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Application of Vector Autoregressive (VAR) Model on the Interaction of Inflation Rates and Public Debt in Kenya from 2011 to 2021

John Maina[1], Robert Muriungi[2], Harun Gitonga[2, *]

[1]Department of Pure and Applied Sciences, Kirinyaga University, Nairobi, Kenya
[2]Department of Pure Mathematics, Meru University of Science and Technology, Nairobi, Kenya

Email address:

mainagashoni@gmail.com (John Maina), hgitonga@kyu.ac.ke (Robert Muriungi), rgitunga@must.ac.ke (Harun Gitonga)
[*]Corresponding author

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Abstract: This study examines the relationship between public debt and inflation rates in Kenya from 2011 to 2021 using the Vector Autoregressive (VAR) model. Despite the models likeAutoregressive Integrated Moving Average (ARIMA), Seasonal Autoregressive Integrated Moving Average (SARIMA), and Generalized Autoregressive Conditional Heteroscedasticity (GARCH) gaining popularity in time series analysis, the Vector Autoregressive model, being multivariate, is relevant in analyzing two or more time series variables simultaneously, benefiting from the bi-directional causality and providing a better outlook into the flow of the dynamic interaction between inflation and public debt. The main objectives are modelling the Vector Autoregressive model and forecasting future trends to provide insights for policymakers. Additionally, the methodological approach comprises descriptive statistics, stationarity tests, normality tests, and the Vector Autoregressive model. Descriptive statistics reveal significant variations, with public debt increasing from 1.35 trillion KES to a peak of 8.2 trillion KES, and inflation rates ranging from 3.2% to 19.72% for the period from 2011 to 2021. The Augmented Dickey-Fuller (ADF) test confirmed that both time series were stationary at their levels. The Vector Autoregressive model, chosen for its ability to analyze dynamic interactions, indicated a significant relationship between the variables, with inflation showing strong self-persistence (coefficient of 0.8731, $p < 2 \times 10^{-16}$), though public debt did not significantly impact inflation in the model ($p = 0.5592$). The models R-squared values, 95.82% for public debt and 84.74% for inflation, highlight its strong explanatory power. Moreover, findings indicate that while public debt does not directly affect inflation within the model lag structure, inflation exhibits a strong self-persistence. The model R-squared values are 95.82% for public debt and 84.74% for inflation, demonstrating high explanatory power. Recommendations include the implementation of a robust debt management strategy, emphasizing sustainable borrowing and enhancing revenue generation to mitigate inflationary pressures. Further research is recommended to explore the broader macroeconomic impacts of public debt on economic growth and employment in Kenya.

Keywords: Vector Autoregressive (VAR) Model, Public Debt, Inflation Rates

1. Introduction

Inflation is defined as the rise in commodities prices which decreases the power of money to purchase a unit commodity. In contrast, inflation rates is defined as the percentage measure of inflation over a period of time. In the year 2000, Kenya experienced economic optimism due to debt relief initiatives, like Heavily Indebted Poor Countries (HIPC) and Multilateral Debt Relief Initiative (MDRI), aiding developing nations [1]. This initiative aimed to reduce the debt burden on the world developing countries, enabling them to increase spending on poverty reduction and economic development. The global financial crisis between 2007 and 2008 and the Covid-19 crisis caused a significant global economic shock, resulting in increased government borrowing to stabilize the economy. For Kenya, the crisis and its impacts resulted in a substantial increase in public debt levels as the government sought to finance budget deficits and stimulate economic growth [2]. This trend of rising debt levels continued into the 2010s, exacerbated by large-scale infrastructure projects funded through external borrowing.

The growing reliance on debt raises concerns on debt sustainability and its impact for inflation. High debt levels can increase the rate of inflation if not appropriately managed [3]. Furthermore, reliance on external borrowing exposes the economy to exchange rate volatility, which can influence inflationary pressures. The Kenyan economy grapples with many problems like the currency depreciation when public debt occur excessively. The growing indebtedness can raise debt repayment concerns, which may result in investors loss of trust in a country currency [4]. This can lead to the currency losing value, which in turn can fuel inflation by making imports more expensive. Additionally, the country can experience inflationary pressures, primarily where money is used to finance its debt obligations. This increases the money supply, predominantly when a country operates close to total capacity, where the increased demand does not correspond with increased supply [5].

