1	-0.227	0.038	AIC	1916.31
			AICc	1916.69
			Seasonality test (p-value)	1

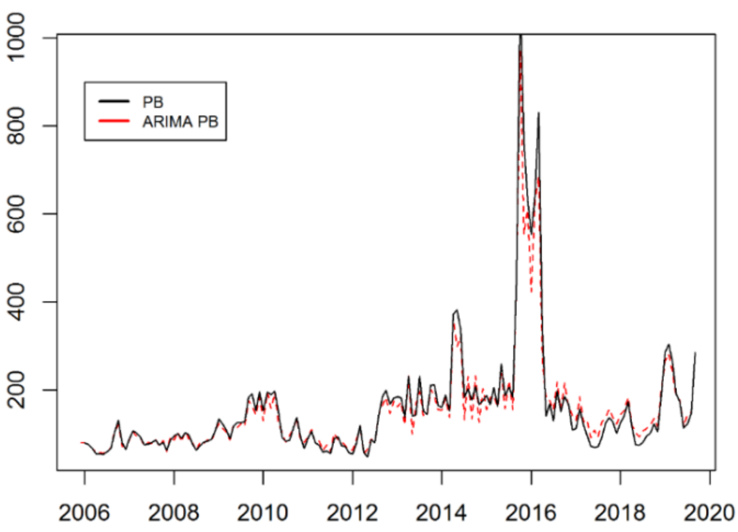

Fig. 7. Estimated model for the spot price (SP) in Case 2.

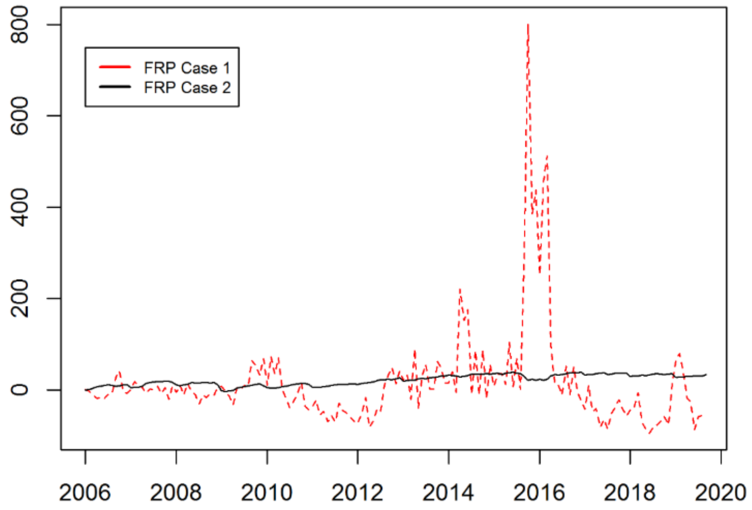

Fig. 8. FRP series with ARIMA spot expectation.

Table 8. Annual summary of the FRP in the two cases of expected spot price measurement. All the values are annual averages.

Year	CP	Case 1			Case 2		
		Est. SP (1)	FRP	FRP% (2)	Est. SP	FRP	FRP%
2006	76.5	83.8	7.3	9%	74.3	-2.9	-4%
2007	81.9	95.4	13.4	14%	81.5	1.4	2%
2008	93.5	106.9	13.4	13%	85.5	-6.9	-8%
2009	113.8	118.4	4.6	4%	123.7	16.2	13%
2010	121.3	130.0	8.7	7%	132.6	2.7	2%
2011	132.1	141.5	9.4	7%	82.0	-51.4	-63%
2012	133.8	153.1	19.3	13%	104.3	-20.3	-19%
2013	139.8	164.6	24.8	15%	165.9	24.5	15%
2014	143.9	176.1	32.3	18%	205.4	65.6	32%
2015	155.7	187.7	32.0	17%	304.7	182.8	60%
2016	167.4	199.2	31.8	16%	322.3	115.9	36%
2017	175.7	210.8	35.0	17%	130.2	-47.1	-36%
2018	189.7	222.3	32.6	15%	125.2	-57.7	-46%
2019	203.0	232.4	29.5	13%	195.8	-8.2	-4%
Average	137.7	158.7	21.0	12.5%	152.4	15.3	-1.5%
St. Dev	38.6	48.1	11.2	4.4%	79.5	66.5	32.9%
Coef. Var	0.280	0.303	0.53	0.353	0.522	4.337	-21.96

Note: (1) Spot price estimated using the methods in Case 1 and Case 2, respectively. (2) With respect to the estimated SP

5. CONCLUSIONS AND RECOMMENDATIONS

This study presents an ex-post measurement of the forward risk premium in the Colombian electricity market explained as the difference between the forward contracts of the electricity price and the expected spot price. To estimate the spot price expectation was presented two possibilities, (i) a linear model and (ii) a SARIMA model. The authors found FRP in Colombia presents two structural change patterns of seasonality and mean reversion patterns. In addition, the FRP has been positive most of the time, suggesting that it is electricity generators that have traditionally paid for risk coverage and users who have assumed the market risk. The results allow regulators, supervisors, and energy market planners to consider the market efficiency, the cost transfer, and the competition.

The risk valuation of the Colombian electricity market measured using the FRP has been marked by three periods with an upward trend, each with different growth rates: 2006–2008, 2009–2015 (highest growth rate), and 2015–2019 (lowest average growth rate).

After the most recent strong El Niño phenomenon, the market agents found the maximum risk market valuation; such valuation seems indeed conditioned by the occurrence of market conditions. The authors found periods in which the El Niño occur can influence the risk premium structure of market agents. Therefore, the regulation should generate user guarantees to face the variability in the market by climatic phenomenon, being hedge mechanisms or risk mitigation chances the adequate.

Of the two methods used in this study, Case 1 present the best performance. Nevertheless, the expectations made with SARIMA require information very close to the maturity period of the contracts, and agents do not have this information when they sign a contract. Colombian electricity market contracts are signed one or two years before the maturity in the aftermath.

The results of this study are favorable for electricity negotiations agents that participate in institutions responsible for planning and structuring the market. To further this analysis, the authors studied the market risk valuation through its determinants. Therefore, future studies should analyze the influence variables for the definition of the FRP, as well as the way the volatility of the observable variable's determinates the risk premium. As a result, sellers, and buyers, as regulators and organizations in charge of supervising the market, can improve their tools to support decision making.

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