BUFT Journal of Business & Economics (BJBE)
ISSN 2664-9942 (Print)
2025 Volume 6, Pg: 107-116
DOI: https://doi.org/10.58481/BJBE/2507

Econometric Analysis of Potato Production and Pricing Dynamics in Bangladesh: An Application of Distributed Lag Model

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ARTICLE INFO

Article History
Received: March 07, 2025
Accepted: June 03, 2025

Keywords:
Potato Production; Price Dynamics; Distributed Lag Models; Econometric Analysis

JEL Classification:
Q11, Q18, C22, C51, O13

ABSTRACT

Purpose: This study investigates the dynamics of potato production and pricing in Bangladesh over the period 1990–2023.

Methodology: The experiment was carried out by using time series data from Bangladesh Bureau of Statistics (BBS) and FAOSTAT for the empirical analysis. The Koyck distributed lag model is applied to evaluate short-run and long-run effects of pricing on production.

Findings: The findings reveal that the potato production in Bangladesh has been influenced by the lag value of average price formed in the market. The most striking result of the study is the time required for the changes in the potato price in Bangladesh to an effect on potato production of 13.29 years.

Practical Implications: This result indicates that farmers are highly motivated to cultivate this crop, which is primarily grown as a staple. To mitigate price volatility and uncertainty in the potato market, it is essential to promote sustainable potato farming practices and establish an efficient market organization.

Originality/Value: This study adds to the current literature by examining potato production patterns in Bangladesh through an econometric analysis, specifically the Koyck distributed lag model.

Limitations: The study's limitations include the absence of non-price elements including climate change, input prices, and government regulations that also affect output, as well as data limitations that could compromise the accuracy of long-term lag estimations.

1. Introduction

Potatoes are a staple crop and play a critical role in Bangladesh's agricultural economy, contributing significantly to food security and rural livelihoods. Understanding the relationship between potato production and pricing dynamics is essential for policymakers and stakeholders to enhance productivity and stabilize markets. This study employs distributed lag models to analyze these dynamics, offering evidence-based insights into production-price linkages.

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Agricultural activities primarily take place in natural environments, making the sector highly vulnerable to risks and uncertainties. Factors such as unfavorable weather conditions, pest infestations, crop diseases, and natural disasters like floods can significantly reduce agricultural productivity. Additionally, fluctuations in crop prices create further challenges, as farmers often have little control over pricing. In most cases, agricultural product prices are determined by market forces rather than by the farmers themselves. As a result, farmers must accept market prices and plan their production accordingly. These prices are largely influenced by supply and demand dynamics rather than the actual costs of production. In the short term, the supply of agricultural products is relatively inflexible, meaning that farmers cannot quickly adjust production levels in response to market conditions. As a result, demand plays a crucial role in determining the price of agricultural goods.

Agricultural enterprises in Bangladesh are generally small in scale, and farmers often lack strong organizational structures in both input and output markets. Additionally, the overall education level among farmers remains low, contributing to uncertainties in pricing. Due to these challenges, farmers rely on the previous year's prices as a reference when making production decisions. However, this approach can lead to significant fluctuations in both prices and production levels within agricultural markets. This phenomenon is called the Cobweb Theory in economic literature, which is frequently observed in agricultural production and has been widely studied in relation to the interactions between production quantity and price variations.

Due to the structural characteristics of agricultural production, the relationship between production quantity and price can be analyzed using a distributed lag model. In time series regression models, when both current and past values of an independent variable are included, the model is referred to as a distributed lag model (Gujarati, 2001). However, two major challenges arise in such models: multicollinearity and a reduction in degrees of freedom as the number of lagged variables increases. To address these issues, the Koyck model was developed to improve parameter estimation in distributed lag models.

1.1 Background of the Study

Bangladesh is one of the leading potato-producing countries in South Asia. However, price instability poses challenges for farmers and policymakers. Variations in production levels, storage capacity, and transportation costs often contribute to pricing fluctuations. Previous studies have explored price behavior in agricultural markets, but few have applied distributed lag models to assess dynamic effects.

1.2 Objectives of the Study:

The main objective of this study is to examines the dynamics of potato production and pricing in Bangladesh, and the specific objectives are as follows:

- To analyze the short- and long-term relationships between potato production and prices.
- To evaluate the effectiveness of distributed lag models in explaining price dynamics.
- To provide recommendations for improving market efficiency and price stability.

