A Fuzzy Logic Approach to Adjusting Monetary Policies in North African Countries

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Abstract:

The study explores the use of fuzzy logic as mathematical approach that handles uncertainty by allowing variables to belong to multiple categories with varying degrees of membership.in analyzing exchange rate fluctuations in Algeria and Tunisia. Using trapezoidal membership functions defined as Low, Medium, and High, the methodology applies fuzzy logic to historical exchange rate data, enabling partial membership across categories and offering a flexible analytical framework. In Algeria, where the exchange rate ranges from 45 to 150, results indicate high volatility, reflected in broader membership intervals (Low: 0.8 at 50, Medium: 0.9 at 75, High: 1.0 at 125). In contrast, Tunisia's exchange rate, ranging from 0.3 to 2.5, shows a more stable environment, with narrower membership ranges (Low: 1.0 at 0.5, Medium: 0.8 at 1.5, High: 0.5 at 2). These findings demonstrate that fuzzy logic improves the interpretation of exchange rate dynamics, enhances forecasting accuracy, supports effective risk management, and strengthens policy formulation—providing a strategic tool for economic decision-making in both countries..

Keywords : Fuzzy logic, exchange rates, fuzzy functions, risk management.

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1.Introduction:

The exchange rate plays a pivotal role in macroeconomic policy, shaping inflation, the trade balance, and foreign reserves(Benmessaoud & Guelmine, 2024).. In North Africa, Algeria and Tunisia operate under distinct exchange rate regimes that frequently diverge between formal declarations and actual practices due to considerations related to inflation, external shocks, and macroeconomic stability(Hasni & Azzaoui, 2024).. While Algeria exhibits an almost structural dependence on hydrocarbon rents as its primary income source, Tunisia relies on tourism alongside several other sectors, rendering both economies vulnerable to global commodity price fluctuations. In both countries, central bank interventions help curb short-term volatility; however, they also generate risks such as real effective exchange rate (REER) misalignment and eroding competitiveness(Benmessaoud & Guelmine, 2024; Hasni & Azzaoui, 2024).. Traditional models consequently struggle to capture the complexity of these dynamics, as multiple economic factors interact under substantial ambiguity and uncertainty. This context underscores the value of fuzzy logic as a flexible framework that offers a more suitable environment for addressing uncertainty associated with exchange rate behavior. Accordingly, this study employs fuzzy-logic inference to examine monetary policy in Algeria and Tunisia, eliciting insights that conventional approaches may overlook and clarifying the implications for more effective economic strategies.

1.1.Problematic of the Study:

Despite official commitments to stable exchange rate regimes, North African economies continue to experience significant REER misalignments due to their reliance on primary commodity exports and frequent external shocks. Traditional econometric models inadequately capture the nonlinear and ambiguous dynamics of these fluctuations, limiting their policy relevance. This study addresses these gaps by applying fuzzy mathematical programming to better analyze exchange rate movements, aiming to inform more flexible and effective economic policies for the region.

1.2.Previous studies:

Kacprzyk, J., & Orlovski, S.A.study (1987) introduced a comprehensive framework for fuzzy optimization and mathematical programming, emphasizing key concepts such as fuzzy constraints, goals, and optima. Published in 1987, the study adopts a theoretical and conceptual methodology, exploring various programming techniques, including fuzzy linear programming, integer programming, and dynamic programming, to address uncertainty and imprecision in decision-making scenarios. The results highlight the significant flexibility and adaptability of fuzzy mathematical programming in solving complex optimization problems, particularly in financial applications like exchange rate modeling, where uncertainty and nonlinearities are prevalent.

Leandro Maciel and Rosangela Ballini study (2020) introduced an interval fuzzy rule-based (iFRB) model for forecasting interval-valued time series in exchange rates. The methodology employs functional fuzzy rules to capture nonlinear relationships in interval-valued data, making it particularly effective for volatile financial variables like exchange rates. The study applies the iFRB model to forecast the EUR/USD exchange rate and compares its performance with traditional econometric models. The results demonstrate that the iFRB model outperforms other approaches in terms of accuracy, highlighting the effectiveness of fuzzy logic in managing uncertainty and volatility in financial data.

1. The theoretical framework of the study

1.1 **Fuzzy Mathematical Programming**

Fuzzy mathematical programming is an advanced tool used to address uncertainties and complexities in financial modeling, particularly in volatile environments such as exchange rate forecasting. Unlike traditional econometric models, fuzzy logic incorporates expert knowledge and subjective judgments through "if-then" rules and membership functions, enabling better representation of uncertainty and nonlinear relationships inherent in financial systems (Song & Chissom, 1993; Kacprzyk & Orlovski, 1987). This flexibility makes it an effective method for analyzing complex financial phenomena.

