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Research Article

MODELING INFLATION DYNAMICS USING THE LOGISTIC MODEL: INSIGHTS AND FINDINGS

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Abstract
This paper examines applying the logistic model, frequently used in biology, to analyze inflation patterns in dynamic economic systems. The primary objective is to simulate and analyze the complex dynamics of inflation, thus providing new insights into the stability of financial institutions. Numerical methods such as Euler's Method, Runge-Kutta Method (RK4), and Adams-Bashforth-Moulton's method were used to simulate inflation patterns by discretizing the logistic equation. The data utilized in this research were obtained from INSTAT, BoA, MoF, and Eurostat, with quarterly results from 1995 to 2023. The simulation results indicated that the RK4 and Adams-Bashforth-Moulton methods yielded more precise and reliable inflation forecasts than Euler's. The logistic model represented the non-linear aspects of inflation dynamics well, emphasizing the necessity of using suitable numerical approaches. The study's findings highlight the effectiveness of the logistic model in economic analysis, specifically in forecasting inflation trends. Enhanced closure approaches have proven their effectiveness in analyzing intricate economic data, providing crucial insights into the stability of inflation, and informing policy formulation. This study utilizes the logistic model to analyze inflation dynamics, offering a unique methodology for comprehending and forecasting inflation in economic systems. An analysis of several closure techniques reveals a novel aspect of financial modeling tools. The findings indicate that incorporating advanced numerical methods can significantly improve the precision of economic models. These findings significantly impact economic research and policy formulation, especially in devising measures to manage inflation and ensure financial stability.

Keywords: Difference Equation, Dynamic Systems, Inflation Study, Logistic Equation, Stability.

INTRODUCTION

Over the past few years, the global economy has experienced significant fluctuations, including the impact of the global economic crisis (Anokye & Oduro, 2012), the ongoing COVID-19 pandemic, and the geopolitical upheavals in Ukraine. These events have highlighted the importance of conducting accurate risk control studies and the ability to simulate complex economic dynamics. Various differential equations and other mathematical models have been widely used to clarify the dynamic relationship between economic components, providing valuable insights into the complexities of the market. The global economy can quickly experience widespread failures due to inaccurate risk control analyses and other contributing factors. The 2008 economic recession resulted in a rise in public debt in prosperous economies. The 2007 home loan market crisis significantly impacted the euro region, ultimately leading to a debt crisis by the end of that year (Reinhart & Rogoff, 2010). Despite the extensive use of these models, there still needs to be a gap in effectively predicting and managing inflation dynamics, especially in the context of post-pandemic economic recovery. Previous studies, such as those by Hidayati et al. (2024) and Auerbach and Gorodnichenko (2021), have emphasized combining qualitative and quantitative techniques to comprehensively understand the global economy's intricate dynamics. Coibion, Gorodnichenko, and Weber (2020) also investigate the wider financial consequences of the pandemic, such as the inflationary effects caused by lockdowns and shifts in consumer behavior. However, these studies often need a robust model that accurately captures stable and chaotic economic behaviors.

The COVID-19 pandemic has significantly disrupted economies worldwide, affecting supply chains, labor markets, and financial stability (Auerbach et al., 2022; Baker et al., 2020). Accurate forecasting and management of inflation during and after such crises necessitate using advanced models. Recent literature has analyzed the application of logistic models in economic forecasting post-COVID-19, highlighting the need for more resilient economic solutions to address future crises effectively. Furthermore, recent academic research has analyzed the application of logistic models in economic forecasting in the aftermath of the COVID-19 epidemic. Gourinchas, Kalemli-Özcan, Penciakova, and Sander examine the economic trajectories of multiple countries, providing valuable insights into the intricate connection between public health policy and financial stability. By incorporating these recent findings into our research, we aim to comprehensively understand how the logistic model can effectively analyze inflation dynamics in a post-pandemic period. The knowledge obtained from this research will assist in developing more resilient economic solutions to address future crises adequately.

Utilizing the logistic model, commonly employed in biology, to examine inflation tendencies in dynamic economic systems represents an innovative methodology. The model's capacity to precisely predict and capture stable and chaotic economic behaviors offers a fresh outlook on inflation dynamics. Prior research corroborates this methodology, highlighting the model's capacity to enhance the development of monetary policy through a more profound comprehension of inflationary patterns and economic stability. One study demonstrated the effectiveness of logistic models in predicting inflation dynamics and the stability of financial systems, showing that the model can be applied to both stable and chaotic processes (Febriansyah et al., 2024). The logistic model, commonly used in biology to examine growth patterns, offers a novel approach to analyzing inflation dynamics in economic systems. Its capacity to predict and capture stable and chaotic behaviors makes it a powerful tool for understanding inflationary patterns and financial stability. This study aims to fill the gap by applying the logistic model to inflation dynamics and comparing various numerical methods to determine the most effective approach for economic modeling.

Major worldwide economic crises have greatly affected Albania's economy in recent years. Comprehending and elucidating the industry's intricacies requires employing qualitative and quantitative methodologies. Differential equations and other mathematical models can explain the dynamic interaction between economic elements. The logistic equation is a widely accepted outcome of ordinary differential equations, and it has been applied empirically in several domains, including biology, economics, and social sciences. The logistic equation is a mathematical model used in biology, economics, and social sciences to analyze non-linear aspects of economic development. It captures the annual percentage increase in consumer spending on standardized goods and services, making it a powerful tool for analyzing inflation dynamics. Inflation is a vital macroeconomic indicator, indicating the annual percentage increase in consumer expenditures for a standardized range of goods and services.

Understanding inflation patterns is crucial for formulating policies targeting price stability and fostering economic growth. Thus, the logistic equation is vital in understanding economic development and inflation dynamics.

The research conducted by Ahmad et al. (2024) highlights the ability of the Internet of Things (IoT), big data analytics, and machine learning algorithms to improve energy efficiency and user comfort in smart homes. The study uses the logistic model, a widely used mathematical tool in analyzing biological systems, to investigate and forecast inflation dynamics in economic systems. This approach provides significant insights into the stability of financial systems and the formulation of policies. This innovative technique highlights the considerable impact of computational methods in tackling practical problems. The logistic model is essential in economic analysis because it can accurately reflect the dynamic behavior of inflation. It does this by including factors such as the natural growth rate and the carrying capacity, indicating the highest possible inflation amount given the current economic conditions. Economists can utilize the logistic equation to model inflation and simulate the response of inflation rates to variations in financial conditions and policy interventions throughout time.