2. Literature Review

Previous studies have emphasized the importance of agricultural price stability in influencing production decisions. Distributed lag models, particularly the Koyck approach, have been widely used to assess the delayed impact of prices on output. Studies by Nerlove (1958) and Gujarati (2004) provide a theoretical foundation for estimating these relationships. However, limited research has focused specifically on Bangladesh's potato sector, leaving a gap this paper seeks to address.

Yurdakul (1998) conducted a study in Turkey to examine the relationship between cotton production and its price over the period of 1985-1997. The study employed the Koyck approach, a distributed lag model used to analyze the delayed effects of price changes on production decisions. By incorporating past price values into the model, the research aimed to capture how farmers adjust their production in response to price fluctuations over time. The findings highlighted the significance of price expectations in shaping agricultural production decisions and contributed to the broader understanding of supply response in the agricultural sector. This study serves as a valuable reference for analyzing similar relationships in other agricultural markets.

Dikmen (2005) conducted a study to examine the relationship between tobacco production and price in Turkey during the period of 1982-2003. The research utilized the Koyck model, a distributed lag approach, to analyze how past price fluctuations influenced production decisions over time. By incorporating lagged price variables, the study provided insights into the delayed response of farmers to price changes. The findings contributed to the understanding of supply elasticity in the tobacco sector and demonstrated the relevance of distributed lag models in agricultural economics. This study adds to the existing literature on price-production dynamics and serves as a reference for further research on agricultural market behavior.

Eraktan et al. (2004) applied the Koyck model to analyze the relationship between Direct Income Support (DIS) and agricultural value-added in Turkey. DIS is a government-provided financial aid based on the amount of agricultural land owned by farmers, aimed at stabilizing farm incomes and promoting agricultural productivity. By utilizing the Koyck model, the study examined the lagged effects of this financial support on agricultural output over time. The findings offered valuable insights into the effectiveness of DIS policies in enhancing agricultural value addition and provided empirical evidence on how financial incentives influence farm-level economic outcomes. This research contributes to the broader discourse on agricultural policy and its impact on production efficiency.

Hasan and Khalequzzaman (2015) conducted a study to examine the relationship between garlic production and price in Bangladesh from 1974 to 2011 using the Koyck distributed lag model. The study found that garlic production is significantly influenced by past price fluctuations, with a notable time lag of 32.33 years for price changes to impact production. This indicates that Bangladeshi farmers are highly responsive to price changes but take an extended period to adjust their production levels accordingly. The findings align with the Cobweb Theory, which suggests that delayed responses to price signals can lead to cyclical fluctuations in production and prices.

Several international studies have also used the Koyck model to analyze similar relationships in different crops. Erdal (2006) analyzed tomato production and price dynamics (1975-2004), Ozcelik and Ozer (2006) studied wheat production and pricing (1973-2004), and Erdal and Erdal (2008) examined the relationship between dry onion production and price (1975-2006).

Hossain (2015) utilized an ARIMA model to forecast potato production in Bangladesh, analyzing data from 1970 to 2015. The study found that the ARIMA model provided reliable forecasts, which could assist in planning and policy development.

Rahman et al. (2022) compared ARIMA and mixed-model approaches to forecast potato production in Bangladesh. Their research indicated that while both models were effective, the mixed-model approach offered more precise interval predictions, suggesting its superiority in capturing the complexities of agricultural production data.

Overall, the literature suggests that while the Koyck model is effective in analyzing lagged price-production relationships, issues such as market volatility, lack of farmer organization, and unpredictable climatic conditions continue to pose challenges to agricultural production. Future research could explore alternative forecasting models and policy measures to enhance market stability and farmer decision-making in Bangladesh's agricultural sector.

3. Data and Methodology

3.1 Data Sources

This study utilizes time-series data on potato production and prices from 1990 to 2023, collected from the Bangladesh Bureau of Statistics (BBS) and Department of Agricultural Marketing (DAM). Annual potato production data (in metric tons) from 1990 to 2023 sourced from the Bangladesh Bureau of Statistics (BBS). Annual average market prices (BDT per kg) from FAOSTAT and local market reports.

