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The Climate Effect on Colombian Coffee Prices and Quantities Based on Risk Analysis and the Hedging Strategy in Discrete Setting Approach

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Abstract

This paper provides a risk-hedging strategy for coffee markets including climate impact in the context of Colombian Coffee producers, companies, regulators, and policymakers. From the intermediaries' perspective, we present a hedging price and quantity risks using financial instruments based on price and weather variables (El Niño and La Niña phenomena). The coffee price and quantities produced are mitigated by the inclusion of climatic variables in two ways: first, through analysing the changes observed in the forward curve against spot price measuring the deterministic effect, known in this market as the forward risk premium. Second, including the weather index in the hedge structure on price and quantity in the coffee market improves the agent's result; this latter aims to improve the hedging claim's performance due to the link between demanded volume and weather-linked index. An experiment shows the strategy profit over the best-performing claim price derived only and without hedging.

Keywords

Weather index, Coffee market, hedging strategy, forward risk premium.

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Introduction

Coffee-producing countries such as Brazil, Vietnam, Colombia, Indonesia, Ethiopia, Honduras, and India centralize trade through federation-like entities in coordination with producer associations (often cooperatives) and futures contracts with Intercontinental Exchange, Inc. (ICE). The fluctuations of prices and quantities for the producers, in contrast to the agreements signed with the federations, establish a risk exposure due to the differences between the international price and the local price, as well as quantities produced and quantities contracted; these distortions financially impact everyone: producers, cooperatives and federations.

The first coffee bean futures market began trading in 1882 (the Coffee Exchange of New York or CECNY). Intercontinental Exchange, Inc. acquired NYBOT in 2007 and changed its name to ICE Futures USA (Jenkins and Barbosa, 2020). This market represents a standard trade coffee quality quoted price is not necessarily the same delivery price at the value traded between buyers and sellers. The price differential reflects the physical market conditions and the quality of the coffee (Federación Nacional de Cafeteros de Colombia, 2020). Three factors explain the coffee price, the C-contract or international price of washed Arabica coffee; the quality differential and the TRM rate and the price differential between buyers and sellers.

Analysing the Colombian coffee price allows us to predict the commodity portfolio using exogenous variables. Studies such as Pham et al. (2019), Martins et al. (2015) and Paes (2010) found the direct effect of climate on coffee prices. The current coffee market (2019-2023) has presented high volatility levels due to the excessive rains, changes in sunlight and soil conditions in Brazil, lowering the market price, and lack of labour in Central America, increasing the price due to the lack of production. Regarding the C contract, there were peaks in December, March, and September. The dollar showed volatility due to the world economic dynamics showing values above 4000 COP, and oil futures showed adverse effects (Federación Nacional de Cafeteros de Colombia, 2020). By 2021, the market's increased interest in Colombian coffee because of the devaluation of the Colombian peso (COP) made this commodity more attractive on the New York Stock Exchange. Even so, the world coffee market had an increase of 7.2% produced from 2020 to 2021. (Increase by 10.2% between 2016 and 2021) (Federación Nacional de Cafeteros, 2021a).

The coffee price and quantities produced are mitigated by the inclusion of climatic variables in two ways: first, through the analysis of the changes observed in the forward curve (future prices at different terms) against spot price (Ravi et al., 2022), measuring the deterministic effect, known in this market as the forward risk premium. Second, the inclusion of weather indices in the structuring of hedging on price and quantity in the coffee market improves the result for the agent; This latter aims to enhance the hedging claim's performance due to the link between demanded volume and weather-linked index (Hazell, 2000).

Results show the inclusion of weather variables improves the hedging claim's performance due to the link between demanded volume and the weather-linked index. An experiment shows the gain of the proposed strategy over the best-performing claim derived on price only and without hedging.

Coffee studies and climate in commodities

The coffee quantities and prices are analysed in the following studies. Cárcamo and Franco (2012) initially stated supply and demand drive coffee prices. Johnson (1957) proclaimed the existence of global inventory (from several producing countries) to avoid volatile price effects. Volume risk is more important than product market risk. Uncertainty about stocks and production expectations generates volatility Rodríguez and Melgarejo (2020) found in their study the stochastic elements influenced by exogenous variables are fundamental in the price analysis. Pham et al. (2019) complement coffee as a climate-sensitive perennial commodity.

With these considerations, current studies on coffee risk hedges incorporate price and weather. Pham et al. (2019) and (Barrios et al., 2022) studied coffee prices; they found climate changes in the asset price, such as a drop in yields and an increase in pests and diseases, or positive effects, such as an increase in the harvesting niche and pollination services. Martins et al. (2015) complement climate hits on the productivity and quality of coffee are related to atypical events (El Niño and La Niña phenomena), generating flawed crops.