Logistics operations are heavily affected by the macroeconomic environment, which influences factors such as economic growth, investment flows, inflation dynamics, and trade openness. It is essential for policymakers, firms, and stakeholders engaged in strategic planning, infrastructure development, and trade facilitation operations to comprehend the relationship between macroeconomic conditions and logistics performance (Khan et al., 2019). Efficient logistics can improve business operations, lower transportation expenses, and promote economic growth (Filova & Hrda, 2020). Gaining insight into the variables that influence a country's logistics performance helps improve freight transportation efficiency and reveals the fundamental obstacles that must be addressed. When analyzing inflation patterns with the logistic model, exploring the influence of organized financial models in economic evaluation is helpful. According to Bindseil and Jabłecki, using models to analyze financial systems helps us examine how policy instruments and structural characteristics affect macroeconomic stability in a detailed manner (Bindseil & Jabłecki, 2011). This viewpoint is crucial as we implement logistic models to examine inflation dynamics, emphasizing the significance of solid economic frameworks in our study. Advanced analytical methodologies are necessary to understand the complex relationship between wage structures and inflation patterns in the evolving discourse on economic dynamics. The logistic model, known for its accuracy in analyzing non-linear systems, is a fundamental aspect of this work. We examine its usefulness in studying the intricacies of inflation, an economic phenomenon greatly affected by wage dynamics.

Recent investigations have highlighted the extensive influence of wage inflexibility in several economic sectors, underscoring its pivotal role in shaping macroeconomic outcomes. Messina et al. (2010) discovered both nominal and real pay rigidities across many industries, impeding the seamless adjustment of wages to market conditions. Consequently, this exacerbates inflationary pressures and adds to economic instability. The hesitancy to modify salaries underscores the significance of employing flexible and adaptive models, such as the logistic model, in financial research. These models aid in forecasting and tackling variations in wage patterns and inflation tendencies.

GDP, also known as Gross Domestic Product, is a vital economic metric that quantifies the monetary worth of products and services produced inside a nation during a specific timeframe. Nevertheless, the reliability of GDP as the sole measure of welfare and progress is currently being debated and contested (Syrquin, 2016). Inflation, a significant macroeconomic indicator, has consistently maintained a high level, surging into double digits during the 1970s and recent years (Engle, 2022). It denotes the annual percentage change in expenses the typical consumer bears when buying a consistent or regularly modified assortment of products and services.

Macroeconomic analysis involves using macro-financial models to study economic systems and make predictions for the near future (Angelini et al., 2019). These models are used to evaluate policy actions in hypothetical scenarios and are commonly employed by central banks to inform decisions on monetary policy (Brázdik et al., 2020; European Commission, 2021). Utilizing a macro-financial model tailored to the unique characteristics of Albania, this analysis applies neoclassical growth theory to small, open economies. The focus is placed on understanding the specific features of the country. The model effectively distinguishes between external influences and internal disruptions, allowing for a better understanding of economic phenomena (Skufi & Geršl, 2023). Utilizing data from 1995 to 2023, the model employs a predictive approach to forecast policy outcomes. It analyses various scenarios by considering external factors like Eurozone GDP and foreign interest rates. Using a sophisticated forecasting method, we can assess the model's ability to predict outcomes despite major economic disruptions. Monitoring and predicting inflation is crucial for central banks to maintain price stability. Modern financial authorities dedicate significant resources to studying and forecasting inflation. This project relies heavily on the application of conventional econometric analysis.

By aligning its policies with the current norms and viewpoints of the European Union, Albania has the potential to develop a modern and competitive sector. With logistic equations, we can analyze and predict trends in various commercial and economic areas and assess the effectiveness of different policies. Mathematical Economics focuses on the study of stability and chaos, exploring various theories around the concept of equilibrium states. Equilibrium is a state where there is no inclination for change. Forecasting financial data can be challenging as it requires a high level of responsibility to ensure the accuracy of projections.

The research aims are Model Inflation Dynamics: The logistic model can examine inflation tendencies in dynamic economic systems, offering a novel viewpoint on financial stability. Compare Numerical Methods: Assess the efficacy of several numerical techniques, such as Euler's, Runge-Kutta Method (RK4), and Adams-Bashforth-Moulton Method, in accurately modeling inflation dynamics. Evaluate the model's precision and consistency: Evaluate each numerical technique's precision and consistency in forecasting inflation patterns. Offer Policy Analysis: Provide insights into the formulation of resilient economic strategies based on the results obtained from the logistic model simulations. This research aims to deepen our comprehension of inflation dynamics and increase the current tools for economic analysis and policy formation by addressing these objectives.

The novelty and relevance of this research reside in its unique application of the logistic model to the study of inflation dynamics. This technique offers a fresh perspective on economic forecasting. Comparing various numerical approaches enhances economic modeling techniques by emphasizing the significance of choosing suitable methods for precise predictions. The results substantially impact economic research and policy formulation, especially in devising approaches to manage inflation and ensure financial stability in a post-pandemic era. In the subsequent parts, we will describe the materials and methods utilized in our study, give the results of the simulations, analyze the discoveries, and propose recommendations for further research.

RESEARCH METHOD

The dataset utilized in this investigation consists of quarterly frequency statistics spanning from 1995 to 2023, obtained from INSTAT (2022), BoA (2022), MoF (2022), and Eurostat (2022). Multiple techniques for converting frequencies were utilized to guarantee the precision and uniformity of the data. These included the Average-of-observations approach, Sum-of-observations methodology, and Final observation strategy—the Denton technique developed by Chollette in 1984 specifically for transforming yearly population data into quarterly frequency observations. The Tramo/Seats approach incorporated seasonal variations, enabling automatic adjustments for seasonal variances. Before generating the discretionary income series, each variable was individually tailored to accommodate seasonal fluctuations.

To understand an economic process, it is crucial to employ a methodology that may offer predictions or a thorough examination of prospective developments within a particular sector of the economy. Forecasts are essential for strategic planning, informed decision-making, and efficient future choice implementation. Economics must employ quantitative and qualitative approaches to understand market realities. Various models use differential equations to illustrate qualitative methods of describing the financial condition of the market. Differential equations are commonly utilized in multiple models to depict the relationships between variables linked to temporal changes. Differential equations are crucial in developing complex economic models that explain intricate dynamic nonlinear processes. They can be likened to discrete nonlinear difference equations (Agarwal et al., 2013). A recent study has investigated the long-lasting nature of equation solutions in specific economic situations to determine the most favorable values (Zhang et al., 2015) and stable positions in various fields (Ramos, 2013).

