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Coffee prices: Mexican, Colombian and future quotes, a statistical cointegration analysis

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ABSTRACT

Objective: to estimate an econometric model for exports price dynamics of Mexican Arabica coffee with the joint influence of Colombian Arabica spot prices, and Arabica coffee futures from the New York Stock Exchange.

Design/Methodology/Approach: we applied unit root tests, cointegration analysis, estimation of a vector model with error correction, Granger's sense causality tests, impulse-response function analysis, and variance decomposition analysis.

Results: results made evident the dynamic relationship between the long-term prices of Colombian Arabica and Mild Arabica under the temporary control of futures quotes.

Limitations/Implications of the study: the estimated model can be expanded by incorporating financial, climate, and policy variables. However, the lack of information available with the same periodicity makes it difficult to develop more robust models.

Findings/Conclusions: the volatility inherent in coffee prices was corroborated, which suggests the importance of properly understanding and modeling these fluctuations in the market. This study provides a deeper insight into the interconnectedness among the various determinants of the coffee market, highlighting the need for effective risk management strategies for participants in this market.

Keywords: vector error correction model (VECM), unit root, cointegration analysis.

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INTRODUCTION

According to the report of the International Trade Centre (ITC, 2021), the International Coffee Organization (ICO, 2023) and Tuyến *et al.* (2020), coffee is one of the most traded tropical crops in the world. Coffee production involves more than 52 producing countries to supply global demand.

Within the coffee production chain, one of the variables of greater interest corresponds to the prices of this aromatic product. Two major varieties of coffee are distinguished in the world: Arabica and Robusta (Otero and Milas, 2001; Tuyến *et al.*, 2020). Derived from this differentiation, the International Coffee Organization registers four types of prices: Colombian Arabica, Mild Arabica, Brazilian beans and Robusta (Figueroa-Hernández *et al.*, 2019).

To study the dynamism of coffee prices, various studies have used bivariate and multivariate models. Some examples of those independent studies are, Otero and Milas (2001); Frey and Manera (2007); Hussien (2015); Jaramillo-Villanueva and Benitez-García (2016); Tuyến *et al.* (2020); Babu and Muniyappa (2021); among others. Within the econometric models used, the following are more relevant, Vector Autoregressive models (VAR), vector error correction models (VECM), cointegration analysis, impulse-response functions, variance decomposition analysis, Granger's sense causality, analysis of cycles and structural changes. Each of them is used to investigate dynamics of price transmission; determinants of exports and demand; asymmetry and dynamics of production costs; as well as their relationships with financial and economic variables affecting coffee prices.

In Mexico, there is not much research on coffee prices where multivariate time series models such as VAR, VECM or cointegration analysis are used. One research under this approach was developed in Mexico by Jaramillo-Villanueva and Benitez-García (2016), who investigated the transmission of international prices to the domestic prices paid to the producer.

On that background, this study aimed to develop a cointegration analysis and the definition of a VEC model to capture the joint price dynamics of Arabica coffee, to deduce the dynamic relationships present among the main prices of this aromatic bean, which in the end rule over Mexican coffee exports. So, the objective was to estimate an econometric model fed by three time-series which correspond to spot and futures prices for Arabica coffee types, with monthly records from 1990 to 2019.

MATERIALS AND METHODS

To form the data vectors, time series were compiled from two different sources, International Coffee Organization (ICO) for spot prices and the investing.com website for futures quotes on the New York Stock Exchange. Time series from the ICO (2023) correspond to the monthly prices of Mild Arabica beans (PM_t), the group to which Mexican Arabica coffee belongs, and the monthly prices of Colombian Arabica beans (PU_t). Meanwhile, the time series from the *investing.com* site correspond to the average monthly quotes of futures contracts listed on the New York Stock Exchange (PW_t). For performing the statistical analyses of this research, the analytical tools integrated in the software Econometric Views v. 12 were used (EViews 12).