Läderach et al. (2017) quantified the impact of progressive climate change on higher-quality coffee, minimising risk production, showing four climate effects with adaptation effects for low altitudes and long-term adaptation for high altitude crops. Tucker et al. (2010) used risk perception on farmers associated with the high risk of climate effects on seed adaptations. However, farmers associated with high-risk events were less likely to make specific adaptations

In studies focused on mathematical or econometric models, Álvarez et al. (2019) analysed the climate as an uncertainty variable on bananas price using Vector Autoregressive (VAR) models, finding the correlation between the price, the asset, and the Chicago Mercantile Exchange climate index. Paes (2010) and Pokorná & Smutka (2010) used linear models to identify weather impacts on the price of coffee in two moments; he found out the rainy season positively affects plant growth and increases grain numbers, and the dry season affects the production in the quantity and quality of the bean. The study predicts events three to six months in advance.

Garcia (2003) used a neural network and ARIMA model to identify price behaviour, showing better results in Variance Error Neural Network in 22% compared to the ARIMA model. Nhung et al. (2020) sought to hedge Vietnamese coffee risk using a Vector Error Correction Model (VECM); they found hedging ratios and the optimal number of each futures contract short-term hedging tools. Makonnen et al. (2021) used quantile regression to identify the temperature impact on futures returns on soybean, corn, cotton and coffee under extreme bear and bull market conditions. Vijayakumar (2022) examined a vector correction model with long-run cointegration in the US dollar index and crude oil on coffee. He discovered the ICO price changes, Arabica coffee futures, crude oil and the US dollar index led to a long-run change in coffee prices.

Materials and methods

Coffee spot price expectations

Riaño (1997) and Pantoja (2012) shows at maturity time T, whoever bought at contract price at time t_o, will have to pay a value Ft_{oT}. In return, the commodity valued at the spot price is P_l Whoever sells the contract in a short position will have a net profit equal to and opposite in sign to the buyer. Formula (1) shows the accurate market price of the commodity.

$$P_t = P_l - Ft_{oT} \quad (1)$$

To measure the forward risk premium (FRP) is the difference between the expected spot price and the contract price. An FRP_{tT} positive value shows a contract price (2) below the expected exchange price (Chen and Ryan, 2023), and the selling agent pays the contract. An FRP_{tT} negative value indicates the price contract is higher than the exchange expectation, and the demand agent pays the hedge (Bessembinder and Lemmon, 2007).

$$FRP_{tT} = E(P_l) - F_{tT} \quad (2)$$

External effects analysis - structural change

Longstaff and Wang (2004) did the Bai-Perron test using structural change time series breakpoints for evidence of significant phenomena showing the number of structural breaks or information restrictions for each m-partition $(T_1, \ldots T_m)$, minimizing the sum-squared residuals $S_T(T_1, \ldots T_m)$ and obtaining the optimal regressions (3).

$$\sum_{i=1}^{m+1} \sum_{t=T_{i-1}+1}^{T_i} [y_t - x_t'\beta - z_t'\delta_i]^2 \quad (3)$$

Greene (2008) and Cermák et al. (2017) recommends using four complementary tests: Chow, CUSUM, OLS-CUSUM and Rec-CUSUM for reading changes in time series. In the first test, Chow (1960) measured the structural change in time series, comparing two regression slopes and proving if they were statistically equal. According to (4) where SSE_R fit the original model $m = 1$, SSE_{NR} as the sum of the SSE of the break models $m = 2, 3$. Then F_{chow} statistic value is greater than the $F_{theoretical}$ evidence of structural change.

$$Y_t = \alpha^m + \varepsilon_t^m + \sum_{t=1}^{n} \beta_k^m X_{tk};$$

$$m = \{1,2,3\};\ F_{chow} = \frac{\frac{SSE_R - SSE_{NR}}{k}}{\frac{SSE_{NR}}{n-2k}} \quad (4)$$

The second test, OLS - CUSUM (Ordinary Least Square CUSUM), explains the stability of coefficients (β) in a recursive multiple linear regression model, based on a sequence of sums of squares, under the null hypothesis of coefficient constancy (5) are recursively linear models $s = k + 1, k + 2, \ldots, n$, where $\varepsilon_t^{(s)}$ is the residuals obtained recursively and measured with standard Brownian process variance. When the residuals exceed the theoretical boundary, there is a structural change.

$$\varepsilon_t^s = Y_t^s - \alpha^s - \sum_{s=k+1}^{n} \beta_k^s X_{tk}^s;$$

$$B^{(n)} = \frac{1}{\hat{\sigma}\sqrt{n}} \sum_{t=1}^{zn} \hat{\varepsilon}_t^{(n)};\ 0 \le z \le 1 \quad (5)$$

The third test is Residuals Rec-CUSUM test also applies residual recursion process (6). w_r is a standardised residual series based on each recursive path's scalar variance-covariance matrix root. It starts from w_r, where w_t are the standardised summation of w_r. Stablished by the minimum confidence ($k \pm a\sqrt{(n-k)}$) and maximum confidence ($n \pm 3a\sqrt{(n-k)}$), whose test analysis is the same as OLS – CUSUM.

$$w_r = \frac{\hat{\varepsilon}_t}{\sqrt{1 + x_t'(X_{t-1}'X_{t-1})^{-1}x_t}} \sim N(0, \sigma_\mu^2);$$

$$w_t = \sum_{r=k+1}^{t} \frac{w_r}{\sigma_\mu};\ \sigma_\mu = \frac{SSE}{n-k};\ E(w_r) = 0;\ \alpha = 0.05 \quad (6)$$

