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COMPARING NUMERICAL METHODS OF THE EVANS PRICE ADJUSTMENT MODEL FOR GLOBAL SILVER PRICE

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Abstract. This study aims to estimate the global prices of silver using the Evans Price Adjustment Model (EPAM). A mathematical model was developed, incorporating silver price, demand, and global supply data from 2013 to 2021 using EPAM. Two numerical methods for solving ordinary differential equations (ODEs) were applied: The fourth-order Adams-Bashforth-Moulton (ABM4) method, with the first four solutions obtained from the fourth-order Runge-Kutta method, another numerical method for solving ODEs, and the Euler numerical method. The same problem was solved using the two stated numerical methods, with the ultimate aim being to investigate the most suitable method for price estimation. Previous research on silver prices used artificial neural networks and autoregressive integrated moving average series models, each with its own strength and weaknesses. Data for this study was collected from the World Bank, a public, open-source, and trustworthy website that provides data on the price of commodities. The results indicate that the ABM4 and Euler methods were able to capture the trend observed in the real silver price dataset. Although the ABM4 model outperformed its counterpart in accurately representing the prices of silver, both approaches yielded results that reflected the trend in the real prices of silver within the specified time frame. The findings of this study will be a useful reference material for investors and other shareholders in the silver business.

Keywords: EPAM, RK4, ABM4, Euler method, numerical solution.

Introduction

Safeguarding businesses and investments portfolios against unfavourable market incidences is a big concern for buyers of financial assets (Sadorsky, 2021). Precious metals are often utilised by businessmen and investors as hedges to thwart unfavourable or adverse economic occurrences (Yaqoob *et al.,* 2016; Iqbal, 2017). Precious metals such as palladium, silver, gold, platinum, and others encompass a range of materials that are considered valuable gifts from nature. These metals are characterised by their scarcity, rarity and high economic worth. Throughout history, they have been treasured as items of immense value. They have served as essential commodities, stored in houses as a means of accumulating wealth and maintaining social status within societies (Pierdzioch *et al.,* 2015). The industrial revolution has repositioned these precious resources as raw materials in various industries, rendering them indispensable for industrial production (Balcilar, Hammoudeh & Asaba, 2015). Additionally, they are used as mediums of exchange or financial instruments within economies. Precious metals play a vital role in the production of automobiles, ornaments, jewellery, computer accessories, and more. They are often combined with other metals to form alloys, which can compensate for any weaknesses in their individual chemical properties (Xu *et al.,* 2022). Many alloys exhibit properties that surpass those of the individual metals themselves. Fluctuations in the prices of precious metals have a significant impact on the management of business operations, the acquisition of raw materials, risk management, and other areas in the resources and mining industry. Furthermore, these metals have wide-ranging effects on financial and economic sectors (Caporin *et al.,* 2015). Many precious metals are used as hedging tools to mitigate risks and maximise profits. Research and modelling of price fluctuations are crucial for designing macroeconomic policies, developing financial derivatives, managing risks, and other related activities. For instance, silver, a prominent precious metal has played a crucial role in the foreign reserve system and served as a medium of exchange.

Silver, alongside gold is recognised as a precious metal esteemed for its beauty and valuable properties. These commodities have consistently remained in demand due to their scarcity and unique characteristics. According to Dutta (2019), silver finds extensive usage in both industrial and commercial applications such as superconductivity, solar panels, water purification, medicine, luxurious jewellery, electronics, and more. In recent years, there has been an increasing realisation of the economic value of silver as an asset. As a result, silver has emerged as one of the most sought-after metals worldwide for domestic and commercial purposes (Sroka, 2022). The price of silver, like other commoditie, experiences frequent fluctuations (Salisu *et al*., 2022). However, the price of silver is particularly susceptible to volatility due to market situations, and to a great degree, negative speculation, and investor sentiment. Despite these continuous price fluctuations, silver remains a popular choice among people and industries, primarily to hedge against unfavourable economic circumstances, like inflation, deflation, scarcity, and significant shifts in the economic landscape. Several factors contribute to the observed anomalies in the price fluctuations, including customer population, worker income levels, quantity demanded, and supplied, availability of technical know-how, the number of companies utilising silver as raw materials, government policies, the exchange rate of the dollar, the prices of substitutes, and many other variables (Guan *et al*., 2021).

