

Revisión de literatura

Analysis of the Determinants of the Precio Interno de Referencia del Cafe in Colombia Using VAR and Quantile Models

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Coffee has been a fundamental pillar in the economic, social, and institutional development of Colombia, acting as one of the main drivers of industrialization and economic growth throughout much of the 20th century (Losada & Yacué, 2015). This industry has not only contributed to the economic stability of the country through exports but has also become a social pillar by providing income to more than 540,000 families and generating approximately one in every three rural jobs in Colombia (Saenz et al., 2021). Its relevance extends beyond the agricultural sector, as it drove the construction of important transportation infrastructure, such as railroads and highways, facilitating the integration of domestic markets and promoting regional development (Losada & Yacué, 2015).

Furthermore, the coffee sector facilitated the establishment of a unified institutional framework through the Federación Nacional de Cafeteros (FNC), an organization that, since 1927, has led efforts to protect producers and promote Colombian coffee as a premium product in international markets (Losada & Yacué, 2015). However, despite its historical and economic importance, the sector currently faces major challenges associated with the volatility of international prices and the effects of climate change. In this context, coffee remains an emblematic industry that stimulates household consumption and represents an essential foundation of rural economic identity in Colombia (Cano Sanz et al., 2012).

In this scenario, the income of producers largely depends on the Precio Interno de Referencia del Café (PIRC), published daily by the FNC. This price serves as a reference value that guides the purchase of dry parchment coffee per 125 kg loads and constitutes the primary transmission mechanism between the international market and the local income received by coffee growers (Oficina de prensa, 2026). Nevertheless, the sustainability of coffee income is influenced by a complex interaction of variables, including the price of the Contrato C on the New York Stock Exchange, the exchange rate, and quality premiums, factors that expose producers to recurring episodes of volatility (Pinzón, 2025).

Given this scenario, academic literature has emphasized the importance of origin differentiation as a strategy to prevent product homogenization, as well as the need to implement predictive tools and risk management mechanisms capable of mitigating market asymmetries and addressing the adverse effects of climate change (Cano Sanz et al., 2012).

To understand the macroeconomic variables that affect the PIRC, we present a brief description of the main factors involved in its formation:

- **Contrato C:** The Contrato C of the New York Stock Exchange represents the main benchmark used to determine the international price of mild Arabica coffee, a category that includes Colombian coffee (ICE Future u.s., s.f.). This price is traded in US cents per pound and is characterized by high volatility, driven by global supply and demand dynamics as well as climatic factor in producing countries, particularly Brazil. In addition, financial speculation in the futures markets significantly influences the formation of this price. Although Contrato C serves as an international standard, there is often a disconnect between this market price and the real production costs faced by local coffee producers (Hazel Boydell, 2018).
- **Exchange rate (TRM):** The TRM is a key factor in the formation of the PIRC because coffee is traded internationally in US dollars, while producers receive payments in Colombian pesos (COP). This variable reflects the number of COP paid for each US dollar, meaning that a devaluation of the COP can increase the PIRC even when international prices remain stable (Superintendencia Financiera de Colombia, 2026). In contrast, periods of revaluation tend to negatively affect the profitability of coffee-growing families by reducing income received in local currency (Uribe Medina, 2011).
- **Prima de calidad:** The quality premium, also known as the differential, refers to the additional value attributed to Colombian coffee due to its reputation, origin, and availability on the international market (Pinzón, 2025). Colombia stands out as the only producer under Contrato C that consistently trades at a premium, while other origins are commonly traded at “at par” or at a discount (Venegas Loaiza, 2019). This differential fluctuates according to market conditions and reflects the recognition of the quality of Colombian coffee compared to other mild coffee varieties (Lozano, 2002).

Overall, this pricing structure means that coffee income is exposed to supply and demand shocks in the international market, exchange rate fluctuations resulting from domestic and external macroeconomic conditions, as well as financial dynamics that influence price formation in futures markets. Consequently, the PIRC incorporates almost immediately changes stemming from global scenarios that are beyond the direct control of producers (Mosquera Lugo, 2020).

Historically, the regulation of global coffee prices was determined by the Acuerdo Internacional del Café (AIC), a quota system designed to maintain high and relatively stable prices through supply control (Lanzetta, 1991). However, after the collapse of the quota agreement in 1989, the coffee

market experienced a liberalization process that transferred price management to the private sector and eliminated, in most producing countries, direct government controls over domestic prices (Pinzón, 2025). This transition marked the beginning of a period characterized by greater volatility, in which prices became mainly dependent on supply and demand dynamics within a free-market environment.