Static risk coverage via quadratic optimisation

Oum and Oren (2009) used the price function (7), where the price given the produced asset quantity is equivalent to the local price f_{tT}, P_l is the asset spot price, and q is asset demand. The procedure can involve an external weather variable of the risk hedge. Pantoja and Vera (2020) set spot price at time T,x_w is a function of weather at time T and total profit Y.

$$y(P_l, q) = (f_{tT} - P_l)q \quad (7)$$

The objective of the function is to maximize the mean-variance process for profit hedging at time T (8). It maximizes the expected utility under the constraint cost of making financial portfolios with contingent rights $x_p(p)$ y $x_w(w)$ are equal to zero.

$$Y(P_l, q, x(P_l), x(w)) = y(P_l, q) + x(P_l) + x_w(w); \quad x(f_{tT})\ (P_l)\ x_w(w) \tag{8}$$

Pantoja and Vera (2020) proposes a restricted continuous solution for portfolios in (9). For this purpose. 1) The independent solution case, where weather is independent of price and production factors (10); and 2) The general solution case, where the set of weather on prices and quantities correlations (11).

$$\max_{x(p),z(\iota)} E(U\left(y(P_l,q,x(P_l),x(w)\right)];$$

$$s.t\ E^{\phi}[x(P_l)] = 0, E^{\phi}[x(w)] = 0 \tag{9}$$

$$x_{P_l} = \begin{bmatrix} \widehat{M_{pP_lP_l}} \\ \phi_{P_l}^T \end{bmatrix}^{-1} \begin{bmatrix} \widehat{c_{P_l}} + \frac{1}{2a}(\hat{\psi}_{P_l} - \hat{\phi}_{P_l}) \\ 0 \end{bmatrix};$$

$$x_w = \begin{bmatrix} \widehat{M_{ww}} \\ \phi_w^T \end{bmatrix}^{-1} \begin{bmatrix} \widehat{c_w} + \frac{1}{2a}(\hat{\psi}_w - \hat{\phi}_w) \\ 0 \end{bmatrix} \tag{10}$$

$$\begin{bmatrix} x_{P_l} \\ x_w \end{bmatrix} = \begin{bmatrix} \widehat{M} \\ B \end{bmatrix}^{-1} \begin{bmatrix} \hat{c} + \frac{1}{2a}(\hat{d} - \hat{b}) \\ 0 \end{bmatrix};$$

$$\lambda_{P_l} = \lambda_w = 1 \tag{11}$$

Results and discussion

For hedging, we use Colombian coffee international prices and Spot prices from Bloomberg and National Weather Service – National Oceanic and Atmospheric Administration. Table 1 provides information on the local price of coffee, the market price, coffee production and a climatic variable using the ONI 3.4. The database uses monthly information from April 2016 to January 2023, making 83 observations. The local price series and the coffee market price series present a variation of 41.8 and 32.25 USD cents with rightward skewness behaviour; Jarque Bera indicates both series are statistically not normally distributed. The coffee production series shows a higher level of deviation, suggesting seasonal volatility; according to Jarque Bera, the coffee quantity presents normal distribution. Regarding the climate series, the ONI 3.4 works with the average values of ocean temperature showing normal distribution according to the Jarque Bera test.

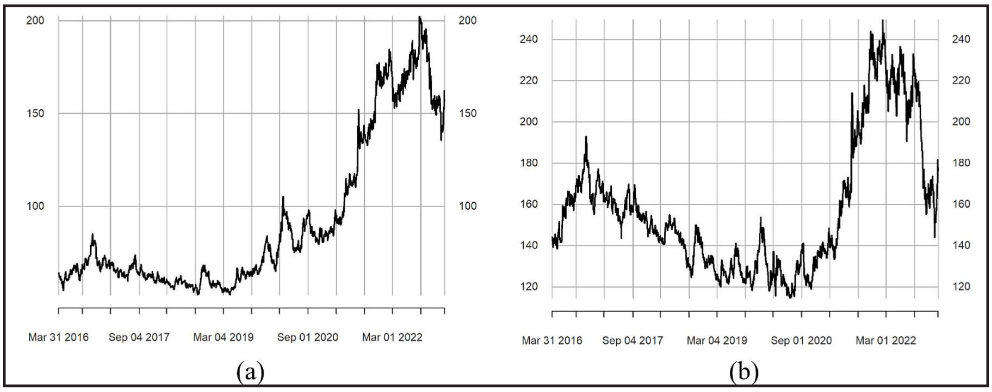
Figure 1 shows the series of Spot prices (local prices) of Colombian coffee and the series of coffee market prices; in both series, until 2020, the coffee price was stable, but compared to the market price, the spot price is below market values, showing speculation effects in production and avoiding the criterion of excessive volatility (Tröster and Gunter, 2022).

Figure 2 shows the development of (2). The process shows forward contracts are negative (the forward price is higher than the expected local price for the coffee future) in time series, showing two moments of lower fall of the FRP are appreciated, in the middle of 2016 and at the beginning of 2022.