Analysing and modelling the price of silver is a challenging task as there are multitudes of complicated factors that influence it. Researchers have utilised different methods to predict the price of commodities. For example, Holt-Winters exponential smoothing was employed to forecast stock prices (Ariyo *et al*., 2014). Similarly, Chatterjee *et al*. (2021) developed an econometric model using the autoregressive integrated moving average model to predict the prices of commodities. They found that their model performed satisfactorily in forecasting short-term commodity prices and highlighted its potential to assist investors and business stakeholders in making decisions related to profit margins.

Chatterjee *et al*. (2021) also employed dynamical systems such as chaos systems and artificial neural networks, to model the commodity prices within a specific time frame. Their models were developed to identify and capture essential features in the dataset, and they reported impressive performance in capturing the intelligent information in the huge dataset and that the predictions made were massively successful. However, it is crucial to acknowledge that commodity prices are influenced by numerous factors; such influences can be modelled using a restricted approach. However, the use of restricted techniques or methods that reduce the number of components or factors that influences the prices of commodities such as Evans Price Adjustment Model (EPAM), come with many offerings. EPAM prioritises demand and supply as the major factors that influence the fluctuations in commodity prices (Sbordone, 2002). Accurately grasping and estimating the global price of silver is necessary for facilitating both short-term and long-term business decision-making. While most investors recognise that a range of factors contribute to commodity price fluctuations, which may vary across societies, the most prominent factors that stand at the intersection of all factors are the parameters captured in EPAM.

EPAM is a price adjustment model that proposes a direct relationship between the difference in quantities demanded and quantities supplied, and the rate of change in commodity prices (Evans, 1983). It can be represented as a simple differential equation that can be solved in its initial condition using any method for solving Ordinary Differential Equations (ODEs), either analytically or numerically. Thus, in this study, to gain a comprehensive understanding of and insight into silver price fluctuations, EPAM was employed to model the prices of the precious metal over a defined period of time, from 2013 until 2021. The model was derived from the quantities of silver supplied and demanded by households and industries. The differential equation obtained from EPAM was solved using the Euler numerical method and the fourth-order Adams-Bashforth-Moulton (ABM4) method. Both approaches are numerical techniques for solving ODEs. However, they differ in terms of accuracy and effectiveness. The Euler method is a first-order numerical technique that takes a single step in the direction of the derivative at each point to approximate the solution of an ODE. On the other hand, the ABM4 method is a higher-order numerical technique that approximates an ODE's solution by combining backward and forward differences (Hoffman & Frankel, 2018). In this study, the ABM4 method was initiated with the fourth-order Runge-Kutta method (RK4) to obtain the solutions for the first few steps, which were then used as the initial values for further solutions computed using the predictor-corrector method. The ABM4 method is more precise and can handle a wider variety of ODEs, including stiff equations. The purpose of comparing the ABM4 and Euler methods is to assess each technique's effectiveness, precision, and simplicity in solving EPAM. These factors will be useful in determining the best numerical approach for EPAM. Although the Euler method is straightforward and easy to use, it may produce inaccurate results, particularly for difficult equations or complex systems. However, it may still produce a worthy solution for less complex problems. The solutions obtained using the two numerical methods for predicting the prices of silver were examined, and the output of both methods will be compared to determine which of them has the higher tendency to capture the trend in the real dataset.

Data Collection

This study utilised silver price data from the World Bank for the years 2018 to 2021. The data was structured in a way that the total quantity demanded by individuals and industries was aggregated and considered as the quantity demanded. Similarly, the supplies from various sources, as provided by the World Bank were summed up and referred to as the quantity supplied. Table 1 provides a summary of the silver prices, quantity supplied and quantity demanded from 2013 to 2021.