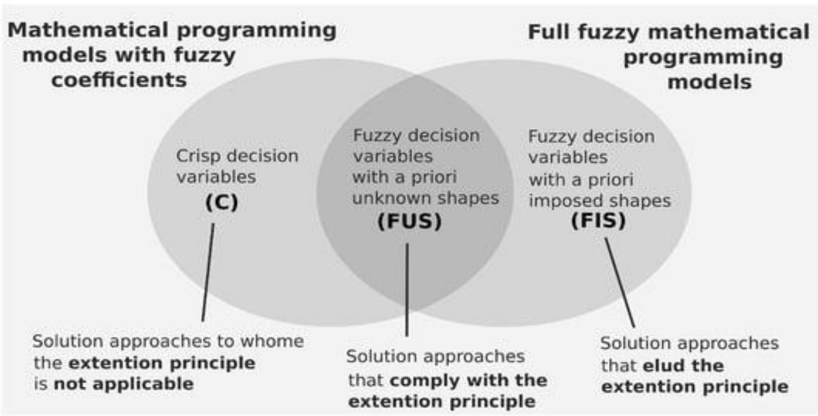
In the context of exchange rate forecasting, fuzzy models have demonstrated superior performance in predicting volatility and identifying patterns of appreciation or depreciation. For example, hybrid models that combine fuzzy time series with techniques like Markov chains or ARIMA have shown higher accuracy compared to classical methods (Tsaur, 2012; Redalyc, 2019). These models are particularly effective in high-volatility scenarios, such as those observed in emerging markets like Algeria. By integrating fuzzy logic into exchange rate modeling, policymakers can obtain more reliable insights into currency dynamics, which can aid in decision-making processes for monetary policy and economic planning (Redalyc, 2019; Tsaur, 2012).

1.2. **Fuzzy Mathematical Programming in Financial Contexts**

Fuzzy mathematical programming is an optimization technique designed to handle problems with uncertainty and imprecision. Unlike traditional programming, which assumes precise parameters, it uses fuzzy sets to represent ambiguous data, allowing for soft constraints and flexible objective functions that better reflect real-world complexities (Inuiguchi & Sakawa, 1998; Optimization Wiki, 2020).

Constraints in fuzzy programming are treated as fuzzy sets with membership functions defining satisfaction levels, from fully to partially satisfied. This approach is particularly useful in financial modeling, where uncertainties in parameters like exchange rates or economic indicators are common. By maximizing the membership degree of the objective function while meeting fuzzy constraints, this method provides a practical framework for decision-making under uncertainty (Dostál & Jankova, 2024; Optimization Wiki, 2020).

Fig (1): Classification of Mathematical Programming Models with Fuzzy Components



Source: Baykasoglu, A., & Göçken, T. (2008).

1,3 Effectiveness of Fuzzy Models in Exchange Rate Forecasting

The use of fuzzy models in exchange rate forecasting has garnered significant attention due to their ability to address uncertainty and nonlinearity, which are inherent in financial data. Numerous studies have demonstrated the superiority of fuzzy-based methods over traditional approaches. For example, a hybrid fuzzy time series (FTS) model combined with ARIMA was shown to outperform conventional models such as EGARCH and PARCH in forecasting the Mexican Peso/US Dollar exchange rate. This model provided enhanced visualization of exchange rate uncertainty and effectively identified patterns of appreciation and depreciation, even in highly volatile environments (Reyes & Aké, 2023).

Similarly, the fuzzy time series-Markov chain model has been proposed to improve forecasting accuracy by integrating temporal dynamics with fuzzy logic. This approach significantly reduced errors, as evidenced by a lower Mean Absolute Percentage Error (MAPE) compared to standalone fuzzy models. Its effectiveness was demonstrated in predicting the Malaysian Ringgit/Singapore Dollar exchange rate, achieving a MAPE value of 0.9895%, which falls under the criterion for highly accurate forecasting (Universiti Malaysia Terengganu Journal of Undergraduate Research, 2021).

Another innovative method utilized hesitant fuzzy sets combined with advanced optimization algorithms. This approach demonstrated superior performance in capturing complex exchange rate behaviors and producing more accurate forecasts than traditional econometric models. The hesitant fuzzy sets allowed for multiple membership grades, improving the representation of uncertainty in exchange rate data (Processes, 2021). These studies highlight the adaptability and precision of fuzzy methodologies in addressing the challenges of exchange rate forecasting**.**

1.4. Traditional vs. Fuzzy-Based Approaches: A Comparative Analysis

Traditional models, such as ARIMA, EGARCH, and PARCH, have been widely used for exchange rate forecasting but often struggle with high volatility and nonlinearity in financial data. Their reliance on rigid statistical assumptions limits their ability to capture uncertainties and dynamic patterns effectively. For instance, ARIMA provides precise point forecasts but lacks the capability to represent prediction intervals, which are crucial for understanding financial volatility (Petrică et al., 2016; Ahmad et al., 2023).

Fuzzy-based approaches overcome these limitations by using linguistic variables and membership functions to model uncertainty. Fuzzy time series (FTS) models outperform traditional methods by providing both point and interval forecasts, essential for analyzing volatility clusters. Hybrid models like FTS-ARIMA or FTS-Markov chain enhance accuracy by integrating probabilistic transitions with fuzzy logic, making them particularly effective in volatile markets (Universiti Malaysia Terengganu Journal of Undergraduate Research, 2021; Reyes & Aké, 2023).