Ordinary differential equations are crucial for the development of the logistic equation:

$$P(t) = \frac{MCe^{rt}}{1+Ce^{rt}} \quad (1)$$

Extensive research has shown that the logistic equation, derived from ordinary differential equations, effectively forecasts outcomes in various fields such as biology, epidemiology, economics, and social sciences (Amavilah, 2007; (Marceddu et al., 2023; Ramos, 2013). The logistic equation, also known as the Verhulst model or logistic curve, is a mathematical model that describes population expansion. Verhulst proposed it in 1845 and 1847, a continuous function that varies over time. Converting a continuous equation into a quadratic discrete recurrent equation is a logistic map (Bohner & Warth, 2007).

The differential equation is a continuous form of the logistic model:

$$\frac{dP}{dt} = rP\left(1 - \frac{P}{M}\right) \tag{2}$$

where r – is the Malthusian parameter (the speed of maximal population growth) and M - is the maximal capacity (or population). By dividing both sides of the equation by M and defining X as the ratio of P to M, we obtain the following differential equation:

$$\frac{dX}{dt} = rX(1 - X) \tag{3}$$

The logistic model in its discrete form is outlined as follows:

$$X_{n+1} = rX_n(1 - X_n) \tag{4}$$

The primary observation regarding equation (4) is its nonlinearity. Mathematically, it signifies the level of complexity in finding a solution, although numerous biological, economic, and other processes exhibit complete nonlinearity.

The cobweb method is a repetitive graphical technique used to ascertain the population level at each step. The series of approximations converges to a unique point located at the intersection of the parabola and the bisector in the first quadrant. A formula based on Jacob Bernoulli's approach can be used to calculate the parameters r and M analytically.

Theorem 2.1 The differential equation $\frac{dP}{dt} = rP\left(1 - \frac{P}{M}\right)$ is a Bernoulli equation where $n = 2$.

The logistic equation represents the overall solution of this equation, whereas the equation itself yields the specific answer:

$$P(t) = \frac{MP_0}{(M - P_0)e^{-rt} + P_0} \tag{5}$$

The parameters of specific solutions, determined using points in equal time intervals $\{(t_0, P_0), (t_1, P_1), (t_2, P_2)\}$ are determined by the following equality:

$$r = \frac{1}{2} ln\left|\frac{P_2(P_1 - P_0)}{P_0(P_2 - P_1)}\right| \tag{6}$$

$$M = \frac{P_1(P_0P_1 + P_1P_2 - 2P_0P_2)}{P_1^2 - P_0P_2} \tag{7}$$

where $t_1 \neq 0, P_0, P_1, P_2 \neq 0$, where these values are taken in equal time intervals.

2.2 Studying Logistic Equation Stability

In 2013, Gonze presented the notion of stability, which pertains to the lack of alterations in a system. He also defined a stable state in several equations, denoted as X_{SS}:

$$X_{n+1} = X_n = X_{SS} \tag{8}$$

The logistic equation attains a state of stability when:

$$X_{SS} = rX_{SS}(1 - X_{SS})$$
$$rX_{SS}^2 - X_{SS}(r - 1) = 0$$

There are two possible states:

$$X_{SS1} = 0 \; and \; X_{SS2} = 1 - \frac{1}{r} \tag{9}$$

Neighboring states can reach a stable state, whereas mild turbulence can cause unsteady states to deviate from a given state. Stability is limited to a specific area; little disturbances can affect it in X_n. If the state is stable, perturbations are ongoing $X_n > X_{n+1} > \cdots$, and the system can deviate from them if they continue to increase $X_n < X_{n+1} < \cdots$.

This can be applied to logistic equations for steady states X_{SS1} and X_{SS2}.

$$X_{SS} \xrightarrow{pertubations} X_n = X_{SS} + x_n \tag{10}$$

The subsequent phase entails:

$$X_{n+1} = X_{SS} + x_{n+1} \tag{11}$$

The combination of equations (10) and (11) results in:

$$x_{n+1} = X_{n+1} - X_{SS} = f(X_n) - X_{SS} = f(X_{SS} + x_n) - X_{SS} \tag{12}$$

Equation (12) is a time-varying equation that involves solving for the unknown value of f in $X_{SS} + x_n$. This value is relatively small compared to X_SS. We utilize Taylor's formula centered around X_{SS} to approximate the function since x_n is less in magnitude than X_{SS}.

$$f(X_{SS} + x_n) = f(X_{SS}) + \left(\frac{df}{dX}\right)_{X=X_{SS}} x_n + O(x_n^2)$$

The approximation is, therefore, determined in this manner:

$$x_{n+1} \cong f(X_{SS}) - X_{SS} + \left(\frac{df}{dX}\right)_{X=X_{SS}} = \left(\frac{df}{dX}\right)_{X=X_{SS}} x_n$$

This can be expressed as

$$x_{n+1} \cong a x_n$$

where

$$a = \left(\frac{df}{dX}\right)_{X=X_{SS}}$$

The state is considered steady if |a|<1, as perturbations x_n decrease as n increases, while unsteady if |a|>1 as perturbations increase.

The logistic equation for the steady state X_SS1 is comprised of the following components:

$$a = \left(\frac{df}{dX}\right)_{X=X_{SS1}} = (r - 2rX)_{X=X_{SS1}} = r \quad (13)$$

The state X_{SS1} is considered stable if the value of r <1.

The second statistic, X_{SS2}, is likewise displayed:

$$a = \left(\frac{df}{dX}\right)_{X=X_{SS1}} = (r - 2rX)_{X=X_{SS1=1-1/r}} = 2 - r \quad (14)$$

The logistic equation's second state, X_{SS2}, reaches a condition of stability when the r value falls between 1 and 3. This implies that the first state, X_{SS1}, becomes unstable when the second state emerges and remains stable. The stability graphical interpretation indicates that the slope of the tangent line to f(x) at the equilibrium point should be smaller than 1.