Table 1: The total supply, demand, and price of silver (Ahmed & Sarkodie, 2021)

Time (years)	Supply (10^9)	Demand (10^9)	Price (US$/Ounce)
2013	0.999	1.116	23.79
2014	1.050	1.084	19.08
2015	1.050	1.160	15.68
2016	1.030	1.030	17.14
2017	1.030	1.000	17.05
2018	1.000	1.030	15.71
2019	1.020	0.990	16.24
2020	0.970	0.892	20.69
2021	1.020	1.029	25.14

Methodology

EPAM is a dynamic model that recognises demand and supply as the main factors responsible for changes in commodity prices. Over time, quantity adjustment, which is the process by which a market excess or scarcity results in a decrease or increase in the quantity of goods, stood out as the major factor that contributes to a discrepancy between supply and demand in the market. Price adjustments serve as a safety net when the amount of goods demanded in the market exceeds the amount of goods supplied; this forces the price to increase, similar to when supply exceeds demand and the price falls. EPAM, which is a straightforward price adjustment model, revolves around the differential equation in Equation (1).

$$\frac{dp}{dt} = k(D-S), \quad p(t_0) = p_0. \tag{1}$$

where $\frac{dp}{dt}$ is the rate of change of the price with respect to time, k is the proportionality constant or the adjustment parameter, S is the quantity supplied and D is the quantity demanded. D and S are the function of price p. To use EPAM, we need an initial value, which is readily available from the dataset. The demand function and the supply function can both be computed using the dataset and the two-point slope equation of a straight line. The demand function and supply function can be obtained using the data in Table 1. The supply function is defined as:

$$S = 0.012739p + 1.2931. \tag{2}$$

where the slope (m) = - 0.012739 and the intercept (c) = 1.2931. Similarly, demand function is as follows:

$$D = -0.0067941p + 0.95437. \tag{3}$$

where the slope (m) = -0.0067941 and the intercept (c) = 0.95437.

The EPAM model was refined by substituting Equations (2) and (3) into the model as defined in Equation (1). The mathematical model for the global price of silver from 2013 to 2021, after simplification can then be defined as:

$$\frac{dp}{dt} = k(0.019533p - 0.33873) \tag{4}$$

Equation (4) can be solved using the variable separable method of solving first-order ODEs. Using the first year as the initial condition gives the solution as shown in Equation (5):

$$p(t) = \frac{Ae^{0.019533kt} + 0.33873}{0.019533} \tag{5}$$

Equation (5) introduces another variable, A. To find the value of A, we use t_0=0 and $p(t_0)$=23.79 as presented in Table 1. Substituting t=0 and $p(t_0)$=23.79 into Equation (5) gives A=0.12596. Now, we need to find the value k of using the same procedure by setting t=1 and $p(1)$=19.08 taken from Table 1 and substitute the value of A obtained previously, in which A=0.12596, into equation (5). Following simplification, it was found that k=67.107. The result following the substitution of all the obtained values gives Equation (6).

It is worth mentioning that Equation (6), with an initial value, can be solved by any numerical method for solving first-order ordinary differential equations. In this study, we solved the problem using the fourth-order Adam Bashforth-Moulton method. The Euler method's computational burden of the calculations was reduced by developing codes in MATLAB to obtain the predicted price of silver from 2013 to 2021.The transformed Equation (5) takes the following form:

$$f(t_i, p_i) = -67.107(0.019533p_i - 0.33873) \quad , \qquad i = 1,2,3\ .\ .\ .,n. \tag{6}$$

which is the equation to be solved using our proposed methods.

Fourth-Order Runge-Kutta Method of Order 4

The Adams-Bashforth-Moulton method is a multi-step method that requires four initial solutions before it can be applied. These initial solutions can be obtained using other numerical methods such as the Euler method and Heun's method. In this study, the fourth-order Runge-Kutta method was chosen due to its excellent performance in solving differential equations. The general equation for the fourth-order Runge-Kutta method is as follows:

$$y_{i+1} = y_i + \frac{h}{6}\left(k_1 + 2k_2 + 2k_3 + k_4\right) \tag{7}$$

where:

$$k_1 = f(t_i, y_i),$$
$$k_2 = f\left(t_i + \frac{h}{2}, y_i + \frac{hk_1}{2}\right),$$
$$k_3 = f\left(t_i + \frac{h}{2}, y_i + \frac{hk_2}{2}\right),$$
$$k_4 = f\left(t_i + h, y_i + hk_3\right).$$