Advanced techniques like Fuzzy Support Vector Regression (F-SVR) combine machine learning with fuzzy logic principles to achieve superior p rediction accuracy. For example, experiments on USD-INR datasets revealed that F-SVR with radial basis kernel functions outperformed classical SVR kernels in terms of accuracy and error reduction (International Journal of Intelligent Systems and Applications in Engineering, 2023).

3.3. Model Formulation for Algerian Dinar Exchange Rate Analysis

The formulation of a fuzzy mathematical programming model for analyzing the Algerian Dinar exchange rate involves several key components:

3.3.1 Objective Function: The primary goal could be to minimize prediction errors or maximize forecasting accuracy

$$Maximize\ \mu\ \overline{G}\ (f(x))$$

where $\mu\ \overline{G}$ represents the membership function of a fuzzy goal set $\overline{G}$ and $f(x)$ is the objective function.

3.3.2 Constraints in Fuzzy Mathematical Programming: Constraints in fuzzy mathematical programming include both deterministic and fuzzy constraints. Deterministic constraints, such as budget limits, are fixed and precise. On the other hand, fuzzy constraints allow for partial satisfaction and are expressed using membership functions. These membership functions define the degree to which a solution satisfies the constraint, ranging from fully satisfied to partially satisfied. For example, fuzzy constraints can be represented as:

$$Ax \in \bar{B}$$

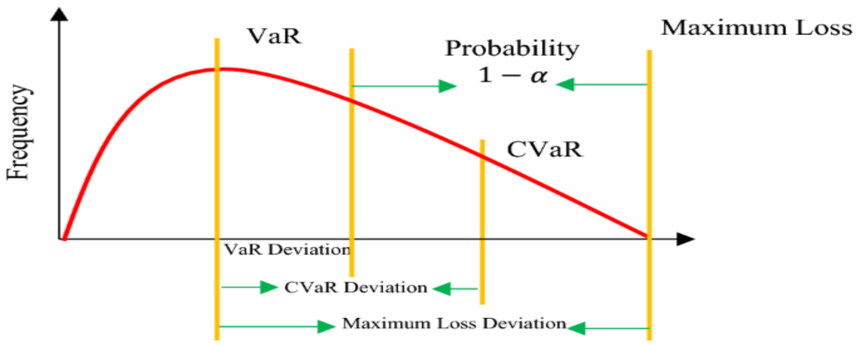
where $\bar{B}$ represents a fuzzy set of acceptable values (Zimmermann, 1997; Inuiguchi & Ramík, 2000). This approach provides flexibility in optimization problems by accommodating imprecision and uncertainty in real-world scenarios. It is particularly useful when strict adherence to constraints is not feasible or when trade-offs are necessary (Veeramani & Sumathi, 2014).

3.3.3 Fuzzy Variables in Mathematical Programming In fuzzy mathematical programming, parameters such as exchange rates are treated as fuzzy numbers to account for their inherent uncertainty. This approach allows for the representation of imprecise or ambiguous data, which is common in real-world financial systems. For instance, fuzzy variables can be expressed as:

$$x_i = a + b\epsilon$$

where a represents the mean value, b denotes the uncertainty interval, and ϵ is a shape parameter defining the degree of fuzziness (Veeramani & Sumathi, 2014; Hamadameen & Zainuddin, 2013). By incorporating fuzzy numbers, this methodology enhances the flexibility and adaptability of optimization models, making them more suitable for handling uncertainty in complex decision-making scenarios.

Fig(2): Risk Functions: Graphical Representation of VaR and CVaR



Source: ResearchGate, from the publication Risk functions: graphical representation of VaR, Deviation, CVaR, Deviation, and Maximum Loss Deviation.

2. The experimental framework for the study

2.1 Description of Data Sources and Preprocessing

The study utilizes historical exchange rate data for the Algerian Dinar against the US Dollar, sourced from reliable institutions such as central banks, international organizations (e.g., International Monetary Fund), and financial databases. Examples include the European Central Bank (ECB) and BIS Data Portal, which provide daily exchange rates spanning decades to capture long-term trends (European Central Bank, 2023; BIS Data Portal, 2023).

Data Preprocessing Steps

- ✓ Cleaning: This step addresses missing values, outliers, and inconsistencies in the raw data to enhance accuracy.
- ✓ Normalization: Data is scaled to ensure uniformity, particularly when combining datasets from different sources.
- ✓ Feature Engineering: Additional variables such as inflation rates, oil prices, or GDP are incorporated to account for factors influencing exchange rates.
- ✓ Visualization: Tools like line plots and histograms are utilized to identify trends and anomalies in the data (Hasni & Azzaoui, 2024; Benmessaoud & Guelmine, 2024).

2.2 Solution Methodology

Possibilistic programming handles uncertainty by maximizing the possibility of achieving optimal solutions while considering imprecise constraints and objectives. It transforms uncertain parameters into possibility distributions, enabling decision-makers to manage vagueness in real-world scenarios (Inuiguchi & Ramík, 2000).