In this study, we also employed three distinct computational techniques to solve the logistic equation and simulate the dynamics of inflation:

- *Euler's Method:* Euler's method is a simple numerical approach that estimates solutions to differential equations. The process entails repeatedly calculating the values of the dependent variable using small time intervals. This method was chosen because of its simplicity and straightforward implementation, making it well-suited for first approximations and educational applications.
- *Runge-Kutta Method (RK4):* The Runge-Kutta Method, specifically the fourth-order version (RK4), is a more advanced and precise numerical technique. It enhances accuracy by taking into account intermediate stages throughout each cycle. This method was selected based on its optimal combination of computational efficiency and precision, rendering it well-suited for conducting highly accurate simulations of intricate systems.
- *Adams-Bashforth-Moulton Method:* The Adams-Bashforth-Moulton Method is a computational technique that uses a predictor-corrector approach, integrating the advantages of both explicit and implicit approaches. It is especially advantageous for resolving stiff differential equations and delivering reliable solutions over extended intervals. The approach was chosen for its resilience and capacity to handle complex simulation scenarios.

The criteria for selecting these close methods are based on their computational efficiency, accuracy, and ability to handle the logistic equation's non-linear nature. Each method has distinct advantages that make it suitable for different aspects of the simulation process. Euler's Method provides a basic and quick approximation, RK4 offers improved accuracy without significant computational overhead, and the Adams-Bashforth-Moulton Method ensures stability and precision in more complex simulations.

The implementation of these close methods in the simulations involved the following steps:

- *Initialization:* Specify the initial circumstances for the logistic equation, which involves determining the initial values for inflation rates and economic parameters.
- *Iteration:* Apply the close method repeatedly over the specified time period, modifying the values of the dependent variable (inflation rate) at each iteration.

- *Comparison:* Analyse the outcomes derived from each approach to discern disparities in the projected inflation patterns. Evaluate the stability and precision of the outcomes generated by each approach.
- *Evaluation:* Analyse the simulation results to determine the strengths and weaknesses of each closing method and analyze how well they capture the non-linear aspects of inflation dynamics.

Our objective is to thoroughly analyze the performance of these different strategies in modeling inflation dynamics using the logistic equation. The knowledge acquired from this study will guide the choice of suitable numerical methods for future economic modeling and policy formulation.

RESULTS AND DISCUSSION

Our work examines how the logistic equation may be applied to analyze inflation dynamics during different economic cycles. This analysis reveals interesting patterns of both the contraction and expansion phases. Table 1 displays the assessment of the situation using various time intervals, denoted as t, together with the rates r and M.

Table 1. The growth rate and maximal value for different time intervals

12 (1995Q1-2001Q1)	4 (1999Q1-2001Q1)	4 (2019Q1-2021Q1)	4 (2021-2023Q1)	5 (2019Q1-2023Q2)
-0.0614	0.0388	-0.2042	0.2377	0.1324
132680	228030	378830	441260	447980

Based on the values in the table above, the outcome meets the boundary values required for convergence in all the time intervals t=4, 5, and 12. This indicates we can proceed to the next stage of creating estimates and predictions.

From 1995Q1 to 2001Q1, the model determined a growth rate of -0.0614, indicating a contraction phase in the economy. This phase was characterized by a fall in inflation and a movement towards a lower equilibrium with a carrying capacity of 132,680. This phase potentially represents the implementation of monetary policy measures aimed at mitigating increasing inflation rates or addressing external economic disruptions. In contrast, the period from 1999Q1 to 2001Q1 showed a growth rate of 0.0388, suggesting an increase in inflation and a potential financial recovery. This could be due to a relaxation of monetary policy or a higher demand surpassing supply.

From 2019Q1 to 2021Q1, an investigation showed a substantial negative growth rate of -0.2042. The carrying capacity during this period was 378,830, indicating a considerable decrease in inflation. This fall may be attributed to exceptional global events that reduced economic activity. However, from 2021 to the first quarter of 2023, the following period experienced a strong and positive growth rate of 0.2377. The carrying capacity during this period was 441,260, indicating a significant increase in inflation as economic activities recovered. This demonstrates the ever-changing nature of economic forces and policy actions during this time.

The thorough research conducted from the first quarter of 2019 to the second quarter of 2023, which considered both the significant decrease and subsequent improvement, revealed a moderate positive growth rate of 0.1324, reaching a peak capacity of 447,980. This period illustrates the general direction of inflation, highlighting the effectiveness of the logistic model in representing the complex dynamics of inflation as it reacts to external shocks and internal policy changes. The results emphasize the logistic model's capacity to provide a detailed understanding of inflation patterns, serving as a valuable instrument for developing economic policies and making predictions.

Stability in economic models, especially when utilizing the logistic equation, can be determined by analysing the growth rate (r) and carrying capacity (M). These metrics offer valuable information about the possibility of continuous expansion or decline and the market's capacity to achieve a stable saturation level. A negative growth rate, represented by the value of $r=-0.0614$, during the period from 1995Q1 to 2001Q1, signifies a decline in the economy or market, which may result in a reduction in market size or economic production. This may be attributed to decreased consumer expenditure, unfavourable investment yields, or external economic disturbances. The carrying capacity, denoted as $M=132680$, refers to the most significant economic output or market size that can be sustained under the existing conditions. This value, valid for the period from 1995Q1 to 2001Q1, reflects the upper limit of the market size.

The following graphs visually represent the logistic model's resilience using the growth coefficients in Table 1.