A statistical analysis was developed to identify the presence of unit root in the three time-series. Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) were applied to test null hypothesis (H_0) that there is a unit root in each of the time series, against the alternative hypothesis that there is no such root.

Taking into account the nature of the time series, spot and futures prices, a vector autoregressive model was proposed with endogenous variables, corresponding to the spot prices of Colombian Arabica and Mild Arabica beans, because dynamics of those develop at spot markets. On the other hand, futures were considered as an exogenous variable, since they are defined in advance by the participants of the exchange, in which speculation plays an important role.

To define the system of dynamical equations we followed the notation of VAR-X models presented in other research (Espinosa and Vaca, 2014; Nicholson *et al.*, 2017):

$$\begin{bmatrix}\Delta PM_t\\ \Delta PU_t\end{bmatrix}=\begin{bmatrix}\theta_1\\ \theta_2\end{bmatrix}=\begin{bmatrix}\varnothing_{11}^1 & \varnothing_{12}^1\\ \varnothing_{21}^1 & \varnothing_{22}^1\end{bmatrix}\begin{bmatrix}\Delta PM\\ \Delta PU\end{bmatrix}_{t-1}+\ldots+\begin{bmatrix}\varnothing_{11}^p & \varnothing_{12}^p\\ \varnothing_{21}^p & \varnothing_{22}^p\end{bmatrix}\begin{bmatrix}\Delta PM\\ \Delta PU\end{bmatrix}_{t-p}+pw_t\begin{bmatrix}\Phi_1\\ \Phi_2\end{bmatrix}+\begin{bmatrix}\varepsilon_{1t}\\ \varepsilon_{2t}\end{bmatrix} \quad (1)$$

The lag order considered in the VAR-X model was a function of the lowest value of five criteria, namely: likelihood ratio (LR), final prediction error (FPE), Akaike information criterion (AIC), Schwarz information criterion (SC) and Hannan-Quinn information criterion (HQ), as indicated by Gebru and Ramakrishna (2018). These criteria for selecting the optimal lag order for a dynamic multivariate system are those usually used in econometric studies involving time series (Gebru and Ramakrishna, 2018; Hamzah *et al.*, 2020).

In order to study the long-term dynamics of the time series, a cointegration vector was estimated. To estimate the cointegration equation, the methodology proposed by Johansen (1988) was followed. In this analysis, the null hypothesis (H_0) that there are maximum r vectors of cointegration was tested against the alternative hypothesis (H_a) that there are more than r vectors of cointegration (Johansen, 1988; Babu and Muniyappa, 2021), where r must be less than the number of endogenous variables of the dynamic system (Engle and Granger, 1987; Johansen, 1994).

With the estimated cointegration equation, a vector with error correction model (VEC) was proposed, in order to generate an econometric model that describes the dynamics of the time series in the short and long term. To identify the causality among the prices of Colombian Arabica and Mild Arabica spot prices and futures, the Granger's sense causality test was applied. Time series were evaluated in pairs with null hypothesis (H_0) that x_t does not cause y_t in the Granger sense, against the alternative hypothesis (H_a) that x_t causes y_t in the Granger's sense.

To synthesize the dynamic structure of the time series, the effects caused by some random shocks of the endogenous variables, on each dependent variable in the VAR-X model were investigated. In the analysis of the impulse-response functions, no random innovations of the exogenous variable of the model were incorporated, according to Brugger and Ortiz (2012). The Cholesky variance decomposition analysis was performed, which allowed isolating the percentage variability of each endogenous variable in the event of a shock in any of the endogenous variables.

RESULTS AND DISCUSSION

According to the results of the unit root test against (ADF) Augmented Dickey-Fuller test and (PP) Phillips-Perron test (Table 1), it was determined that the time series are integrated in the same order since stationarity is achieved in first differences (Table 2). This attribute of the time series is common in the economic and financial series, which are usually (I(1)), this is, they are integrated of order 1 (Granger, 1988; Brugger and Ortiz, 2012).This condition is essential to propose multivariate models which aim to capture the dynamics of stochastic variables (Stock and Watson, 1993; Jordán, 2014).