Hybrid models:

Hybrid models integrate fuzzy logic with traditional statistical approaches like ARIMA or advanced time-series techniques. These models aim to:

- ✓ Enhance forecasting accuracy by leveraging the strengths of different methodologies.
- ✓ Maximize membership values while respecting both hard and soft constraints.

This flexible framework provides more accurate solutions for complex forecasting problems (Romain et al., 2023; Aminian et al., 2006).

Methodology

- **Data source** ***https://perspective.usherbrooke.ca/bilan/servlet/BMTendanceStatPays?langue=fr&codePays=DZA&codeStat=PA.NUS.FCRF&codeStat2=x***
- **Study period:** 1960–2023 (annual). Note any gaps in availability, definitional breaks, or revisions. Specify any transformations applied (e.g., logs, differences) and alignment procedures across series.
- **Selection criteria for Algeria and Tunisia:** Selected for methodological reasons: both countries share exposure to external shocks yet differ structurally and institutionally in exchange-rate management. Algeria operates a managed-flexibility arrangement with pronounced rent dependence, linking exchange-rate dynamics to energy-market volatility and, at times, monetary financing in episodes of recurrent fiscal deficits. Tunisia relies on globally integrated sectors (tourism, services, light manufacturing) under a more competitiveness-oriented and comparatively transparent exchange-rate framework. The shared regional context and the availability of long time series for key indicators (REER, inflation, balance of payments, commodity prices, tourism flows) enable cross-period, cross-regime comparative testing. This combination supports the identification of interpretable rules, tracing of effects, and mapping of model outputs into an integrated framework for policy, competitiveness, and monetary stability.

3. Model Development

3.1 Incorporation of Fuzzy Logic into Exchange Rate Modeling

Fuzzy logic has become increasingly popular in exchange rate modeling due to its ability to handle uncertainty and nonlinear relationships in financial data. By transforming vague or imprecise inputs into linguistic variables using membership functions, fuzzy logic provides a flexible framework for analyzing complex financial systems.

✓ Applications: Fuzzy-based models have been applied to foreign exchange forecasting, where they often outperform traditional models by better capturing the chaotic nature of exchange rate movements (Korol, 2014).

✓ Hybrid Approaches: Hybrid models, such as combining fuzzy logic with support vector regression (F-SVR), have demonstrated improved accuracy in predicting exchange rates. These models integrate fuzzy membership functions to manage uncertainties in the data, enhancing prediction reliability (International Journal of Intelligent Systems and Applications in Engineering, 2023).

3.2 Constructing and Optimizing the Fuzzy Model

The process of constructing and optimizing a fuzzy model for exchange rate forecasting involves several key steps:

▪ Data Preprocessing: Historical exchange rate data is cleaned and normalized to remove noise and ensure consistency. This step is crucial for improving the quality of input data (Leu et al., 2009).

▪ Fuzzification: The universe of discourse is divided into intervals using membership functions (e.g., triangular or Gaussian). Linguistic terms such as "high," "medium," or "low" are assigned to these intervals to represent levels of variables (Ferrer-Comalat et al., 2021).

▪ Rule Construction: Fuzzy rules are developed based on expert knowledge or data-driven methods. For example, a rule might state: "IF inflation is high AND oil prices are low, THEN the exchange rate will depreciate."

▪ Optimization: Advanced algorithms such as genetic algorithms or electromagnetic field optimization are used to fine-tune the parameters of membership functions and rules, ensuring optimal performance (Hernandez Medina et al., 2007).

▪ Defuzzification: The final step involves converting fuzzy outputs into crisp values using methods like centroid defuzzification, enabling actionable predictions (Processes, 2021).

3.3 Managing Uncertainty and Nonlinear Patterns in Exchange Rate Forecasting

Exchange rates are influenced by multiple factors, including economic indicators and geopolitical events, which introduce significant uncertainty and nonlinearity. Fuzzy logic addresses these challenges by enabling approximate reasoning and accommodating imprecise input data.

- **Fuzzy Time Series Models:** Combining fuzzy time series models with Markov chains effectively captures temporal patterns and reduces forecasting errors, achieving higher accuracy compared to standalone models (University Malaysia Terengganu Journal of Undergraduate Research, 2021).
- **Type-2 Fuzzy Systems**: These systems extend traditional fuzzy logic by incorporating additional layers of uncertainty through interval-based membership

functions. They have proven particularly effective in managing non-stationary noise and dynamic behaviors in financial datasets (Hernandez Medina et al., 2007).