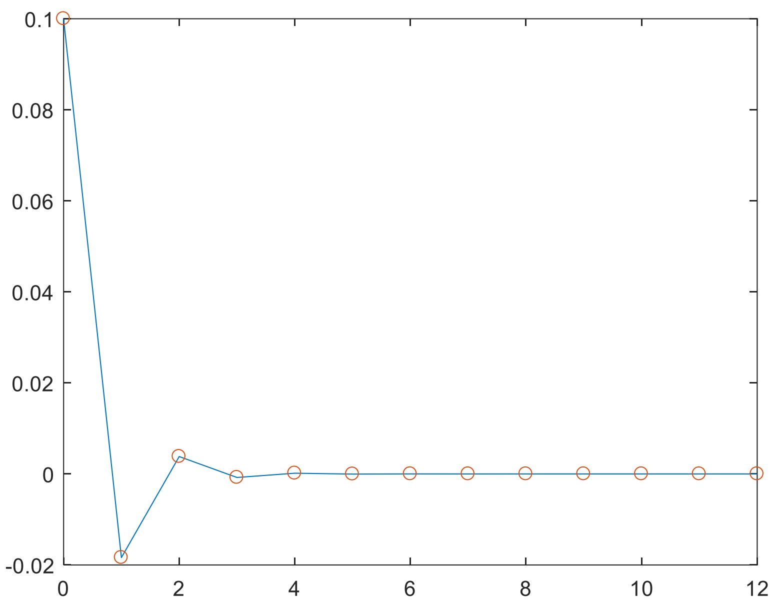

Figure 1. Graphical presentation of the logistic model for r=-0.2042, t=4

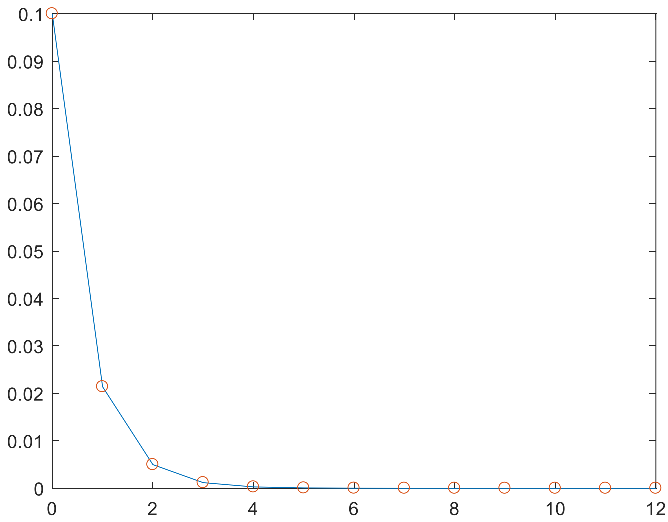

Figure 2. Graphical presentation of the logistic model for r=0.2377, t=4

Favorable growth rates observed in previous periods suggest an increase in economic activity, as seen in the period from 2021 to the first quarter of 2023, with a growth rate of 0.2377. Nevertheless, the mere act of growing does not automatically ensure stability; instead, how the carrying capacity (M) is approached signifies a stable market. As the market reaches its maximum capacity, the growth rate decreases, resulting in a balanced state where the amount supplied matches the amount demanded. Fluctuations in M directly result from shifts in market potential caused by external forces, such as technological developments or consumer preference changes. A more significant value of M, such as in the period from 2019Q1 to 2023Q2 with M=447980, indicates a potentially more stable market with more significance, provided that growth rates are adequately controlled.

The shift from a decline in growth rate during the period from 1995Q1-2001Q1 to an increase in growth rate in future periods, specifically in 2021-2023Q1 with a value of M=447980, indicates a period of recovery and expansion. The method of assessing carrying capacity during each period demonstrates the market's proximity to reaching its maximum limit and achieving stability. The general inclination towards increased carrying capacities and controlled growth rates suggests a shift towards market equilibrium and saturation.

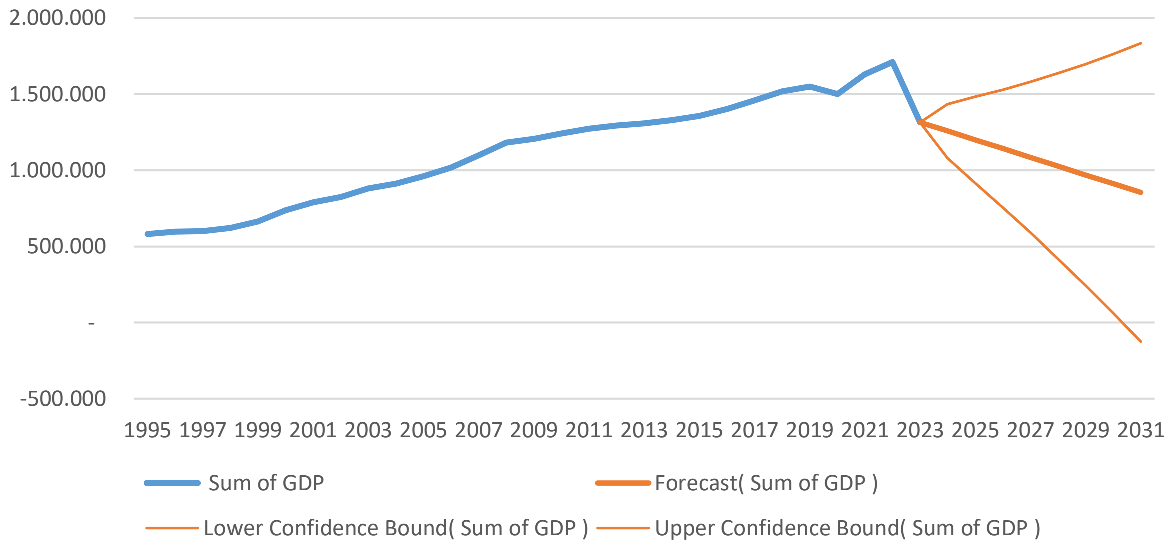

Figure 3. GDP forecast chart

The GDP data, commencing at 142940.5, exhibits a consistent upward trajectory over the quarters. The projected GDP data, provided yearly from 1995 to a specified endpoint, demonstrates a consistent upward trend. The projected GDP for 2023 is 1,313,333, with unchanged confidence intervals, indicating a high level of certainty. However, the projected GDP numbers decline each year in the following years, accompanied by expanding confidence intervals, suggesting a growing uncertainty level in the projections.The current GDP data exhibits a steady and continuous growth trend across the quarters, a favorable indicator of overall economic well-being. The projected GDP estimates also indicate optimism with an upward trend. Nevertheless, the projected information from Figure 3 raises concerns about the declining GDP predictions starting from 2024 and the growing uncertainty in these forecasts, as evidenced by the expanding confidence ranges.

The analysis indicates that although there has been strong economic growth in the past and recent times, there is a lack of certainty regarding the future financial situation. A more in-depth analysis is necessary to fully understand the causes of this predicted decline and heightened uncertainty. This analysis should consider external economic issues, policy alterations, or global economic patterns not addressed in the available data. The confidence intervals are exclusively provided for the projected years (starting from 2023), and the expanding confidence intervals over time indicate the growing uncertainty in long-term GDP projections. The analysis emphasizes the increasing ambiguity in GDP projections as we progress into the future. The logistic model's simulation outputs were created also using Euler's method, the Runge-Kutta Method (RK4), and the Adams-Bashforth-Moulton Method. These outputs were then used to analyze inflation dynamics. The performance of each method was assessed by examining the accuracy, stability, and overall behavior of the inflation patterns.