Variable	**Local Coffee Price (P_l)**	**Coffee Market (F_{tT})**	**Production (q)**	**ONI 3.4 (w)**
Min	52.18	114.35	616	25.28
Median	70.74	150.25	1089.5	26.82
Mean	92.27	157.97	1121.68	26.79
Max	202.34	249.65	1743	28.72
Standard Dev	41.8	32.25	214.94	0.9
Variance Coefficient	0.45	0.2	0.19	0.03
Jarque Bera	368.81	275.3	4.29	4.65
P-value Jarque Bera	0	0	0.12	0.1

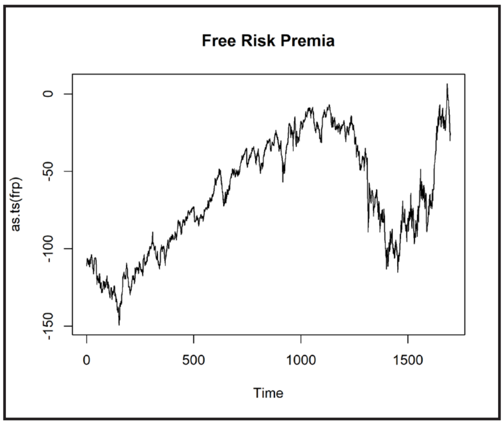
Source: own elaboration based on data from Bloomberg (2023)

Table 1: Colombian coffee market database and ONI 3.4.



Source: own elaboration based on data from Bloomberg (2023).

Figure 1: Coffee local price (left) and Coffee market price (right) from 2016 to 2023.



Source: own elaboration based on data from Bloomberg (2023)

Figure 2: Forward risk premium in the coffee market.

Structural change analysis

Table 2 shows the results of structural change tests of models (3-5) applied in Figure 2; the tests show structural change processes statistically verifiable through P-values; the 0% value shows an alternative hypothesis identifying structural change setting in the times series on FRP.

Test	Statistic	P-value
Chow	4648.1	0%
OLS CUSUM	10.047	0%
Recursive CUSUM	5.6376	0%

Source: own elaboration based on data from Bloomberg (2023)

Table 2: Statistical tests for structural change.

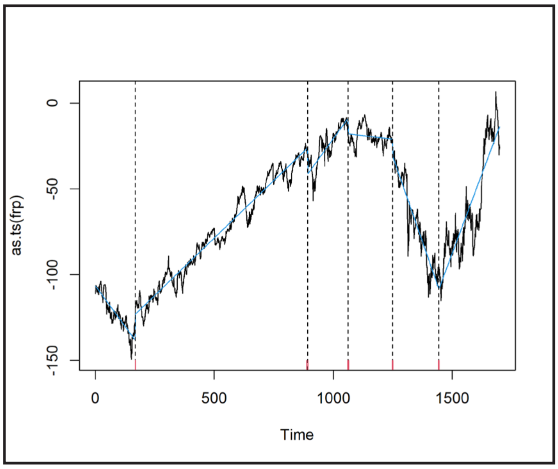
Applying Bai Perron structural change (6), we identify six climatic breakpoints between 2016 and 2022. In 2016 the FRP structure was affected by a weak Niña phenomenon. From 2016 to 2019, two climatic phenomena increased the value of the FRP until they approached zero risk values. Between the final 2019 and the middle of 2020, no climatic event affected the local prices, and between 2020 and 2023 La Niña Phenomena were relevant for the local prices.

Table 3 and Figure 3 shows the climate breakpoints identified by the FRP in (2). In 2016, climate conditions increased world coffee production in Central America, Brazil, and Colombia. The explanation obeys Brazil's price expectation was lower due to a reduction in rainfall in the southern region of Minas Gerais and an increase in temperature impacting production. In addition, speculation about Vietnamese coffee production in the fall of 2017/18 (Federación Nacional de Cafeteros de Colombia, 2016).

Breaks	(Intercept)	Trend	Phenomenon
1/4/2016 – 1/12/2016	-106.295	-0.189	La Niña weak
2/12/2016 – 30/10/2019	-145.585	0.134	La Niña – El Niño weak
31/10/2019 – 24/07/2020	-212.491	0.192	No event
27/07/2020 – 22/4/2021	0.277	-0.017	La Niña moderated
23/4/2021 – 27/01/2022	466.797	-0.398	La Niña moderated
28/01/2022 – 2/2/2023	-643.855	0.371	La Niña moderated

Source: own elaboration based on data from Bloomberg (2023)

Table 3: Breakpoints for climate events in the Forward Risk Premium. (Null and CCM, 2023).



Source: own elaboration based on data from Bloomberg (2023)

Figure 3: Structural change processes of the FRP series under Bai and Perron (1998) methodology.

For the second period on record, the coffee price fell to 135cUSD/lb due to the expectations and weather rectification of the Brazilian crop and a positive coffee production level for Colombia, Honduras, and Peru. In 2017/18, the coffee price decreased for market supply by selling mild coffees and considerable inventory from importing countries. In 2018, the arabica coffee price recorded a systematic fall (29% between January and December 2018) caused by a downward trend influenced by the depreciation of the Real currency (R$) and the increase in Brazilian export estimates. Political and social factors and speculative Bolsonaro's political victory in 2018-19 accelerated the price decline (Federación Nacional de Cafeteros, 2017,2018). This event occurred until July 2020 as a market lag of the high volatility in the New York quotation. The effect of the exchange rate COP/USD and the fall in economic dynamics increased the devaluation effect in Colombia.