Time series were adjusted to an autoregressive vector model co-integrated with exogenous variable (VAR-X). This specification differs from some research on coffee, such as Jaramillo-Villanueva and Benitez-García (2016) and Tuyến *et al.* (2020). These discrepancies could be attributed to the difference in the period of analysis and the number of series considered, which are usually bivariate models.

According to the lowest value of these five criteria, Likelihood Ratio (LR), Final prediction error (FPE), Akaike information criterion (AIC), Schwarz information criterion (SC) and Hannan-Quinn information criterion (HQ); it was concluded that the time series under study fit a model with two lags (Table 3).

The cointegration analysis with Johansen's methodology made it possible to observe that both the trace statistic (Table 4) and the maximum Eigenvalue statistic show that there is at least one cointegration vector at a significant level of 5% (Table 5); which agrees with the results of Jaramillo-Villanueva *et al.* (2016). These results confirm, from a statistical point of view, that the model under consideration has the capacity to capture the short- and long-term dynamics of spot prices of Arabica coffees, taking into account the dynamics of futures.

Table 1. Unit root test results with levelled data.

Variable	Augmented Dickey-Fuller			Phillips-Perron			Conclusion
	t-Statistic	tc 5%	Prob.*	t-Statistic	tc 5%	Prob.*	
PM	−2.9553	−3.4229	0.1466	−2.1152	−3.4228	0.535	Unit root
PU	−2.2935	−3.423	0.4359	−2.5854	−3.4228	0.2873	Unit root
PW	−2.9074	−3.4231	0.1614	−2.655	−3.4228	0.2563	Unit root

**p-value* for Augmented Dickey-Fuller and *p-value* for Phillips-Perron. PM: Mild Arabica; PU: Colombian Arabica; PW: future quotes.

Table 2. Unit root test results with data in first differences.

Variable	Augmented Dickey-Fuller			Phillips-Perron			Conclusion
	t-Statistic	tc 5%	Prob.*	t-Statistic	tc 5%	Prob.*	
PM	−10.553	−1.9418	0.0000	−15.6477	−1.9418	0.0000	Stationary
PU	−9.3416	−1.9418	0.0000	−18.9764	−1.9418	0.0000	Stationary
PW	−7.3654	−1.9418	0.0000	−15.6773	−1.9418	0.0000	Stationary

**p-value* for Augmented Dickey-Fuller and *p-value* for Phillips-Perron. PM: Mild Arabica; PU: Colombian Arabica; PW: future quotes.

Table 3. Results in lag length for the Vector Autoregressive model (VAR).

Lag	LR	FPE	AIC	SC	HQ
0	NA	8525.000	14.727	14.749	14.735
1	671.090	1191.500	12.759	12.826	12.786
2	43.4624*	1071.408*	12.653*	12.765*	12.697*
3	7.1675	1073.600	12.654	12.812	12.717
4	2.4471	1091.000	12.671	12.873	12.751

* Minimum value. LR: likelihood ratio; FPE: final prediction error; AIC: Akaike information criterion; SC: Schwarz information criterion; HQ: Hannan-Quinn information criterion.

Table 4. Results of cointegration analysis with trace statistic.

H_0, number of CI vectors	Eigenvalue	Trace statistic	0.05 Critical value	Prob.*
No vectors**	0.7304	464.7	25.872	0.0000
At most 1 vector	0.0355	12.481	12.518	0.0507

* *p-value* of MacKinnon-Haug-Michelis (1999); ** Null hypothesis rejection.

Table 5. Results of cointegration analysis with the maximum Eigenvalue statistic.