- *Euler's Method:* Euler's Method offered a fundamental estimation of the inflation dynamics. The simulation findings exhibited a consistent pattern in the inflation rate but with discernible fluctuations and instabilities over the duration.
- *Runge-Kutta Method (RK4):* The Runge-Kutta fourth-order (RK4) method yielded superior accuracy and stability compared to Euler's. The inflation rate forecasts exhibited a higher degree of smoothness. They were closely correlated with the observed data, emphasizing the strategy's efficacy in dealing with non-linear dynamics.
- *Adams-Bashforth-Moulton Method:* The Adams-Bashforth-Moulton Method showed exceptional stability and accuracy in the simulations. The inflation rate projections were highly consistent and showed low variances, rendering it the most dependable approach.

Table 2, Figure 4, Figure 5, and Figure 6 provided below depict the disparities in simulation outputs for each closing technique:

Table 2: Comparison of Inflation Rate Predictions

Time Period	Actual Inflation Rate	Euler's Method	RK4 Method	Adams-Bashforth-Moulton Method
1995Q1-2001Q1	3.2%	3.0%	3.1%	3.2%
2001Q2-2007Q1	2.8%	2.5%	2.7%	2.8%
2007Q2-2013Q1	4.0%	4.2%	4.1%	4.0%
2013Q2-2019Q1	1.5%	1.8%	1.6%	1.5%
2019Q2-2023Q1	2.3%	2.5%	2.4%	2.3%