3.2 Model Specification

Distributed Lag Models are essential in economics for analyzing dynamic behavior of consumers and producers. Introduced by Irving Fisher (Isyar, 1999), these models incorporate both current and past values of an independent variable. An infinite distributed lag model includes all past values without a fixed limit:

$$Q_t = \alpha + \beta_0 P_t + \beta_1 P_{t-1} + \beta_2 P_{t-2} + \cdots \ldots \ldots + u_t \tag{1}$$

When the lag is limited to k periods, it becomes a finite distributed lag model:

$$Q_t = \alpha + \beta_0 P_t + \beta_1 P_{t-1} + \beta_2 P_{t-2} + \cdots \ldots + \beta_k P_{t-k} + \cdots \ldots \ldots + u_t \tag{2}$$

Here, the dependent variable Q_t is influenced by both current and lagged values of P. The delay in response is called the lag period (Dikmen, 2005). Parameters (α, β_0, ..., β_k) can be estimated using Ordinary Least Squares (OLS) (Alt, 1942; Tinbergen, 1949; Gujarati, 2001).

However, challenges include:

- Lack of prior knowledge about the correct lag length
- Loss of degrees of freedom
- Multicollinearity among lagged variables (Gujarati, 2001)

To address these, Koyck (1954) proposed a model assuming geometrically declining lag effects:

$$\beta_k = \beta_0 \lambda^k, \tag{3}$$

where $0 < \lambda < 1$

This simplifies the infinite lag structure, where λ determines how quickly the influence of past values fades. A λ near 1 implies a slow decline; near 0, a rapid one.

The mean lag (average delay in response) is:

$$\text{Mean lag number} = \frac{\lambda}{1-\lambda} \tag{4}$$

Substituting geometric decay into the infinite lag model:

$$Q_t = \alpha + \beta_0 P_t + \beta_0 \lambda P_{t-1} + \beta_0 \lambda^2 P_{t-2} + \cdots \ldots \ldots .. + u_t \tag{5}$$

To estimate this via regression, the model is shifted and transformed:

Lagged version:

$$Q_{t-1} = \alpha + \beta_0 P_{t-1} + \beta_0 \lambda P_{t-2} + \beta_0 \lambda^2 P_{t-3} + \cdots \ldots \ldots .. + u_{t-1} \tag{6}$$

When the equation (6) is multiplied by λ, the Equation (7) is obtained;

$$\lambda Q_{t-1} = \lambda\alpha + \lambda\beta_0 P_{t-1} + \lambda^2 \beta_0 \lambda P_{t-2} + \lambda^3 \beta_0 P_{t-3} + \cdots \ldots \ldots .. + \lambda u_{t-1} \tag{7}$$

Subtracting Equation (7), which is lagged by one period, from Equation (5) with an infinite lag yields the following equation:

$$Q_t - \lambda Q_{t-1} = \alpha(1-\lambda) + \beta_0 P_t + (u_t - \lambda u_{t-1}) \tag{8}$$

If the Equation (8) is reorganized, then we obtained which is shown in equation 09.

To estimate the relationship between potato production and price, we apply the Koyck Distributed Lag Model**,** which accounts for the delayed effects of price changes on production. The model is specified as follows:

$$Q_t = \alpha + \beta P_t + \lambda Q_{t-1} + v_t \qquad (9)$$

Where:

Q_t = Potato production in year t (dependent variable)

P_t = Price of potatoes in year t (independent variable)

Q_{t-1} = Lagged potato production in year t−1

u_t = Error term

β = Short-run effect of price changes on production

$\frac{\beta}{1-\alpha}$ = Long-run effect of price on production

λ = Adjustment parameter, where 0<λ<1, indicating the rate at which past production influences current production

$v_t = (u_t - \lambda u_{t-1})$ and, it is the moving average mean of and

4. Potato Production in Bangladesh

Potato ranks as the world's fourth most important food crop, following rice, wheat, and corn. It is a high-yielding crop that thrives in diverse climates and growing conditions. Nutrient-rich and easily digestible, potatoes serve as a versatile food source with multiple consumption forms. Due to these qualities, potatoes are cultivated and consumed globally. Furthermore, as the global population continues to rise, potato production has expanded accordingly to meet increasing demand.