In the last (sixth period), the risk premium shows that there is a change in agents' expectations, having values of the forward contracts below the Spot prices determined by the international coffee market, modifying the C contracts by the expectations of lower production due to world health conditions and adverse weather quality (Federación Nacional de Cafeteros, 2020, 2021b).

Hedging model with discrete quadratic optimisation

The static risk coverage (10) and (11) shows two results. The independent case shows the hedging without the correlation between the price of coffee production and the weather index; and the second is the general case considers the correlations between local prices, quantities, and weather index.

Independent case

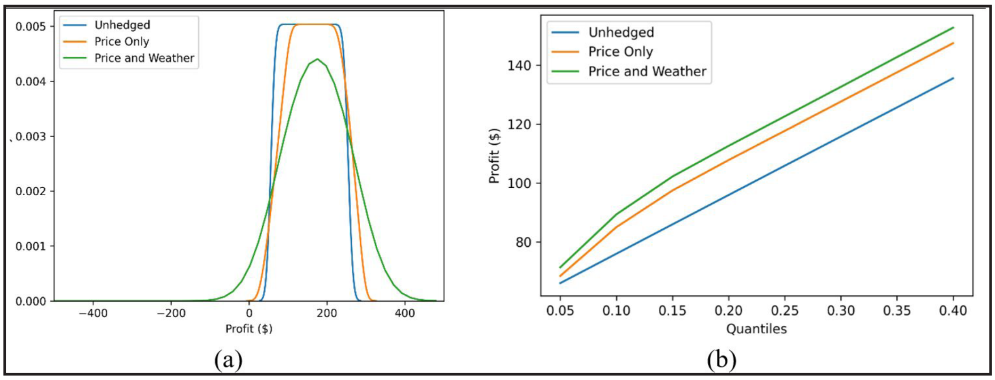
For a discrete solution in an independent case, Table 4 shows the parameters the distributions operate in (10). The correlation levels between price and quantity are inverse expected in market terms. Concerning the correlation between coffee quantities and climate can be explained by extreme climate phenomena where high levels of rainfall or drought alter the coffee quantities.

Table 5 shows the distribution parameters function and the measurement of coffee prices; the correlation factors between prices, quantities and the weather factor are negative, explaining the price will increase if coffee production is lower.

ψ:	$log(P_l) \sim N(2.07, 0.14^2)$	$q \sim N(1038.34, 218.85^2)$	$w \sim N(26.38, 0.78^2)$
	$Cor(log(P_l),q) = -0.35$	$Cor(w,q) = -0.34$	$Cor(w, log(P_l)) = 0$
ϕ:	$log(P_l) \sim N(1.92, 0.17^2)$	$w \sim N(26.78, 0.89^2)$	$Cor(w, log(P_l)) = 0$

Source: own calculations based on data from Bloomberg (2023)

Table 4: Fitting parameters for the optimisation of the independent case.



Source: own elaboration based on data from Bloomberg (2023)

Figure 4: Distribution of profits in the independence case for different strategies: no hedging, price only and price plus weather. (a): profit density distribution, (b): profit quantiles.

%	No hedge	Price only	Price and Weather
5	66.055	68.491	71.414
10	76.021	85.034	89.369
15	85.982	97.469	102.202
20	95.93	107.776	112.594
25	105.862	117.672	122.597
30	115.758	127.598	132.603
35	125.621	137.503	142.687
40	135.502	147.397	152.663

Source: own elaboration based on data from Bloomberg (2023)

Table 5. Profits in the independent case for coffee price hedging.

The weather effect affects production when it is extreme, explaining the conditions of the last three years of the series. Figure 4(a) shows the density distribution of profits, which due to the characteristics of contracts with expectations with forward contracts above local prices, the application of weather identifies risk effects on profits making the series more concentrated. Figure 4(b) shows the improvement of the agent's utility function when price and weather hedging is applied, obtaining better profits in using a forward contract. including the payoffs resulting of the hedging claim.

General case

Table 6 shows the relationship between spot prices and weather is inversely proportional. When the weather has extreme effects, like warm months from March to June (El Niño phenomenon), prices have low market expectations, and for the La Niña phenomenon, the price increased due to a shortage of rainfall.

Table 7 and Figure 5 show the direct correlation between price and weather, such as suitable options in the strategy reflecting higher levels of portfolio utility.

Applying the general case adds the correlation between local price and weather; in the independent case, this value is zero. In the general case, the local price and weather relationship is negative; the hedge portfolio has a similar effect to the independent case; generating this hedge gives better gains than strictly analysing price, weather, and no hedge, with the best result being the price and weather application of hedging (Table 7).