The Adams Bashforth-Moulton Method

The Adams-Bashforth-Moulton method is a multistep numerical technique that requires some of its parameters to be obtained from another method. In this case, the first four values of the predicted silver price were obtained from the Runge-Kutta method. To apply RK4, the values of k_1, k_2, k_3 are calculated using the known value of k_0, which is the initial price at time $t=0$. The relationship for k_i is shown in Equation (1). We then substitute the values of k_i into the general Equation (6) to obtain P_{i+1} .

$$p_{i+1} = p_i + \frac{h}{6}\left(k_1 + 2k_2 + 2k_3 + k_4\right). \quad (8)$$

Bu using the price of silver in 2013 as the initial value for p_0, we will obtain the value for p_1. The process will be repeated for three more iterations to obtain a total of four initial solutions. They are then used in Equation (8) of the Adams-Bashforth predictor method, which can be rewritten as:

$$p_{5,p} = p_4 + \frac{h}{24}\left(55y_4' - 59y_3' + 37y_2' - 9y_1'\right). \quad (9)$$

Once we have obtained the value of $P_{5,p}$, we can substitute this value into Equation (9) of the Adams-Moulton corrector method to obtain a more accurate value for P_5:

$$p_{5,c} = p_4 + \frac{h}{24}\left(9y_5' + 19y_4' - 5y_3' + y_2'\right). \quad (10)$$

The process will be repeated for each solution obtained from the Adams-Bashforth predictor method and the corresponding corrected solution will be obtained using the Adams-Moulton corrector method, which will yield the prediction for the price of silver until the stopping criterion is met.

Flowchart of the Adams-Bashforth-Moulton Method and the Steps Involved

The flowchart below shows the incorporation of EPAM and the fourth-order Adams-Bashforth-Moulton method (Figure 1).

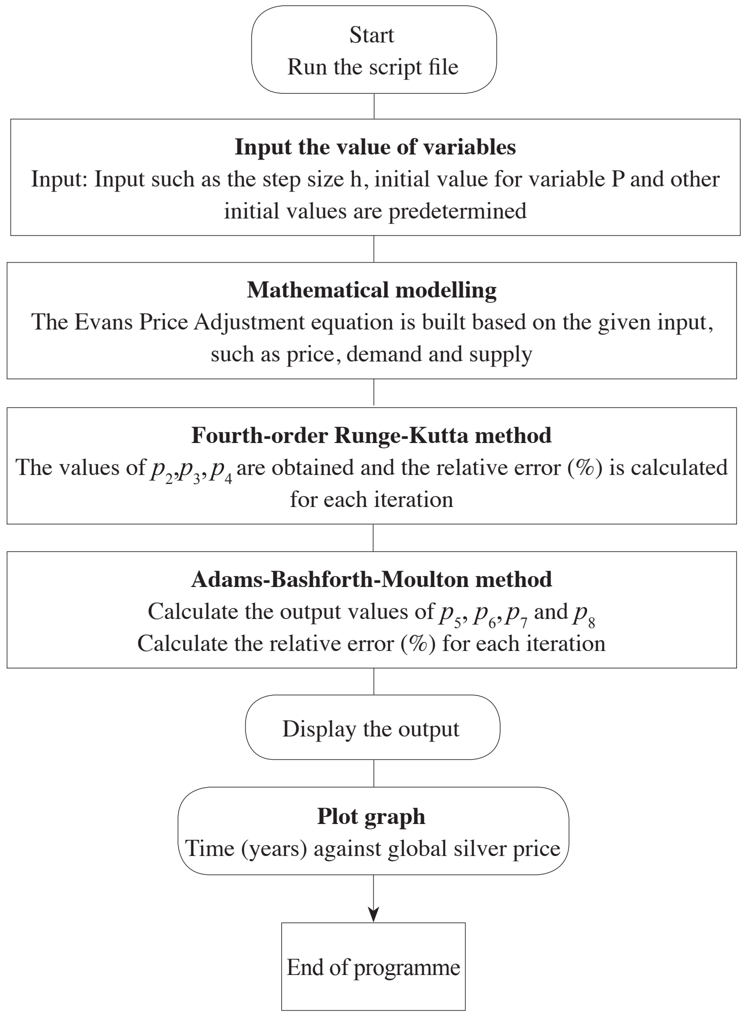

Figure 1: Flowchart of the Adams-Bashforth-Moulton method

Step 1: The basic parameters for the computations are set, which include the initial condition corresponding to the price of silver at time t=0, the differential equation to be solved, step size h, the computed value of the drift and the diffusion term obtained from the actual data, before the script is run.