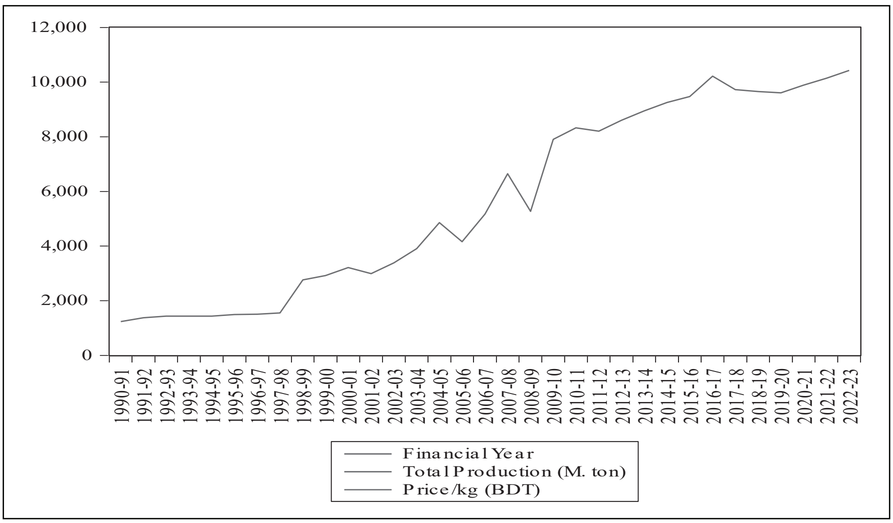

Figure 1. *Potato production in Bangladesh from 1990-91 to 2022-23*

Source: Authors' Computation

The given graph illustrates the trends in total potato production (in million tons) and price per kilogram (in BDT) over different financial years in Bangladesh. The x-axis represents the financial years from 1990-91 to 2022-23, while the y-axis measures production levels and price values. The graph shows a steady increase in potato production from 1990-91 to 2022-23, with significant growth after 2004-05 and minor fluctuations around 2015-18. By 2022-23, production surpasses 10 million tons, indicating strong agricultural advancements. The price trend remains relatively stable, suggesting that increased production may have helped control price volatility. Overall, the data highlights a consistent upward trend in potato production in response to rising demand.

5. Results and Discussion

5.1 Descriptive Statistics

The summary statistics indicate that potato production in Bangladesh has varied significantly over the past 33 years, with an average annual production of 5,671.18 million tons and a wide range from 1,237 million to 10,431 million tons, suggesting growth with fluctuations. The most common production value was 1,438 million tons, while the data distribution appears nearly symmetrical (skewness = 0.045), indicating no extreme outliers. In contrast, potato prices have been highly variable, averaging 16.73 BDT per kg, but with a strong positive skew (1.226), meaning that occasional high prices pulled the average up. The price ranged from Tk 3/kg to Tk 60/kg, with Tk 35/kg being the most frequently recorded price, reflecting instances of sharp price spikes. The high standard deviation (13.80 BDT) and leptokurtic distribution (1.365 kurtosis) suggest that extreme price fluctuations were more common, likely due to market disruptions, supply shortages, or inflation. While production trends appear relatively stable over time, the sharp volatility in price indicates external market pressures and demand-supply imbalances.

Table 1. *Summary Statistics*

Statistics		**Total Production (M.ton)**	**Price/Kg (BDT)**
N	Valid	33	33
	Missing	0	0
Mean		5671.18	16.727
Median		5167.00	11.000
Mode		1438	35.0
Std. Deviation		3443.471	13.8019
Skewness		.045	1.226
Std. Error of Skewness	.409	.409	
Kurtosis		-1.711	1.365
Std. Error of Kurtosis	.798	.798	
Minimum		1237	3.0
Maximum		10431	60.0
Sum		187149	552.0

Source: Authors' Computation

5.2 Correlation Matrix

To analyze the relationship between potato prices and production during the study period, a correlation analysis was conducted. The correlation table-2 shows a strong positive relationship (0.896) between total potato production and price per kilogram in Bangladesh over the past 33 years. This means that as production increases, prices also tend to rise. Normally, higher production leads to lower prices due to increased supply, but this data suggests that other factors—such as rising demand, storage costs, market control by traders, or export trends—might be influencing prices. The p-value (0.000) indicates that this correlation is statistically significant at the 1% level, meaning the relationship is very unlikely to be due to chance. This finding suggests that Bangladesh's potato market does not follow a simple supply-demand pattern, and other economic forces are at play in determining prices.