4. Results and Discussion

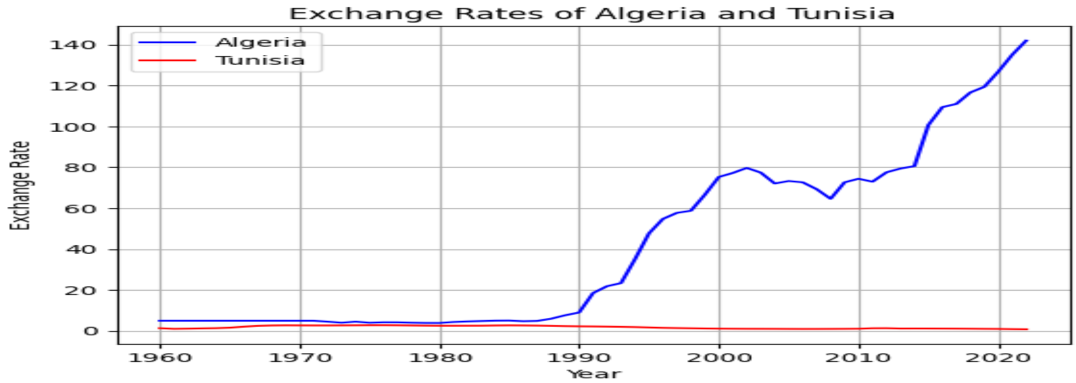
The case study applies the developed fuzzy logic-based model to forecast the Algerian Dinar (DZD) exchange rate. By analyzing historical data and time variations, the study aims to capture the key factors influencing the Dinar's movements, such as oil prices and inflation, and assess the model's effectiveness in handling uncertainties and nonlinear patterns in exchange rate fluctuations.

Table (1): Selected Data on Exchange Rates for Algeria and Tunisia (1960–2023)

Year	ALG.EX	TUN.EX
1960	4.937	0.420
1961	4.937	0.420
1962	4.937	0.420
….	…	…
2023	135.843	3.106

Source: https://perspective.usherbrooke.ca/

Fig(3): Exchange rates of the north Africa countries



Source: Created by the researchers based on R

The figure shows the exchange rates of Algeria and Tunisia from 1960 to 2020. Algeria's exchange rate (blue line) demonstrates a significant increase starting in the late 1980s, peaking around 2010, and then stabilizing at a high level. In contrast, Tunisia (red line) exhibit relatively stable exchange rates throughout the period, with only slight increases over time. The sharp rise in Algeria's exchange rate suggests a devaluation of its currency relative to others, likely due to economic or policy changes during that time. Tunisia maintained more consistent exchange rate policies or economic stability compared to Algeria.

4.1. Descriptive Statistics

Descriptive statistics provide an essential foundation for analyzing data by summarizing key measures such as central tendency, dispersion, and range. This step helps identify patterns, trends, and variability within datasets, offering valuable insights for informed decision-making and further statistical modeling.

Table (2): Summary of Exchange Rate Statistics for Algeria and Tunisia

Statistic	Algeria	Tunisia
Min	3.83700	0.402000
1st Quartile	4.93700	0.524500
Median	20.15450	0.935500
Mean	42.99347	1.114156
3rd Quartile	74.60450	1.380250
Max	141.99500	3.106000

Source: Created by the researchers based on R

Algeria shows extreme exchange rate volatility, with values ranging from 3.837 to 141.995, a mean of 42.99347, and a median of 20.1545. This wide spread reflects deep currency devaluation over time, likely influenced by inflation, external shocks, and weak monetary control. The large gaps between quartiles further highlight persistent instability in Algeria's exchange rate behavior. In contrast, Tunisia demonstrates a relatively stable exchange rate pattern, with values ranging from 0.402 to 3.106, a mean of 1.114156, and a median of 0.9355. The narrow range and low central tendency suggest stronger monetary policy management, reduced exposure to severe currency shocks, and more effective control over exchange rate fluctuations compared to Algeria.

4.2. Fuzzy Mathematical Modeling

- **Fuzzy Setps for modeling Inputs (ALG.EX, TUN.EX)**

The fuzzy sets defined as `$Low` [0.00, 0.25, 0.50], `$Medium` [0.25, 0.50, 0.75], and `$High` [0.50, 0.75, 1.00] serve as linguistic representations of exchange rate levels, capturing distinct economic conditions. These sets classify the normalized exchange rate data into meaningful categories, facilitating an analysis that blends mathematical precision with economic interpretation.

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Table(3) :Fuzzy function classification used

alg_range <- seq(min(data$ALG.EX), max(data$ALG.EX), length = 100)
tun_range <- seq(min(data$TUN.EX), max(data$TUN.EX), length = 100)

Source: Created by the authers based on R

- ✓ The **Low exchange rate** range denotes a strong domestic currency relative to the reference currency, typically benefiting importers through reduced import costs but potentially harming export competitiveness.
- ✓ The **Medium exchange rate** range reflects a balanced or moderate currency valuation, implying a stable trade environment with minimal risks to either imports or exports.
- ✓ The **High exchange rate** range indicates a weaker domestic currency, often resulting in increased costs for imported goods while enhancing the competitiveness of exports. This condition may also contribute to inflationary pressures and economic strain on businesses reliant on imports.

Such classifications are invaluable for assessing exchange rate risks, informing monetary policies, and guiding strategic business decisions. For instance, policymakers can intervene to stabilize the currency during periods of high exchange rate volatility, while businesses can adapt their trade strategies based on the prevailing rate category.