ψ:	$log(P_l) \sim N(2.07, 0.14^2)$	$q \sim N(1038.34, 218.85^2)$	$w \sim N(26.38, 0.78^2)$
	$Cor(log(P_l),q) = -0.35$	$Cor(w,q) = -0.34$	$Cor(w, log(P_l)) = -0.30$
ϕ:	$log(P_l) \sim N(1.92, 0.17^2)$	$w \sim N(26.78, 0.89^2)$	$Cor(w, log(P_l)) = -0.46$

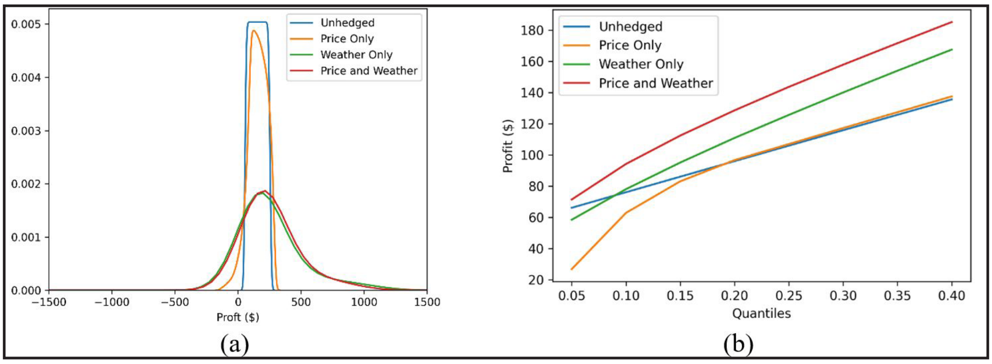
Source: own calculations based on data from Bloomberg (2023)

Table 6: Fitting parameters for the general case optimisation.

%	Price only	No hedge	Weather Only	Price and Weather
5	26.724	66.055	58.38	71.347
10	62.777	76.021	77.989	94.135
15	83.005	85.982	95.054	112.326
20	96.593	95.93	110.812	128.483
25	106.865	105.862	125.562	143.525
30	117.119	115.758	139.947	157.747
35	127.275	125.621	153.87	171.518
40	137.402	135.502	167.417	185.085

Source: own elaboration based on data from Bloomberg (2023)

Table 7: Profits in the general case for coffee price hedging.



Source: own elaboration based on data from Bloomberg (2023)

Figure 5: Distribution of profits in the general case for different strategies: No hedging, price only, weather only, and price and weather. (a): profit density distribution, (b): profit quantiles.

Conclusion

The study measures the climate effect (Oceanic Niño Index) on the price of coffee in Colombia through two methodologies; i) the structural change on forward risk premium (FRP) and ii) risk hedging through a discrete optimisation with the climate effect as an exogenous variable explains the price and production of the asset between April 2016 and January 2023.

For the development process, first, we identify the Forward Risk Premium with the Spot Price (Local Coffee Price) and the market price; the result of FRP shows a derivative behaviour above the market price until 2020 passing this year, the market expectations change leading higher prices than the agreed futures. Studying the price behaviour, we use structural change tests to identify five moments of change in the series, allowing us to understand the strong dependence of the climatic variable on market expectations; both the market reports and the climatic moments identified coincide with the spot prices changes when a climate phenomenon (Niño or Niña) also changes.

Using the last information, we apply as a climate variable by the ONI index (Oceanic Niño Index 3.4) in a discrete quadratic optimisation hedging portfolio, the results show the correlations of price, quantities, and climate are inverse, the strict relationship with price and climate (independent case), as the relationship between ONI, local price, and quantity (general case) has better profit results when including the design rather than not.

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References

[1] Álvarez, M., Luján, G. and Pantoja, J. (2019) "Instrumentos financieros derivados del clima como herramienta de cobertura en la industria bananera del Urabá antioqueño", Magister Thesis, EAFIT, Medellín. [Online]. Available: https://repository.eafit.edu.co/handle/10784/13564 [Accessed: May 10, 2023]. (In Spanish).

[2] Bai, J. and Perron, P. (1998) "Estimating and Testing Linear Models with Multiple Structural Changes", *Econometrica,* Vol. 66, No. 1, pp. 47-78. E-ISSN 1468-0262, ISSN 0012-9682. DOI 10.2307/2998540.

[3] Barrios, G., Galván, O., Pérez, F., Sangerman, D. M. and García, R. (2022) "Price hedging for coffee, using the futures market", *Revista Mexicana de Ciencias Agrícolas*, Vol. 13, No. 6, pp. 1147-1154. ISSN 2007-0934. DOI 10.29312/remexca.v13i6.3313.

[4] Bessembinder, H. and Lemmon, M. (2007) "Equilibrium Pricing and Optimal Hedging in Electricity Forward Markets Equilibrium Pricing and Optimal Hedging in Electricity Forward Markets", *The Journal Finance*, Vol. 57, No. 3, pp. 1347-1382. E-ISSN 1540-6261. DOI 10.1111/1540-6261.00463.

[5] Cárcamo, U. and Franco, L. (2012) "Una aproximación a la estimación de rendimientos de conveniencia y precios teóricos de futuros para commodities agropecuarios en Colombia", *Cuadernos de Administración,* Vol. 25, pp. 141-173. ISSN 0120-4645, E-ISSN 2256-5078. DOI 10.11144/Javeriana.cao25-44.aerc. (In Spanish).