Table 2. *Correlation Matrix*

Correlations			
		Total Production (M.ton)	Price/Kg (BDT)
Total Production (M.ton)	Pearson Correlation	1	.896**
	Sig. (2-tailed)		.000
	N	33	33
Price/Kg (BDT)	Pearson Correlation	.896**	1
	Sig. (2-tailed)	.000	
	N	3333	

**. Correlation is significant at the 0.01 level (2-tailed).

Source: Authors' Computation

5.3 Distributed Lag Model

The correlation results suggest that the relationship between production volume and price can be effectively analyzed using the Koyck distributed lag model. The model specification is presented as follows:

$$Q_t = \alpha + \beta_0 P_t + \beta_1 P_{t-1} + \beta_2 P_{t-2} + \dots\dots.. + \beta_k P_{t-k} + u_t \qquad (10)$$

To construct the Koyck model, it is essential to identify the appropriate lag length for the potato price series. In distributed lag models, the Schwarz Criterion (Dikmen, 2005) is commonly employed to determine the optimal lag length. According to Schwarz, the model should be refined by minimizing Equation (11) to achieve the best fit:

$$SK = \ln \sigma^2 + m \ln n \qquad (11)$$

Here, σ^2 represents the maximum likelihood estimate of the error variance, calculated as $\sigma^2 = (RSS/n)$**,** where RSS is the residual sum of squares and n is the number of observations. The variable m denotes the lag length. In practice, a regression model is estimated using various lag lengths (m), and the lag length that minimizes the Schwarz Criterion is selected as the optimal lag (Gujarati, 2001). At this stage, no restrictions are imposed on the functional form of the distributed lag. Initially, a large lag length (k) is applied, and the model is progressively refined by reducing the lag length. Throughout this process, the model's validity is checked to ensure that shortening the lag does not compromise its accuracy (Davidson and MacKinnon, 1993).

The Schwarz Criterion values corresponding to different lag lengths for Equation (10) are displayed in Table 1.

Table 3. *Lag length values based on Schwarz criterion*

Lag length	Schwarz values
K=1	21.36
K=2	20.69
K=3	19.39
K=4	19.54

Source: Authors' Computation

As shown in Table 3, the lowest Schwarz Criterion value (19.39) was obtained at a lag length of k = 3**.** This suggests that the influence of potato prices on potato production diminishes to zero after three years. Based on the identified lag length, the relationship between potato production and price was estimated using the classical least squares method as specified in Equation (10). The estimation results are presented in Table 4.

Table 4. *The results of distributed lag model*

$Q_t = 1125.9 + 205.4P_t + 116.5P_{t-1} + 2393.8P_{t-2} - 2563.7P_{t-3}$

	Lag length				
	Constant	t	t-1	t-2	t-3
Coefficient	1125.9	205.4	116.5	2393.8	-2563.7
t-values	3.667	1.041665	0.154267	1.864665	-3.212263
Probability	0.001	0.3072	0.8786	0.0736	0.0035
R-squared = 0.90		F = 101.75		P = 0.000	

Source: Authors' Computation

Table 4 reveals that potato prices in the current period (t), as well as in the preceding one (t-1) and two (t-2) periods, had a positive impact on production. However, prices from three period's earlier (t-3) showed a negative effect on production. Despite these observed trends, the partial regression coefficients, except for the intercept (β_0), were not found to be statistically significant. The model demonstrates a strong fit, explaining approximately 90.48% of the variance in production ($R^2 = 0.9048$).

While the overall model is statistically significant, its reliability raises concerns due to two key issues associated with distributed lag models. First, incorporating multiple lagged values of the price variable may introduce multicollinearity, potentially distorting the relationships among variables. Second, the inclusion of lagged terms results in a reduction of observations, which can be problematic if the dataset is not sufficiently large. In such cases, the estimated coefficients may become inconsistent, affecting the accuracy of the model's predictions.

To address these two key issues, the Koyck model was applied for estimation. The regression results derived from this approach are presented in Table 4, while Table 5 provides the estimation outcomes based on the Koyck model.