H_0, number of CI vectors	Eigenvalue	Max Eigenvalue statistic	0.05 Critical value	Prob.*
No vectors **	0.7304	452.22	19.387	0.0001
At most 1 CI vector	0.0355	12.481	12.518	0.0507

* *p-value* of MacKinnon-Haug-Michelis (1999); ** Null hypothesis rejection.

This latter variable was not considered by Jaramillo-Villanueva and Benitez-García (2016) or by Tuyển *et al.* (2020); however, the inclusion of the dynamics of coffee futures quotes leads to a better modelling between these two linked markets, spot and futures, as it was stated by Babu and Muniyappa (2021).

The linear combination that maintains a long-term equilibrium relationship between the spot price of Colombian Arabica coffees and the spot prices of mild Arabica coffees, such as coffees from Mexico, fits a model with a linear trend and a constant term, according to Equation (2):

$$PM_{t-1} = 107.6943 + 0.076325PU_{t-1} + 0.066254T \quad (2)$$

As we found a cointegration equation between the endogenous variables of the model VAR-X(2) means that the specification and estimation of a error correction model (VEC) is justified (Jordán, 2014), with which it is possible to study the price dynamics in the spot markets of Arabica coffees. Based on the above, the following two equations were estimated:

$$\begin{aligned}\Delta PM_t = &-0.798EC_{(2)} + 0.3015\Delta PM_{t-1} + 0.2021\Delta PM_{t-2} - 0.2351\Delta PU_{t-1} \\ &-0.1226\Delta PU_{t-2} + 0.751PW_t - 90.549\end{aligned} \quad (3)$$

$$\Delta PU_t = -0.928EC_{(2)} + 0.5978\Delta PM_{t-1} + 0.2398\Delta PM_{t-2} - 0.5749\Delta PU_{t-1} - 0.1923\Delta PU_{t-2} + 0.8755PW_t - 105.5853 \quad (4)$$

The notation $EC_{(2)}$ represents equation (2).

Colombian Arabica coffees were found to have a higher adjustment speed compared to Mild Arabica in the long term. This is due to Colombia's level of participation in international Arabica coffee markets, since that is the country with the highest production and marketing of Arabica variety (ICO, 2023). On the contrary, countries producing Mild Arabica coffees have a lower percentage share in international trade. This is the case of Mexico, which reflects in a lower adjustment speed; however, this value is higher than that found by Jaramillo-Villanueva and Benitez-García (2016). Such discrepancies can be attributed to the difference in the period of analysis and the specifications of the model, since those authors developed the analysis only with spot prices. One of the series was adjusted with the producer price index (domestic price), which probably introduced biases, as this was the result of a series that was constructed with interpolations.

The Granger's sense causality test showed that the time series referring to the spot prices of Mild Arabica, Colombian Arabica and Arabica futures coffee prices present a bidirectional causality in the Granger sense. Similar results were reported by Otero and Milas (2001) and Babu and Muniyappa (2021), who stated that precisely in the Arabica coffee market there is this particular situation of bilateral causality between spot and futures prices, unlike what occurs in the Robusta coffee market.

Finally, with the impulse-response function analysis, using the Cholesky decomposition with one-standard-deviation and the variance decomposition analysis over a length of 12 monthly periods (one year), shocks of the endogenous time series in the short term in the face of shocks in each of the variables were identified. From these tests, temporal responses were identified in only three periods (a quarter). In the face of a positive shock in the prices of Colombian Arabica, the price of Mild Arabica presented a negative temporal response for three periods. Whereas in the face of a shock in the spot prices of Mild Arabica, the prices of Colombian Arabica presented a very notable positive temporary response. After the three periods of impact from any random shock in each of the variables, the responses tend to an asymptotic equilibrium (Figure 1).