Historically, global coffee prices were regulated by the International Coffee Agreement (AIC), a quota system designed to maintain high and relatively stable prices through supply control (Lanzetta, 1991). However, after the dissolution of the quota agreement in 1989, the coffee market underwent a process of liberalization that transferred price management to the private sector and eliminated, in most producing countries, direct government controls over domestic prices (Pinzón, 2025). This transition marked the beginning of a period characterized by greater volatility, in which prices began to depend primarily on supply and demand dynamics in a free-market environment.

Currently, the primary benchmark for forming the international price of Arabica coffee is Contrato C of the New York Stock Exchange (ICE) (ICE Future u.s., s.f.). This mechanism has encouraged the increasing financialization of the coffee market, allowing institutional capital to enter through financial derivatives and index funds. A critical aspect of this dynamic is that the volume of futures contracts traded has exceeded global physical coffee production by more than 21 times, creating a structural disconnect between prices observed on the exchange and the actual income received by coffee farmers on their farms (Suárez Rodríguez et al., 2026).

In response to this unstable environment, different coffee-producing countries have implemented strategies aimed at protecting and stabilizing coffee income. Brazil, for example, has used financial instruments such as put options, while Costa Rica and El Salvador have established emergency funds to compensate producers during periods of low prices (Wanzala & Obokoh, 2025). In the Colombian case, mechanisms such as the Contrato de Protección de Precios (CPP) and the Mecanismo de Compensación del Ingreso Cafetero (MeCIC) have been developed to guarantee a minimum level of income during sharp declines in the international market or significant increases in production costs (Pinzón, 2025).

Globally, product differentiation has also been promoted as a strategy to avoid product homogenization and command higher prices in the international markets. These initiatives include the promotion of specialty coffees, organic certifications, and Fair-Trade labels, which seek to

recognize premiums associated with quality, sustainability, and social responsibility (Cano Sanz et al., 2012). Furthermore, some sectors of the industry have proposed abandoning contrato C as the only benchmark for price formation, suggesting alternative models based on transparency and real production costs. Under this approach, long-term fixed contracts between producers and coffee roasters are promoted to reduce dependence on market speculation (Hazel Boydell, 2018).

Based on this review, it was possible to identify that first analytical approaches were dominated by econometric models designed to measure volatility and the relationship between market variables. In the Colombian context, Chávez Pinzón & Pardo Calderón identified that the exchange rate and the Contrato C are key determinants in the formation of domestic coffee prices, while Estrada Blandón demonstrated that scenario simulation allows for the measurement of financial risk exposure in exporting companies within the sector. Similarly, international studies such as those conducted by Chaovanapoonphol et al. and Wanzala & Obokoh show that coffee price volatility presents persistence and asymmetric responses, confirming that market movements do not follow a linear behavior.

In this regard, analysis of the coffee market in Colombia and internationally, has evolved from the use of traditional linear models toward more advanced artificial intelligence techniques and stochastic simulations aimed at capturing the complexity and high volatility of the sector. In Colombia, several studies have employed Vector Autoregressive (VAR) models to identify the dynamic impact of international price shocks on macroeconomic variables such as GDP, household consumption, and investment (Cano Sanz et al., 2012). In a complementary way, Vector Error Correction Models (VECM) have been used to analyze long-term structural changes in the participation of coffee within the gross domestic product, considering factors related to market liberalization and legal reforms (Saenz et al., 2021).

Meanwhile, for forecasting PIRC in the short- and medium-term, the literature highlights the use of time series models such as ARIMA (0,1,0), which has demonstrated high accuracy in projecting upward trends in the price of dry parchment coffee in Colombia. However, these models present higher levels of uncertainty as the forecasting horizon becomes longer (Pinzón, 2025). Likewise, in the field of financial risk management for exporting companies, Monte Carlo Simulation has been implemented as a multivariate technique capable of modeling thousands of possible scenarios and estimating the probability that PIRC may fall below production costs or exceed certain expected profitability levels (Estrada Blandón, 2020).

Internationally, the complexity of the futures market and the growing financialization of the sector have driven the development of tools focused on the analysis of financial speculation. In this context, indicators such as the Net Positioning Index (NPI) have been empirically validated through Threshold Regression and Threshold Autoregressive (TAR) models, which allows to capture how extreme speculative positions widen the gap between exchange prices and physical (spot) prices (Suárez Rodríguez et al., 2026). Similarly, to understand price transmission and market efficiency, several studies have employed cointegration and Granger Causality tests, linking international prices with retail prices in the main consumption centers (Cifuentes & Nates, 2016).