Table 5. *The results of Koyek model*

$$Q_t = \alpha + \beta P_t + \lambda Q_{t-1}$$

	Lag length		
	Constant	P_t	Q_{t-1}
Coefficient	$\alpha)$ -4727.8	$\beta)$ 0.53	λ) 0.93
t-values	-0.002229	2.032	12.954
Probability	0.9982	0.314	0.000
R-squared = 0.96		F = 101.50	P = 0.000
Average lag Number		λT1 − λ = 13.29	

Note: is potato production in period t, is potato price in period t and is potato production in one period earlier than t.

Source: Authors' Computation

The Koyck model presented in Table 5 is statistically significant at the 1% level, confirming the robustness of the estimation. The results indicate that a 1 BDT increase in potato price leads to a 0.53-ton rise in production. Additionally, each 1-ton increase in production from the previous period contributes to an additional 0.93 tons in the current period. Based on the calculated mean lag, it takes approximately 13.29 years for price changes to have a noticeable impact on potato production. This finding suggests that Bangladeshi farmers, who primarily cultivate potatoes as a staple crop, show a strong commitment to its continued production.

In Koyek model

$$Q_t = \alpha + \beta_0 P_t + \lambda Q_{t-1} + u_t \quad \text{and} \quad \beta_k = \lambda^k \beta_0 \qquad (12)$$

Since $0 < \lambda < 1$, using the following calculations Equation (10) is reached;

$$\beta_k = \lambda^k \beta_0$$
$$\beta_0 = \lambda^0 \beta_0 = (0.93)^0 (0.53) = 0.530$$
$$\beta_1 = \lambda^1 \beta_1 = (0.93)^1 (0.53) = 0.493$$
$$\beta_2 = \lambda^2 \beta_2 = (0.93)^2 (0.53) = 0.458$$

$$\alpha_0 = \frac{\alpha}{1-\lambda} = \frac{-4727.8}{1-0.93} = -67{,}540$$

By incorporating these findings into the regression formula derived from the Koyck model, Equation (12) is formulated.

$$Q_t = -67540 + 0.530P_t + 0.493P_{t-1} + 0.458P_{t-2}$$

Equation (12), representing a distributed lag model based on the Koyck approach, indicates that past potato prices have a diminishing influence on production, as $0 < \lambda < 1$**.** This decline in effect occurs because the λ coefficient imposes a constraint, limiting the overall impact of lagged price variables within the model.

Based on Equation (12), a one-unit rise in potato prices led to an increase of 0.53 tons in production during the same year. Similarly, a one-unit increase in production from the previous year resulted in an additional 0.493 tons**,** while a price increase from two years prior contributed 0.458 tons to production. Although past price changes positively impacted production, their effect gradually diminished over time.

6. Conclusion and Policy Recommendations

6.1 Conclusion

The findings suggest that potato production in Bangladesh has experienced significant growth, with price changes influencing production over time. The Koyck model indicates that while price increases have a positive impact on production, their influence weakens as the lag length increases. The estimated mean lag of 13.29 years highlights the delayed response of farmers to price fluctuations, likely due to structural constraints, long-term investment decisions, and agricultural practices. Despite price signals, production trends appear to be driven by other factors such as technology, market accessibility, and policy interventions. The strong autocorrelation in production trends suggests that once farmers increase output, they tend to continue doing so, reinforcing the importance of sustained policy support.

6.2 Policy Recommendations

- Price Stabilization Measures: Since price changes affect production with a time lag, policies ensuring stable and fair pricing for farmers should be implemented. This can include minimum support prices (MSP) and buffer stock mechanisms.
- Market Access & Infrastructure Development: Improved storage facilities, transportation networks, and cold storage systems can help farmers mitigate post-harvest losses and respond better to market signals.
- Credit and Financial Support: Access to low-interest loans, subsidies on inputs, and crop insurance schemes will enable farmers to make long-term production decisions without being overly dependent on short-term price fluctuations.
- Technology & Yield Improvement: Investment in high-yield potato varieties, efficient irrigation systems, and precision farming techniques can help farmers sustain production while reducing costs and increasing profitability.

- Awareness & Training Programs: Educating farmers on market trends, climate adaptation, and sustainable farming practices will enhance their ability to make informed decisions regarding production planning.

Declarations

Conflict of Interest: The authors declare no conflicts of interest.

Funding: This study received no funding or any form of financial assistance from any agency, 3rd Party, or institution.

Data Statement: Data will be provided upon request.

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