The variance decomposition of the time series corresponding to the spot prices of Mild Arabica coffees and Colombian Arabica coffees shows that in the face of an innovation in the spot prices of Mild Arabica, the dynamics of the same variable is more than 97% explained throughout the period, with very little influence of the temporary behavior of the spot prices of Colombian Arabica. On the other hand, a random shock in the prices of Colombian Arabica showed a significant variability in the prices of Mild Arabica, which reveals the market power of Colombian Arabica coffees. Despite the great variability of Mild Arabica facing Colombian Arabica shocks, after three quarters, price variations in the dynamic system were observed to be equally distributed (close to 50%).

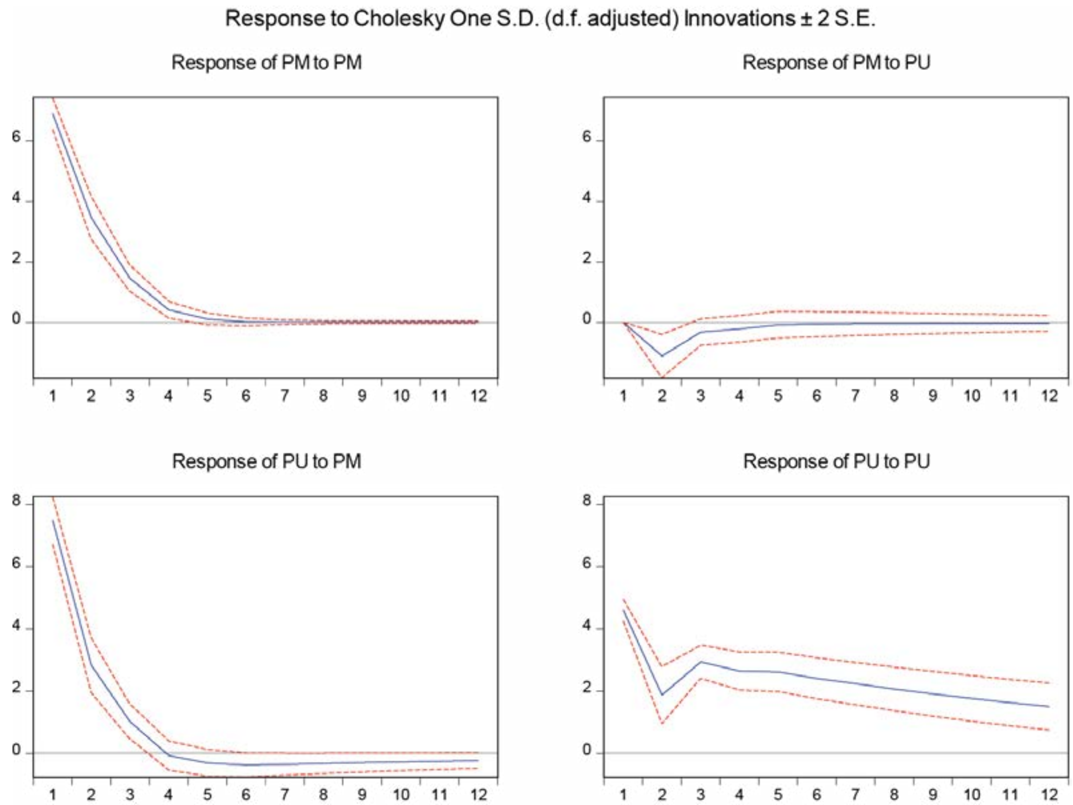

Figure 1. Impulse-Response Functions.

CONCLUSIONS

The spot prices of Colombian Arabica coffee and the spot prices used by Mexico for green coffee exports (Mild Arabica) are closely related in the long term. Sudden changes in any of these prices have only temporary effects, which dissipate over time. This research offers quantitative tools for coffee producers in Mexico to manage risks and thus minimize the losses they frequently face.

A strategic alternative for risk management by domestic producers is the consideration of financial instruments, such as coffee future quotes. In order to reduce the gap between spot prices and futures prices, since it is currently coffee futures that direct the dynamics of spot prices. However, this approach presents significant challenges for the national coffee production sector, especially due to the predominance of smallholdings in that sector.

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