Step 2: By implementing a looping computation, the values for P_1, P_2 and P_3 are calculated using the fourth-order Runge-Kutta method as part of the first four initial solutions for the differential equation. Thus, the RK4 method will output (t_i, P_i) for i=0,1,2,3.

Step 3: The output of the step 2 will be utilised in the Adams-Bashforth predictor method to generate subsequent prices of the silver (P'_4,P'_5,P'_6,... P'_n) and the subsequent corrected silver prices (P'_4,P'_5,P'_6,... P'_n) are obtained using the Adams-Moulton corrector method. The iteration will continue until the desired number of months is reach, at which point the process will be stopped.

Step 4: The output of the loop will be used for analysis and investigation of the trend. These results will be compared with the real silver prices and the results from the other method.

Step 5: A graph of prices of silver against time is plotted to visually represent the data for easy comparison and analysis of the trend.

The Euler Method

The Euler method also known as the Euler-Cauchy equation is a point-slope method to solve first-order ordinary differential equations numerically. This method has played a significant role in the development of other numerical methods. It can be used to solve EPAM, a first-order differential equation. By employing the Euler method at predetermined intervals, a series of solutions can be generated to represent the predicted prices obtained from real dataset. The effectiveness of the Euler method in capturing the pattern in the real dataset will be assessed. The Euler method approximates solutions by applying the concept of tangent lines, taking into account the initial value selected from the real dataset from the World Bank.

A first-order ordinary differential equaton is given in the form of Equation (11):

$$\frac{dy}{dx} = f(x,y)\ ,\ y(x_0) = y_0. \tag{11}$$

The numerical solution to Equation (11) can be obtained at any value of x using Euler's formula as shown in Equation (12):

$$y_{n+1} = y_n + hf(x_n, y_n). \tag{12}$$

where h is the step size and can be obtained using $h = \frac{x_n - x_0}{n}$. Equation (12) can then be rewritten as Equation (13) in terms of price and time:

$$p_{i+1} = p_i + hf(t_i, p_i),\ \ i = 0,1,2,3...,n \tag{13}$$

Using the silver prices in 2013 as p_0 with the step size being h=1, p_1 can be obtained. The computation will continue to predict the price of silver by repeating the steps shown above and will terminate when it reaches the maximum number of desired years. The values of p_i represent the predicted prices of silver starting from 2013 to 2021.

Flowchart of the Euler Method and the Steps Involved

The flow chart below incorporates EPAM with the Euler method.