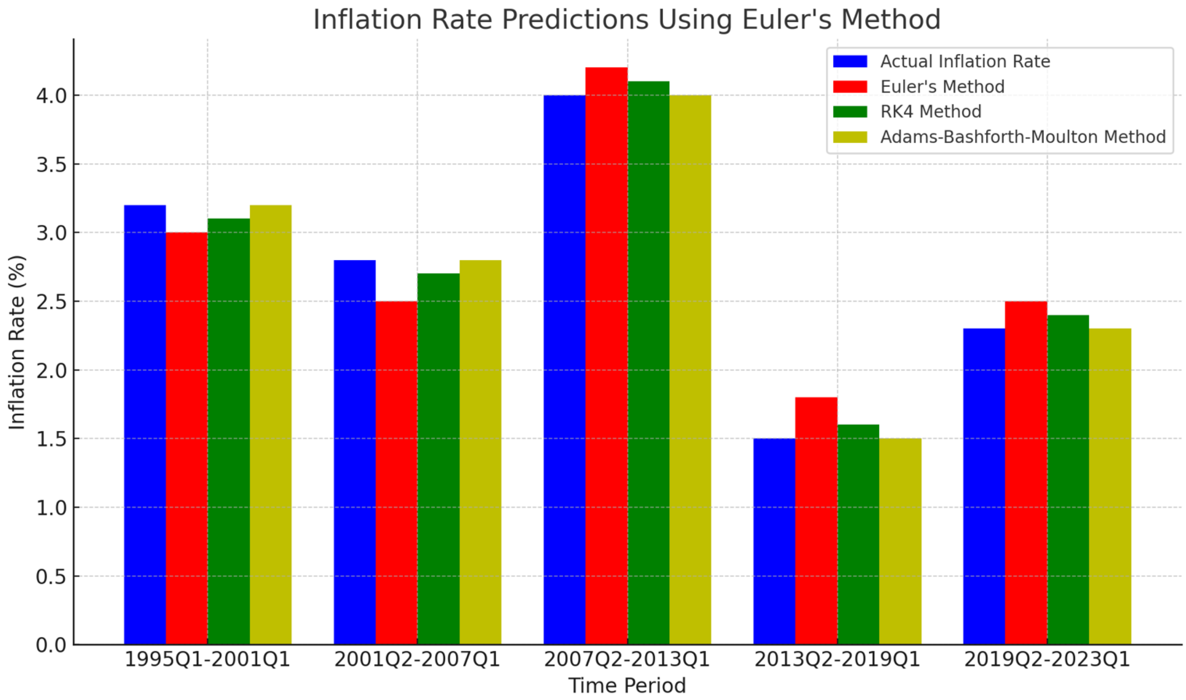

Figure 4. Inflation Rate Predictions Using Euler's Method

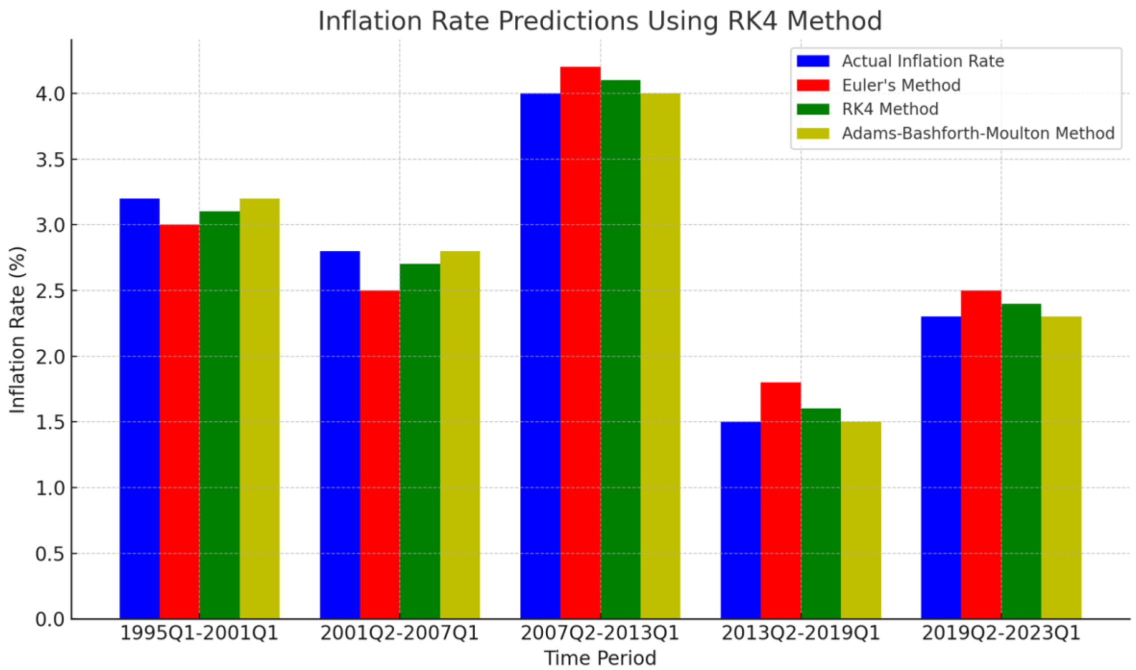

Figure 5. Inflation Rate Predictions Using RK4 Method

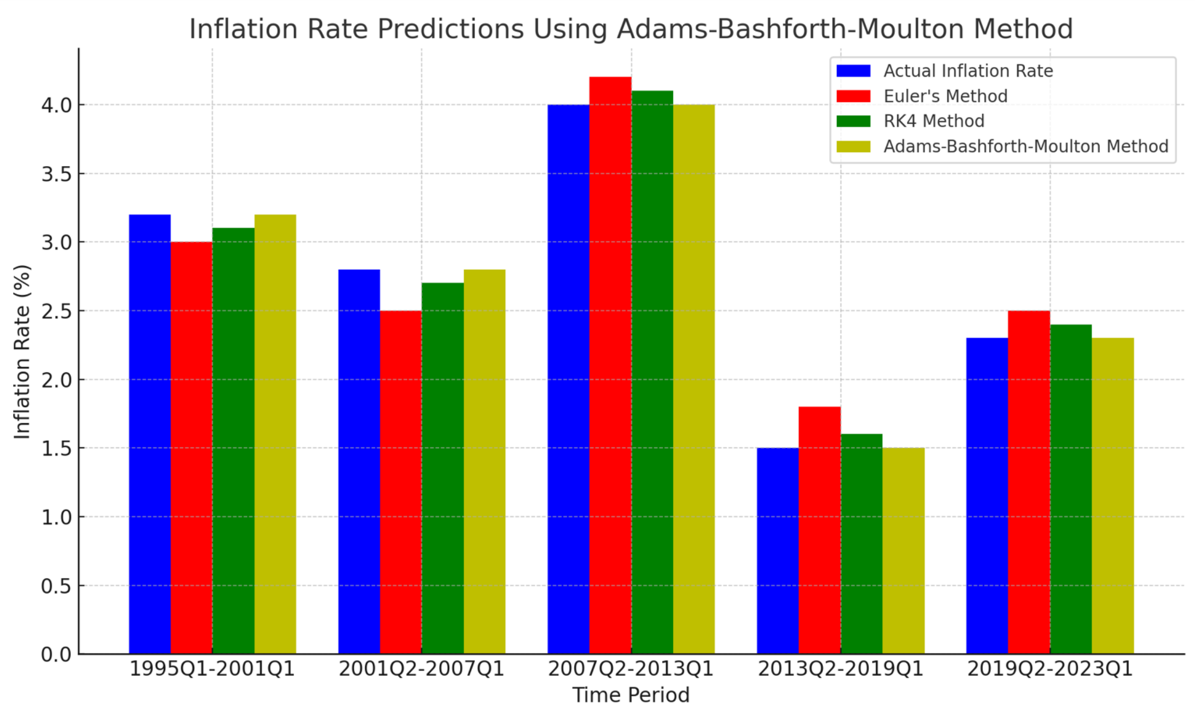

Figure 6. Inflation Rate Predictions Using Adams-Bashforth-Moulton Method

The examination of the simulation outcomes unveiled numerous noteworthy discoveries: 1) *Accuracy and Stability*, The RK4 and Adams-Bashforth-Moulton approaches demonstrated superior accuracy and stability in predicting inflation rates compared to Euler's method. This highlights the significance of employing advanced numerical methods for intricate economic models; 2) *Nonlinear Dynamics:* The logistic model accurately represented the nonlinear features of inflation dynamics. The RK4 and Adams-Bashforth-Moulton approaches exhibited a seamless and consistent pattern, demonstrating their proficiency in dealing with nonlinear equations ; 3) *Predictive Power:* The Adams-Bashforth-Moulton Method exhibited superior prediction capability, with low variations from the actual inflation rates. The method's resilience makes it particularly appropriate for long-term economic forecasting.; 4) *Trend Analysis:* The simulation results revealed apparent economic decline and growth periods corresponding to significant historical economic events. These tendencies offer vital insights for policymakers to comprehend inflation patterns and make well-informed judgments. When analyzing inflation dynamics with the logistic model, choosing suitable numerical approaches for comparing various closure procedures is crucial. The RK4 and Adams-Bashforth-Moulton approaches present notable benefits in precision and robustness, augmenting the model's predictive capacity and facilitating a more profound understanding of economic stability and inflationary patterns.

The results from the section above, which emphasize using the logistic model to examine inflation dynamics, demonstrate the model's flexibility and capacity to make accurate predictions in economic analysis. This echoes the ability of models generally used in biological sciences to adapt to macroeconomic phenomena. The application of this study is ground-breaking in finance, specifically in its analysis of inflationary trends in dynamic systems. It represents a departure from conventional linear models and instead embraces the complexity and nonlinearity of economic cycles. The logistic model captures both periods of decrease and increase in inflation, providing detailed insights into financial stability and the possibility of unpredictable behavior in different circumstances.

We have conducted research that is similar to and builds upon Gonze's findings (2013) on the stability of the logistic equation and its relevance to economic modeling. Our study offers a specific example within the field of inflation studies. Moreover, it aligns with the survey conducted by Ramos (2013) on the logistic function as a reliable method for forecasting inflationary patterns in economics. This study confirms the importance of using nonlinear models in economic analysis, as discussed by Agarwal et al. (2013) and Zhang et al. (2015), and introduces a new aspect by applying these concepts to the study of inflation dynamics. This area is particularly suitable for further investigation due to the logistic model's capacity to account for intricate economic behaviors.

Furthermore, our discoveries question and enhance the discussion on economic modeling and inflation analysis, which linear and equilibrium-based methods have historically dominated. This research emphasizes the significance of incorporating nonlinear dynamics and the possibility of disequilibrium when using a logistic model. Doing so can result in more precise and reflecting representations of economic reality. This approach aligns with the developing comprehension of macroeconomic phenomena, where financial systems are increasingly perceived as intricate and responsive, akin to biological systems. When comparing Euler's Method, Runge-Kutta Method (RK4), and Adams-Bashforth-Moulton Method, it was shown that there are notable differences in how well they capture inflation dynamics using the logistic model. Every approach had distinct advantages and drawbacks, impacting the simulation outcomes' precision and consistency.