Table(4): Target classification for each country

Alg_range	3.837000	5.232535	6.628071	8.023606	9.419141	10.814677
Tun_range	0.4020000	0.4293131	0.4566263	0.4839394	0.5112525	0.5385657

Source: Created by the authers based on R

In Algeria**,** the exchange rate spans from 3.837 to 141.995, reflecting severe volatility**.** This wide fluctuation is mainly driven by **i**nflation, external shocks, and dependency on oil revenues**.** The sharp increase in values suggests weak monetary stability and limited policy control.

In Tunisia**,** the exchange rate ranges from 0.402 to 3.106, indicating relative stability**.** Despite ongoing political and economic pressures, the narrower range implies stronger monetary policy management **and** less exposure to extreme shocks **c**ompared to Algeria.

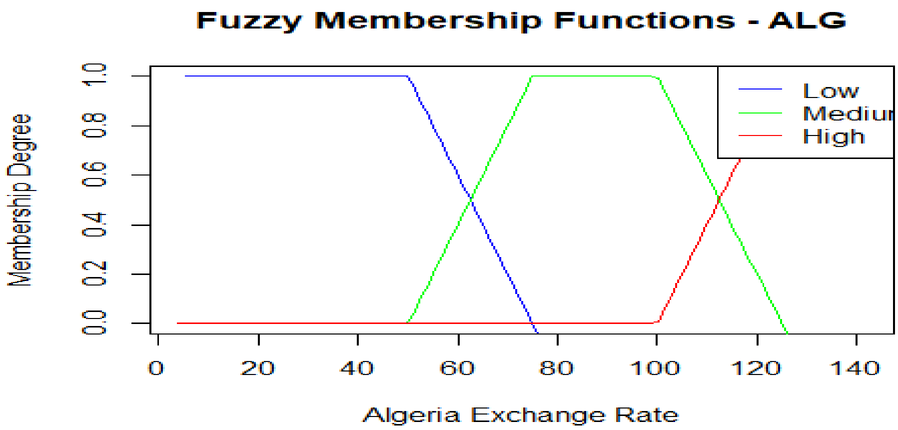
Table(5): Comparison Table of Fuzzy Sets and Economic Implications

Fuzzy Set	Range	Economic Interpretation	Implications
Low	[0.00, 0.25, 0.50]	Strong domestic currency; reduced import costs but lower export competitiveness.	Encourages import activities; may discourage export growth.
Medium	[0.25, 0.50, 0.75]	Balanced currency valuation; stable trade environment.	Minimal economic risks; supports both import and export activities without significant distortions.
High	[0.50, 0.75, 1.00]	Weak domestic currency; higher import costs, improved export competitiveness, but potential inflation.	Promotes exports; burdens importers and may lead to inflationary pressures.

Source: Created by the authers based on R

This structured framework provides a comprehensive approach to modeling exchange rate fluctuations and their economic consequences, integrating fuzzy mathematical programming with practical applications for decision-making.

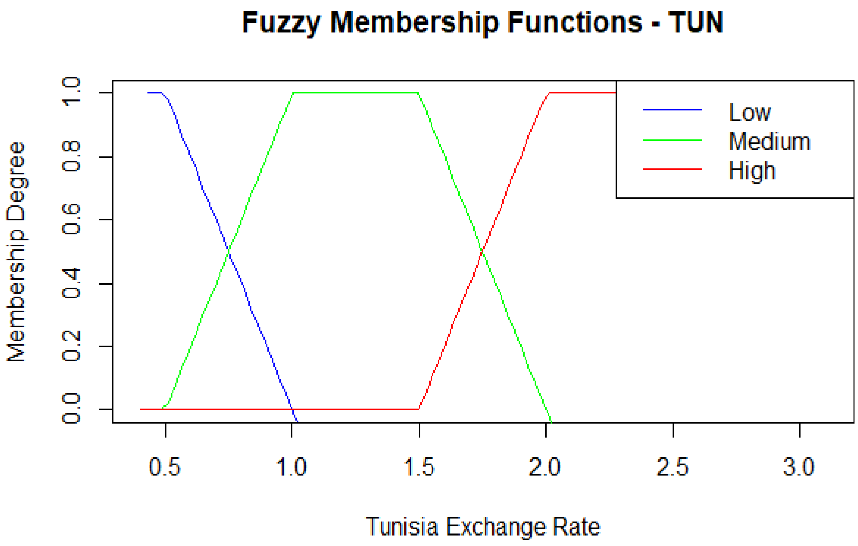
Fig(4): Fuzzy Membership Functions - Algeria Exchange Rate (ALG.EX)