In recent years, Machine Learning techniques have started to outperform traditional linear methods in predicting global coffee prices. Models such as Random Forest (RF), XGBoost, and Gradient Boosting have demonstrated a greater capacity to integrate climate variables, such as the El Niño phenomenon, together with production data from leading countries such as Brazil and Colombia (Byrareddy et al., 2026). As a result, these approaches have improved the accuracy of price forecasts in an environment characterized by high volatility and uncertainty.

In addition, recent literature has explored advanced neural network architecture designed to capture complex patterns and nonlinear dependencies in the dynamics of the coffee market. Among the main methodologies are:

- Extreme Learning Machines (ELM): models that offer lower computational cost and better performance than the Multilayer Perceptron (MLP) in the estimation of Arabica and Robusta coffee price (Deina et al., 2022).
- Long Short-Term Memory (LSTM) y CNN-BLSTM: architectures used to capture deep temporal dependencies and complex patterns associated with price formation, especially in specialty coffee markets (Pinto Rodriguez et al., 2025).
- Modelos de volatilidad (GARCH, EGARCH y TARCH): essential tools for analyzing the leverage effect, a phenomenon in which negative shocks or price declines generate more persistent volatility than positive shocks in producing countries (Wanzala & Obokoh, 2025).

Overall, advances in econometric and computational modeling, which have evolved from traditional linear models such as ARIMA and Exponential Smoothing (ES) toward techniques based on artificial intelligence and advanced neural networks, have made significant contributions to the coffee sector. These tools have enabled a deeper understanding of price volatility and cycles, facilitating the design of more robust risk management and financial planning strategies. Likewise, they have improved the capacity of producers and exporters to anticipate adverse scenarios and short-term climate shocks.

However, the literature also identifies important gaps and structural limitations. Among these, there remains limited integration between advanced analytical models and methodologies specifically applied to the analysis of the PIRC in Colombia. In addition, information asymmetry continues to pose a critical obstacle, since many of these sophisticated models are not easily accessible to small coffee producers. As a result, producer vulnerability remains due to the structural disconnect between prices observed in financial markets and the reality of production costs.

In this context, the following table presents a summary of the literature reviewed, including the main methodologies, contributions, and research gaps identified in previous studies.

Categoría	Estudios representativos	Metodologías principales	Principales aportes	Vacíos identificados
Volatilidad y especulación financiera	Suárez-Rodríguez et al. (2026); Wei Yao & Alexiou (2024); Wanzala & Obokoh (2025)	TVP-VAR, TAR, Threshold Regression, modelos GARCH	Evidencian persistencia de volatilidad, financiarización del mercado y efectos de la especulación sobre los precios del café.	Limitada integración entre especulación financiera, ingresos reales del productor y análisis no lineales.
Modelos econométricos tradicionales	Cano Sanz et al. (2012); Saenz et al. (2021); Alonso & Estrada (2016); Díaz-Pinzón (2025)	VAR, VECM, Cointegración, Granger, ARIMA	Identifican determinantes macroeconómicos del precio del café y efectos dinámicos sobre PIB, consumo e inversión.	Escasa incorporación de variables climáticas, asimetrías y dinámicas estructurales complejas.
Gestión del riesgo y simulación financiera	Estrada Blandón (2020); Haldar & Damodaran (2022)	Simulación de Montecarlo, ARDL, valoración financiera	Desarrollo de herramientas para cobertura de riesgo, contratos forward y análisis de transmisión de precios.	Poca evidencia sobre impacto financiero en pequeñas y medianas empresas exportadoras.
Inteligencia artificial y Machine Learning	Byrareddy et al. (2026); Deina et al. (2022); Pinto-Rodriguez et al. (2025)	Random Forest, XGBoost, Gradient Boosting, ELM, LSTM, CNN-BLSTM	Mejoran la precisión predictiva integrando variables climáticas y patrones no lineales.	Necesidad de integrar variables cualitativas, especulación financiera y análisis híbridos aplicados al PIRC.
Institucionalidad	Losada & Yacué (2015);	Revisión	Explican el papel de las	Insuficiente análisis

y estructura del mercado cafetero	Lanzetta (1991); Lozano (2002)	documental, análisis histórico y econométrico	instituciones, primas de calidad y liberalización del mercado cafetero.	sobre desigualdades regionales y comportamiento de primas en mercados diferenciados.
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As a result, the following research question appears: How does the Internal Reference Price for Coffee (PIRC) in Colombia respond to its main economic determinants, and how does the effect of these factors vary under extreme risk scenarios?

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