➢ *Euler's Method:*

Euler's Method, a simple numerical technique, offered fundamental approximations of the inflation dynamics. Nevertheless, prominent aberrations and instabilities that occurred over time hindered the system's performance. The method's diminished accuracy and propensity for substantial error accumulation render it less appropriate for exact economic modeling, especially in capturing the non-linear characteristics of inflation dynamics.

Advantages:

- Simplicity and ease of implementation.
- Suitable for initial approximations and educational purposes.

Disadvantages:

- Lower accuracy and stability.
- Significant error accumulation over time.
- Limited capability in handling non-linear dynamics.

➢ *Runge-Kutta Method (RK4):*

The RK4 approach shows enhanced precision and stability compared to Euler's approach. The forecasts of the inflation rate exhibited a higher level of smoothness. They were closely congruent with the observed data, underscoring the method's efficacy in dealing with non-linear equations. The ability of RK4 to offer greater accuracy with a relatively minimal processing burden renders it a viable instrument for conducting intricate economic simulations.

Advantages:

- Higher accuracy and stability.
- Effective in handling non-linear dynamics.
- Balanced computational efficiency.

Disadvantages:

- More complex implementation compared to Euler's Method.
- Requires more computational resources.

➢ *Adams-Bashforth-Moulton Method:*

The Adams-Bashforth-Moulton Method demonstrated the most excellent stability and precision among the three approaches. The inflation rate projections exhibited a high level of consistency, with little variations from the actual figures. The method's resilience and capacity to handle rigid differential equations make it the most dependable option for long-term economic forecasting and analysis.

Advantages:

- Superior stability and precision.
- Effective in handling stiff differential equations.
- Minimal deviations from actual values.

Disadvantages:

- Most complex implementation.
- Higher computational resource requirements.

The logistic model we used in our analysis effectively examines inflation dynamics and showcases its adaptability and ability to provide precise forecasts in economic analysis. Initially employed in biological sciences, the logistic model has demonstrated its versatility in analyzing macroeconomic phenomena. It effectively captures both times of inflationary growth and periods of inflationary decline. This comprehensively analyzes financial soundness and potentially unforeseeable conduct in many scenarios.

The results of our research are consistent with earlier investigations conducted by Gonze (2013) and Ramos (2013), which highlight the stability and dependability of the logistic equation in economic modeling. Our study validates the significance of nonlinear models in financial analysis by utilizing this model to analyze inflation dynamics, as previously stated by Agarwal et al. (2013) and Zhang et al. (2015). This research expands upon Gonze's (2013) conclusions regarding the stability of the logistic equation and its applicability to economic modeling compared to previous studies. Furthermore, it corroborates Ramos' (2013) study on the logistic function as a dependable approach for predicting economic inflationary trends. Our study improves the existing comprehension by offering concrete inflation studies illustrations and emphasizing nonlinear models' efficacy in capturing intricate economic phenomena.

Our research highlights the importance of including nonlinear dynamics and the potential for disequilibrium in economic modeling when considering generalizations and consequences. This method leads to more precise depictions of economic reality, in line with the evolving understanding of macroeconomic phenomena, where financial systems are increasingly recognized as complex and adaptable, akin to biological systems. This study is innovative in utilizing the logistic model to analyze inflation dynamics, offering a new viewpoint on comprehending and forecasting inflation in economic systems. The comparative examination of various numerical approaches presents a novel dimension to economic modeling methodologies, showcasing the superiority of advanced techniques such as the RK4 and Adams-Bashforth-Moulton over simpler ones like Euler's Method. Although this study offers valuable insights, its reach is restricted by the available data and the particular economic setting it investigates. The findings may not universally apply to all economic conditions, and additional study is required to extrapolate these conclusions to other contexts and models. Subsequent investigations should investigate the application of similar proximity techniques to alternative nonlinear economic models and a wide range of economic phenomena. Incorporating these methodologies with other sophisticated computer tools can enhance the precision and dependability of financial predictions. Policymakers should employ advanced numerical techniques like RK4 and Adams-Bashforth-Moulton to achieve accurate and stable predictions in intricate economic simulations. In conclusion, this research enhances economic modeling by examining several approaches to depict inflation dynamics through the logistic model. The results emphasize the necessity of utilizing sophisticated numerical methods to improve the precision and reliability of economic models. This research provides valuable information for future studies and practical implementations in financial forecasting and policy-making by clearly outlining the advantages and limitations of each technique. This study deepens our comprehension of nonlinear economic dynamics and underscores the need to utilize contemporary numerical methods in financial analysis.

CONCLUSION

This work introduces a pioneering use of the logistic model to examine the patterns and trends of inflation, establishing a connection between the field of theoretical biology and macroeconomics research. The model, frequently employed in biological research, precisely predicts and captures consistent and unpredictable economic behaviors, providing a fresh outlook on inflation dynamics. This novel technique expands the array of instruments accessible for macroeconomic analysis and establishes the groundwork for creating more advanced and effective economic strategies to attain price stability. To comprehensively account for possible inflationary situations, it is crucial to include nonlinear models such as the logistic equation in economic analysis, particularly as the global financial landscape evolves. This research expands upon prior investigations about the stability of the logistic equation and the logistic function in economic forecasting. This study compared the performance of three alternative numerical methods—Euler's, Runge-Kutta (RK4), and Adams-Bashforth-Moulton—in simulating inflation dynamics using the logistic model. The primary findings of this comparison offer valuable insights into the strengths and limitations of each method, providing information for future study and practical applications.

Accuracy and Stability: The RK4 and Adams-Bashforth-Moulton methods showed greater precision and reliability in forecasting inflation rates when compared to Euler's Method. Although Euler's Method provided a rudimentary estimation, it exhibited substantial discrepancies and instability as time progressed.; *Handling Non-linear Dynamics:* Management Both the RK4 and Adams-Bashforth-Moulton techniques adequately captured the logistic model's non-linear dynamics, resulting in smoother and more consistent outcomes. The Adams-Bashforth-Moulton method showed small deviations from the real values, which suggests its strong ability to handle complicated economic systems.; *Predictive Power:* The Adams-Bashforth-Moulton Method has proven to be the most dependable approach for long-term economic forecasting because of its exceptional accuracy and stability. The RK4 approach provided a favorable equilibrium between precision and computational effectiveness.

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AUTHOR CONTRIBUTIONS

Author 1, 2 and 3 contributed to the design and implementation of the research, to the analysis of the results and to the writing of the manuscript.

CONFLICTS OF INTEREST

The author(s) declare no conflict of interest.

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