Source: Created by the authers based on R

Economically, the application of fuzzy membership functions to Algeria's exchange rate offers several significant advantages for decision-making and policy formulation. The figure illustrates the classification of Algeria's exchange rate into three fuzzy linguistic categories—Low (Blue), Medium (Green), and High (Red)—using membership functions. The (Low) category is fully applicable for exchange rates below 50, with membership gradually decreasing as the rate approaches 75. The (Medium) category represents exchange rates between 50 and 125, peaking at full membership between 75 and 100, then tapering off. The (High) category begins at 100, with membership increasing to full applicability for rates above 125. These membership functions enable a smooth transition between categories, allowing the exchange rate to partially belong to multiple categories at once. For instance, an exchange rate of 75 could partially fall into both "Low" and (Medium) categories, offering valuable insights into the state of the economy. This nuanced classification supports gradual policy responses, allowing Algeria to adjust its monetary policies—such as interest rate changes or foreign exchange interventions—more progressively, rather than reacting to fluctuations in an abrupt or binary manner. Fuzzy logic provides a deeper understanding of exchange rate dynamics, facilitating more informed and adaptable responses. Additionally, fuzzy sets enhance forecasting accuracy by modeling potential exchange rate fluctuations, enabling businesses and investors to better anticipate future trends and plan accordingly. This is particularly useful for sectors sensitive to exchange rate changes, such as trade and foreign investment. Furthermore, fuzzy logic aids in risk management by offering a range of possible outcomes, allowing financial institutions and exporters/importers to hedge against exchange rate risks and stabilize their financial strategies. For Algeria, understanding the fuzzy nature of exchange rate fluctuations is crucial for supporting international trade, particularly with key European and African partners. A weaker currency, indicated by partial memberships in (Low) and (Medium), may signal a favorable environment for exports. Finally, fuzzy logic helps policymakers address periods of exchange rate volatility by identifying early signs of potential transitions, allowing for timely interventions to maintain economic stability. In conclusion, fuzzy membership functions offer a sophisticated tool for modeling exchange rate uncertainty, improving decision-making, and supporting more flexible and informed economic policies in Algeria.

Fig(5): Fuzzy Membership Functions – Tunisia Exchange Rate (TUN.EX)



Source: Created by the researchers based on R

The figure illustrates the fuzzy classification of Tunisia's exchange rate into three linguistic categories—Low, Medium, and High—using membership functions. The Low category (Blue) is fully applicable for exchange rates below 0.5, with membership decreasing to 0 as the rate reaches 1. The Medium category (Green) represents exchange rates between 0.5 and 2, peaking at full membership around 1–1.5, and tapering off after 2. The High category (Red) begins at 1.5, with membership increasing to full applicability for rates above 2. These membership functions enable Tunisia's exchange rates to belong partially to multiple categories, allowing for nuanced analysis in fuzzy modeling. Economically, this classification offers several advantages, such as improved forecasting, more precise risk management, and the development of adaptive monetary policies. For instance, by identifying an exchange rate of 1.5 as having partial memberships in both Medium and High categories, policymakers can anticipate gradual transitions, enabling them to implement phased adjustments in interest rates or foreign exchange interventions.

Compared to Algeria, where the exchange rate categories span different ranges (Low below 50, Medium between 50 and 125, and High above 125), Tunisia's narrower range reflects its different monetary context and policy environment. This indicates that Tunisia operates with tighter fluctuations and a more controlled exchange rate regime. For example, an exchange rate classified as Low in Tunisia would likely correspond to a different economic implication than in Algeria, where broader thresholds apply. Additionally, Tunisia's fuzzy modeling allows for refined economic strategies tailored to its exchange rate structure, particularly in sectors like trade and foreign investment. While Algeria benefits from fuzzy modeling to manage its resource-driven economy, Tunisia's classification emphasizes managing exchange rate volatility in a diversified economic framework. In both cases, fuzzy logic enhances decision-making by offering a flexible tool for interpreting exchange rate uncertainties, thereby fostering economic stability and strategic trade partnerships.

Table (6): Comparative Analysis of Fuzzy Classification of Exchange Rates

Aspect	Algeria	Tunisia
Low Membership Range	Below 50, gradually decreases to 0 at 75	Below 0.5, decreases to 0 at 1
Medium Membership Range	Between 50 and 125, peaks between 75 and 100	Between 0.5 and 2, peaks between 1 and 1.5
High Membership Range	Begins at 100, peaks above 125	Begins at 1.5, peaks above 2
Economic Context	High variability due to resource dependency	Controlled fluctuations, reflecting smaller market size
Policy Benefits	Supports large-scale adjustments for resource-driven fluctuations	Enables precise management of smaller-scale shifts
Key Feature	Broader ranges reflect significant volatility	Narrower ranges tailored for controlled management
Fuzzy Logic Application	Helps manage resource-related exchange rate volatility	Allows for strict control over minimal variations

Source: Created by the authers based on R

4.3. Structural and Institutional Interpretation of Fuzzy Outcomes

The sharp divergence in fuzzy membership ranges between Algeria and Tunisia is not a mere statistical artifact; rather, it reflects deep structural and institutional differences. In Algeria, the broad overlap across the “low,” “medium,” and “high” exchange rate categories is attributable to a rentier economic model that relies heavily on hydrocarbon exports, which account for more than 90 percent of export revenues. This dependence generates recurrent shocks to the public finances and the balance of payments, pushing the central bank toward reactive interventions that are often opaque. Moreover, the absence of a transparent, rules-based exchange rate framework despite official announcements of a “managed float” leads to persistent misalignments and the emergence of a parallel market, thereby heightening uncertainty. It is precisely this institutional opacity that the fuzzy-logic approach captures effectively: the partial membership of exchange rate values in multiple categories reflects the “liminal” conditions faced by market participants as they navigate dual pricing regimes and unforeseen policy shifts.