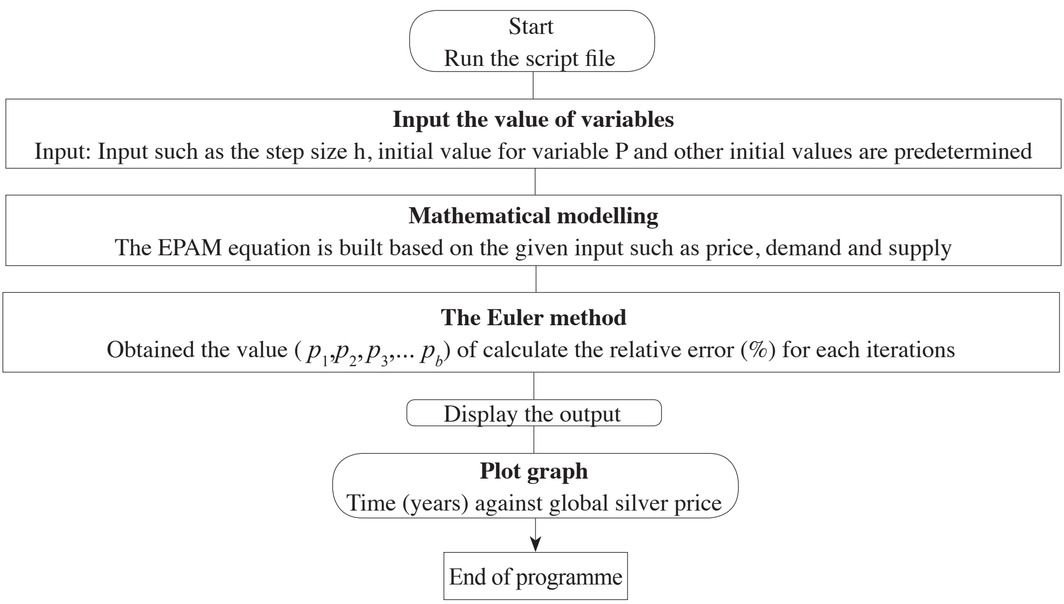

Figure 2: Flowchart of the Euler numerical method

Step 1: Define the function $f(t,p)$ and the initial value, which is obtained from the dataset, which is at time t=0 with the corresponding price $p(t_0) = p_0$. Set the appropriate value for h and the number of iterations n.

Step 2: Perform the iteration from j=1 to n, set $m=f(t_0,p_0)$ such that $p_1 = p_0 + hm$ loop for the values of p_j until n, which is the desired number of years.

Step 3: The results of the looping is the set of prices that will be used for analysis of the global prices of silver. They will be compared with the real silver prices, as well as the predicted prices of silver from the other method.

Step 4: The graph of the predicted silver prices obtained using Euler method is plotted to have a visual representation of the predicted prices of silver for easy comparison and analysis of the trend in the dataset.

Results and Discussion

Results of the Fourth-Order Adams-Bashforth-Moulton Method

The m-files were executed successfully, providing the results for each numerical method, which are the predicted global silver price using EPAM. At the same time, the results of each method were plotted on a graph in terms of silver prices against time. The real silver prices are also plotted on the same graph for comparison.

Table 2: The real prices of silver and the predicted prices obtained using ABM4

Time (years)	Real Silver Price in US$/Oz	Predicted Price	Error
2013	23.79	23.79	0
2014	19.08	19.25	0.88312
2015	15.68	17.91	12.4511
2016	17.14	17.51	2.11308
2017	17.05	16.99	0.35314
2018	15.71	16.86	6.82088
2019	16.24	17.36	6.45161
2020	20.55	17.62	16.62883
2021	25.40	17.21	47.58861

From Table 2, the predicted prices of silver from 2013 to 2021 obtained using ABM4 is plotted on a graph. The real prices of silver between 2013 to 2021 was also plotted on the same graph.

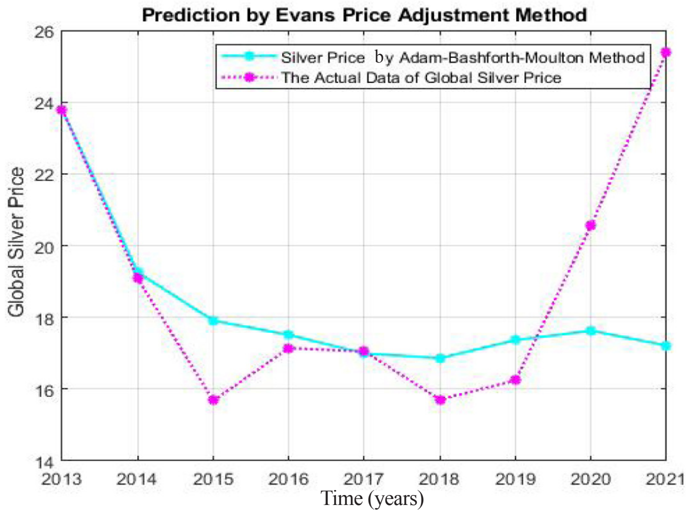

Figure 3: The predicted silver prices obtained using ABM4 against the real silver prices from 2013 to 2021

Table 3 represents the obtained predicted prices of silver and the real prices of the silver in the years under review using Euler method, while Figure 2 depicts the graph of the information detailed in Table 3.