[6] Čermák, M., Malec, K. and Maitah, M. (2017) "Price Volatility Modelling – Wheat: GARCH Model Application", *AGRIS on-line Papers in Economics and Informatics*, Vol. 9, No. 4, pp. 15-24. ISSN 1804-1930. DOI 10.7160/aol.2017.090402.

[7] Chen, H. and Ryan, J. K. (2023) "Optimal specialty crop planning policies with yield learning and forward contract", *Production and Operations Management*, Vol. 32, No. 2, pp. 359-378. ISSN 1059-1478. DOI 10.1111/poms.13842.

[8] Chow, G. (1960) "Tests of equality between sets of coefficients in two linear regressions", *Econometrica,* Vol. 28, No. 3, pp. 591-605. E-ISSN 1468-0262, ISSN 0012-9682. DOI 10.2307/1910133.

[9] Federación Nacional de Cafeteros de Colombia (2016) "*Comportamiento de la Industria Cafetera Colombiana 2016*", Bogotá, Colombia. [Online]. Available: https://federaciondecafeteros.org/static/files/Informe_Industria_2016.pdf [Accessed: May 10, 2023]. (In Spanish).

[10] Federación Nacional de Cafeteros (2017) "*Comportamiento de la Industria Cafetera Colombiana 2017*", Bogotá, Colombia. [Online]. Available: https://federaciondecafeteros.org/static/files/Informe_Industria_2017.pdf [Accessed: May 10, 2023]. (In Spanish).

[11] Federación Nacional de Cafeteros (2018) "*Comportamiento de la Industria Cafetera Colombiana 2018*", Bogotá, Colombia. [Online]. Available: https://federaciondecafeteros.org/app/uploads/2019/10/Informe_de_la_Industria_Cafetera_20182.pdf [Accessed: May 10, 2023]. (In Spanish).

[12] Federación Nacional de Cafeteros (2020a) "*Informe de Gestión 2021*", Bogotá, Colombia. [Online]. Available: https://federaciondecafeteros.org/wp/listado-publicaciones/informe-de-gestion-2020/ [Accessed: May 10, 2023]. ISSN 2711-3728. DOI 10.38141/10793. (In Spanish).

[13] Federación Nacional de Cafeteros (2020b) "Informe del gerente al congreso nacional de cafeteros", *88 Congreso Nacional De Cafeteros,* Bogotá, Colombia. [Online]. Available: https://federaciondecafeteros.org/app/uploads/2022/09/2.Informe-del-Gerente-al-88-Congreso-Nacional-de-Cafeteros-Virtual.pdf [Accessed: May 10, 2023]. (In Spanish).

[14] Federación Nacional de Cafeteros (2021a) "Informe del Gerente General", *89 Congreso Nacional de Cafeteros Virtual*, Bogotá, Colombia. [Online]. Available: https://federaciondecafeteros.org/wp/category/nacional/89-congreso-nacional-de-cafeteros-virtual/ [Accessed: May 10, 2023]. (In Spanish).

[15] Federación Nacional de Cafeteros (2021b) "*Informe de Gestión 2021*", Bogotá, Colombia. [Online]. Available: https://federaciondecafeteros.org/app/uploads/2022/05/IG-2021_Digital.pdf [Accessed: May 10, 2023]. ISSN 2711-3728. DOI 10.38141/10793. (In Spanish).

[16] Garcia, I. (2003) "Análisis y predicción de la serie de tiempo del precio externo del café colombiano utilizando redes neuronales artificiales", *Universitas Scientiarum*, Vol. 8, pp. 45-50. [Online]. Available: http://hdl.handle.net/10554/31210. [Accessed: April 23, 2023]. E-ISSN 2027-1352, ISSN 0122-7483.

[17] Greene, W. H. (2008) "*Econometric Analysis*", 8th ed., Pearson/Prentice Hall, New York. ISBN 10 0134461363, ISBN 13 978-0134461366.

[18] Hazell, P. (2000) "*Could futures markets help growers better manage coffee price risks in costa rica?*". 42 p. [Online]. Available: https://ageconsearch.umn.edu/record/16057/ [Accessed: April 23, 2023]. DOI 10.22004/ag.econ.16057.

[19] Jenkins, M. and Barbosa, F. (2020) "The specialty coffee trading company (TSCT): future and option contracts", *Emerald Emerging Markets Case Studies,* Vol. 10, No. 2, pp. 1-18. DOI 10.1108/EEMCS-04-2020-0122.

[20] Johnson, L. L. (1957) "Price instability, hedging, and trade volume in the coffee futures market". *Journal of Political Economy,* Vol. 65, No. 4, pp. 306-321. E-ISSN 1537-534X, ISSN 0022-3808. DOI 10.1086/257937.

[21] Läderach, P., Ramirez–Villegas, J., Navarro-Racines, C., Zelaya, C., Martinez–Valle, A. and Jarvis, A. (2017) "Climate change adaptation of coffee production in space and time", *Climatic Change*, Vol. 141, pp. 47-62. E-ISSN 1573-1480, ISSN 0165-0009. DOI 10.1007/s10584-016-1788-9.