By contrast, Tunisia’s narrower membership functions reflect a more diversified economy anchored in services, tourism, and light manufacturing, alongside a monetary framework characterized by greater transparency and gradual steps toward exchange-rate liberalization. Despite challenges such as fiscal deficits and political instability, the central bank’s incremental approach has reduced the frequency and intensity of shocks, enabling clearer signaling and more predictable policy responses outcomes that are directly visible in tighter, less overlapping membership functions.

Accordingly, the fuzzy model’s role extends beyond classical prediction of exchange rate behavior under assumptions that exclude uncertainty; it also provides a diagnosis of the monetary regime’s soundness and resilience. Wider, more diffuse membership functions may serve as early-warning indicators of institutional fragility, whereas tighter, more delineated functions suggest greater policy coherence and stronger market confidence.

5.Conclusion

Applying fuzzy logic to the classification and forecasting of exchange rate volatility in Algeria and Tunisia is not merely a quantitative analytical device; it constitutes a methodological shift in how policymakers understand ambiguity and uncertainty in turbulent economic environments. Whereas conventional models impose sharp, definitive boundaries in prediction, a fuzzy framework enables the deliberate use of the “gray zone” in exchange rate decision-making—within a more realistic and flexible setting—such that a given value can simultaneously belong to more than one category (low, medium, high) to varying degrees, thereby more accurately capturing a nonlinear, multidimensional economic reality.

The deeper implications of this study lie in demonstrating how an economy’s structural configuration—resource-based, as in Algeria, versus diversified and small-scale, as in Tunisia—provides a robust lens through which to understand the nature of volatility and its predictability. In Algeria, the wide span of membership functions is not a mere statistical artifact; it signals structural fragility and dependence on exogenous, uncontrollable drivers such as oil prices, which calls for policy models capable of gradual adaptation to shocks rather than delayed or abrupt responses. By contrast, Tunisia’s relatively narrow membership functions suggest a comparatively mature conduct of monetary policy, yet one still vulnerable to structural pressures, warranting the reinforcement of predictive instruments to forestall the erosion of control.

Theoretically, the study contributes to reframing monetary stability in developing-economy contexts: stability cannot be gauged solely by price steadiness, but by the system’s adaptive responsiveness to uncertainty. It also highlights the added value of fuzzy logic as a vehicle for integrating policymakers’ qualitative expertise with quantitative evidence, thereby narrowing the gap between academic analysis and policy execution.

Taken together, the contribution of this model extends beyond predictive accuracy to empowering decision-makers to adopt calibrated, flexible, and context-aware choices. The study thus invites a reconsideration of conventional monetary policy models in favor of more adaptive and intelligent methodologies that can be generalized to other economies in the southern Mediterranean or Africa confronting similar external volatility and primary-commodity dependence.

6.Recommendations

Strategic recommendations are designed to address critical economic challenges faced by North African countries, particularly Algeria and Tunisia. These measures aim to enhance economic resilience, improve monetary policy effectiveness, and strengthen regional cooperation to mitigate risks associated with exchange rate volatility and external economic shocks.

- ✓ **Increase economic diversification**:
  Shift towards diversifying income sources and reduce reliance on primary commodity exports such as oil and gas in Algeria. Economic diversification helps reduce sensitivity to external shocks such as global commodity price fluctuations.
- ✓ **Enhance stability in the exchange rate market**:
  Develop strategies aimed at achieving stability in exchange rate markets in the countries (Algeria and Tunisia) through the integration of flexible monetary policies. This may include adopting mechanisms to reduce severe exchange rate fluctuations.
- ✓ **Improve intervention mechanisms in the exchange rate market**:

Improve the effectiveness of central bank interventions in exchange rate markets by using innovative monetary tools that help reduce undesirable fluctuations, through the development of more efficient strategies.

- ✓ **Adopt more flexible monetary and fiscal policies**:
  Guide governments to adopt more flexible monetary policies in response to economic challenges, enabling them to adapt to sudden changes in global markets without severely impacting currency stability.
- ✓ **Use technology to analyze exchange rate data**:
  Adopt advanced technologies such as artificial intelligence (AI) and machine learning to analyze exchange rate data more accurately. This can help predict future fluctuations and make economic decisions based on more advanced analyses.
- ✓ **Develop regional cooperation**:
  Strengthen cooperation among North African countries in the field of monetary policies to mitigate common challenges arising from exchange rate fluctuations and share experiences on currency management strategies and long-term development of unified monetary systems.
- ✓ **Raise awareness among policymakers about modern tools**:
  Organize workshops and training seminars for policymakers and economic specialists in the region about modern analytical tools like fuzzy mathematical logic and how to apply them in economic decision-making to improve monetary policy management.

7.References

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