Results from the Euler Method

Table 3: The real prices of silver and the predicted prices obtained using the Euler method

Time (years)	Real Silver Price in USD/Oz	Predicted Price Euler Method	Error in Using Euler Method (%)
2013	23.79	23.79	0
2014	19.08	15.34	24.3807
2015	15.68	17.96	12.6949
2016	17.14	17.15	0.05831
2017	17.05	17.40	2.01149
2018	15.71	17.32	9.29561
2019	16.24	17.35	6.39769
2020	20.55	17.34	18.51211
2021	25.40	17.34	46.48212

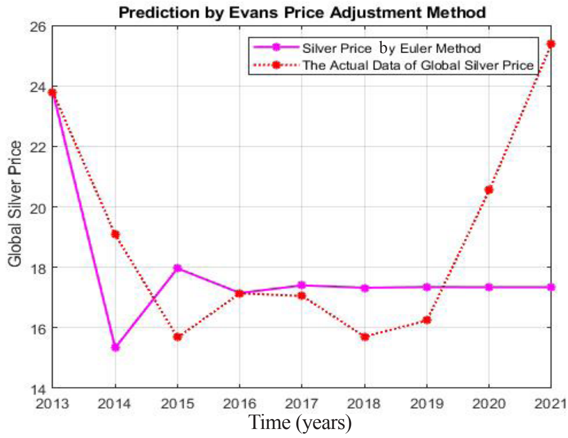

Figure 4: The predicted prices of silver obtained using the Euler method against the real silver prices

To visually investigate how the Euler method and the Adams-Bashforth-Moulton method compared with the actual prices of silver in the years under review, a graph containing the results of the Euler method, Adams-Bashforth-Moulton method, and the real silver prices was plotted (Figure 4).

Figure 5: A graph containing the predicted silver prices obtained using the Euler method and ABM4 against the real prices of silver

Discussion

The fourth-order Adams-Bashforth-Moulton method (ABM4) and the Euler numerical method were utilised to estimate the prices of silver between 2013 to 2021 (Figure 5). As shown in Figure 3, the estimated prices of silver obtained from both numerical methods exhibited a common trend and reasonably fit with the real dataset. The errors from ABM4 are much lower than those from the Euler method, except for 2016, where the latter method performed better. It can be observed that between 2020 and 2021, both methods showed a large variation from the real dataset. This can be attributed to the post-COVID-19 era, where many nations are recovering from the economic impact of the pandemic and the resumption of production activities may have contributed to the increase in the price of silver due to excessive demand from various sources. Silver prices experienced abnormal volatility during these to years. COVID-19 has significantly impacted the global economy, leading to economic stagnation. The process of recovering from this stagnation has the potential to result in inflationary pressures. Silver, being a previous metal that is in high demand can be used as a hedge to counterbalance the effect of such stagnation, creating more market for it even when its price is high. people's scepticism regarding the resurgence of a pandemic often leads them to adopt precautionary measures by increasing their purchases and storing them in their homes. This behaviour serves as a means to mitigate the potential impact of unforeseen situations. Other factors can also play a significant role in the surging of commodity prices; technological advancement can broaden the usability of precious metals. It was reported that silver has been recently used in the production of silver nanoparticles, which are widely used in many research areas such as biological apparatus, chemical sensors, wearable technology, photovoltaic technology, silver nanowire, and many more. This could lead to a higher demand for silver, consequently causing a surge in its price (Sofi *et al.,* 2021).

From Figures 1 and 2, it can be observed that the predicted prices of silver follow the movement of real prices of silver, except for the years 2020 and 2021, which can be attributed to the reasons highlighted earlier. Additionally, it is worth noting that the average CPU time required for the successful execution of the programme using ABM4 is significantly lower than that of the Euler numerical method. The difference in computational time between ABM4 and the Euler method is 0.14062 seconds while the elapsed time difference is 0.005897 seconds. Based on this analysis, it can be concluded that ABM4 is more suitable for estimating the prices of silver using the available data on demand, supply and historical silver prices from 2013 to 2021.

Conclusion

We successfully estimated the global silver prices from 2013 to 2021 using two numerical methods, namely the Adams-Bashforth-Moulton method (ABM4) and the Euler method. They were used to solve the EPAM developed using the data on the real prices of silver for the specified years. This study focused on analysing the relationship between quantities supplied, quantities demanded, and silver prices through the EPAM model. Based on the results, it can be affirmed that ABM4 performed better and is more suitable for estimating the global silver prices. Utilising this model has several advantages, including serving as a valuable tool for investors in detecting trends in silver prices, aiding in better decision-making, and providing opportunities for more profit in the trading of silver.

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