[22] Longstaff, F. A. and Wang, A. W. (2004) "Electricity Forward Prices: A High-Frequency Empirical Analysis", *Journal of Finance,* Vol. 59, No. 4, pp. 1877-1900. E-ISSN 1540-626. DOI 10.1111/j.1540-6261.2004.00682.x.

[23] Makkonen, A., Vallström, D., Uddin, G. S., Rahman, M. L. and Haddad, M. F. C. (2021) " The effect of temperature anomaly and macroeconomic fundamentals on agricultural commodity futures returns", *Energy Economics*, Vol. 100. p. 105377. E-ISSN 1873-6181, ISSN 0140-9883. DOI 10.1016/j.eneco.2021.105377.

[24] Martins, E., De Oliveira, L. E., Santos, L. P., De Mendonça, M. J. and de Souza, S. P. (2015) "*Influência das condições climáticas na produtividade e qualidade do cafeeiro produzido na região do Sul de Minas Gerais*". [Online]. Available: http://www.sbicafe.ufv.br:80/handle/123456789/8153 [Accessed: April 23, 2023]. (In Spanish).

[25] Nhung, N. T., Ngan, N. N., Hong, T. T. and Cuong, N. D. (2020) "Hedging with commodity futures: evidence from the coffee market in Vietnam", *Investment Management and Financial Innovations,* Vol. 17, pp. 61-75. E-ISSN 1812-9358, ISSN 1810-4967. DOI 10.21511/imfi.17(4).2020.06.

[26] Null, J., CCM (2023) "*El Niño and La Niña Years and Intensities*", [Online]. Available: https://ggweather.com/enso/oni.htm (accessed 3.12.23) [Accessed: Dec. 3, 2022].

[27] Oum, Y., Oren, S. (2009), "VaR Constrained Hedging of Fixed Price Load-Following Obligations in Competitive Electricity Markets", *Risk and Decision Analtsis*, Vol. 1, No. 1, pp. 43-56. E-ISSN 1875-9173, ISSN 1569-7371. DOI 10.3233/RDA-2008-0005.

[28] Paes de Camargo, M. B. (2010) "The Impact of Climatic Variability and Climate Change on Arabic Coffee Crop in Brazil", *Bragantia,* Vol. 69, No. 1, pp. 239-247. ISSN 1678-4499. DOI 10.1590/S0006-87052010000100030.

[29] Pokorná, I. and Smutka, L. (2010) "What is the structure of the coffee market: Can the real poor benefit from the coffee trade?", *Agris On-Line Papers in Economics and Informatics*, Vol. 2, No. 2, pp. 27-37. ISSN 1804-1930.

[30] Pantoja, J. (2012) "Modelling risk for electric power markets", *Revista Innovar Journal*, Vol. 22, pp. 51-66. E-ISSN 2248-6968, ISSN 0121-5051.

[31] Pantoja-Robayo, J. and Vera, J. C. (2020) "Static hedging of weather and price risks in electricity markets", O*ptimization and Engineering,* Vol. 22, pp. 2779-2799. E-ISSN 1573-2924, ISSN 1389-4420. DOI 10.1007/s11081-020-09581-0.

[32] Pham, Y., Reardon-Smith, K., Mushtaq, S. and Cockfield, G. (2019) "The impact of climate change and variability on coffee production: a systematic review", *Climatic Change*, Vol. 156, pp. 609-630. E-ISSN 1573-1480, ISSN 0165-0009. DOI 10.1007/s10584-019-02538-y.

[33] Ravi, A., Praveen, T. and Anjum, A. (2022) "View of Derivatives and Price Risk Management: A Case of Indian Commodity Cotton Futures and Spot Prices in India", *Journal of Positive School Psycology*, Vol. 6, No. 6, pp. 9391-9397. ISSN 2717-7564.

[34] Riaño, J. (1997) "El mercado de futuros y la volatilidad del precio internacional del café", *Ensayos Sobre Economía Cafetera*, Vol. 13, pp. 83-96. ISSN 2248-8731. (In Spain).

[35] Rodríguez, A. and Melgarejo, M. (2020) "Identification of Colombian coffee price dynamics", *Chaos*, Vol. 30, No. 1, p. 013145. ISSN 1054-1500. DOI 10.1063/1.5119857.

[36] Tröster, B. and Gunter, U. (2022) "*Trading for speculators: The role of physical actors in the financialization of coffee, cocoa and cotton value chains*", ÖFSE Working Paper No. 68. [Online]. Available: http://hdl.handle.net/10419/258998 [Accessed: April 23, 2023].

[37] Tucker, C. M., Eakin, H. and Castellanos, E. J. (2010) "Perceptions of risk and adaptation: Coffee producers, market shocks, and extreme weather in Central America and Mexico", *Global Environmental Change,* Vol. 20, No. 1, pp. 23-32. ISSN 1872-9495, ISSN 0959-3780. DOI 10.1016/j.gloenvcha.2009.07.006.

[38] Vijayakumar, A. (2022) "Impact of the US Dollar Index and Crude Oil on Prices of Arabica and Robusta Varieties of Indian Coffee. Business Perspectives and Research", *Business Perspectives and Research*. E-ISSN 2394-9937, ISSN 2278-5337. DOI 10.1177/22785337221077399.