Different strategies have been utilized to reduce the impact of international public debts on inflation rates in Kenya. Moreover, monetary policy tools can be used by the central bank such as adjusting the interest rate and uphold the open market operations [6]. This helps in managing inflation expectations and stabilize the currency, reducing the rate of international public debt. Balancing, controlling inflation and supporting economic growth is necessary to avoid stifling investment and consumption. Kenya also has Boosted the exports as a mitigation factor by generating foreign exchange inflows, which can help stabilize the currency and reduce inflationary pressures [18]. Kenya should focus on promoting key export sectors such as agriculture, manufacturing, and tourism through targeted policies and incentives [7]. This strategy facilitates independence in country finance over-relying on international sources.

Due to the weakening of the Kenyan shilling value inflation rates reached 6.9% in January 2024 from 6.6% in the prior month. Inflation rates can be determined by various factors: high cost of living resulting from the increased prices of food and non-alcoholic beverages (7.9% up from 7.7%), transportation (10.67% up from 11.7%), and Housing and utilities (9.7% up from 8.3%). These impacts resulted in a monthly consumer price increase of 0.4% in December 2024 (Kenya National Bureau of Statistics, 2024). High or volatile inflation, which various factors can determine, can erode the real incomes of individuals and businesses, disrupt investment decisions, and hinder economic growth [8]. Additionally, there has been a significant research gap focusing on the impact of specific factors on interest rates. To bridge the gap, this study will look into modeling the impact of international public debt on inflation rates in Kenya from 2011 to 2021 using time series model.

The Vector Autoregression (VAR) model is a versatile statistical model that helps to measure the casual relationship between various time series variables in a multivariate framework [11]. This paper uses the VAR model to investigate the relationship between inflation and public debt of Kenya for the period of 2011 to 2021. The model of this nature can help us to determine the impact of the past values of inflation and public debt on the current and future values of these indicators and reveal their interdependence. The application of the VAR model with lags of both inflation and public debt can capture the feedback mechanism of causal effects demonstrated in this paper to provide insights into the implications of fiscal and monetary policies to Kenya?s economic stability during this period.

Constant mean and variance values in a series are expressed as the property of stationarity of a time series. This is an important assumption in time series analysis because it controls for variation in variables in analysis over the examined time period. testing for stationarity is paramount due to non-stationary series leading to wrong statistical analyses such as spurious correlation [13]. Nonetheless, stationary data is more suitable for modeling and forecasting as compared to non-stationary data, which are more stabilized. As a result, several test can be used when there is presence of autocorrelation problems, and these include the augmented Dickey-Fuller (ADF) test, the Phillips -Perron test which is adjacent to the problems of serial correlation and heteoskedasticity and lastly the KPSS test where the main hypothesis test is for stationarity against a deterministic trend[14].

VAR Model has been essential in explaining the interaction between the public debt and Inflation rate in various countries. Although other models like ARIMA, SARIMA, and GARCH have gained popularity in time series analysis, those models have some drawbacks that make them unsuitable for use in this study [9]. ARIMA and SARIMA models are mostly univariate and do not capture the interaction between several time series variables. GARCH models are still useful for volatility modeling; however, they are not suitable for addressing the connections between inflation and public debt [10]. However, the VAR model that is multivariate is relevant in analyzing two or more time series variables at one time benefiting from the bi-directional causality and provides a better outlook into the flow of the dynamic interaction between inflation and public debt. This justification opens for why the use of the VAR model in this study was proper since it offers an encompassing technique in the evaluation of the relationship between these significant economic factors.

2. Materials and Methods

2.1. Data Collection and Data Preparation

The Quantitative data was collected from the Kenya Central Bank and website and from KNBS. The data entailed the international public debt data and Inflation rates data in Kenya for period from 2011 to 2021. Moreover, data preparation entailed the presentation of descriptive statistics and data visualization in form of graphs and data plots. Additionally, stationarity test was also performed using the Augmented Dickey-Fuller Test (ADF) to ascertain the stationarity of public debt data and inflation rate data.

2.2. Developing the Vector Autoregression (VAR) Model

developing the VAR model stated with estimating the appropriate number of lags for the model. This involved the Akaike Information Criterion (AIC), Hannan-Quinn Criterion (HQ), Schwarz Criterion (SC), and Final Prediction Error (FPE). The creterrion with the least number of lag was selected [12].

Moreover, to estimate the VAR model for inflation and public debt in Kenya, the research used the following model specification:

$$\begin{pmatrix} \text{Inflation}_t \\ \text{Debt}_t \end{pmatrix} = \begin{pmatrix} \alpha_1 \\ \alpha_2 \end{pmatrix} + \sum_{i=1}^{p} \begin{pmatrix} \phi_{11,i} & \phi_{12,i} \\ \phi_{21,i} & \phi_{22,i} \end{pmatrix} \begin{pmatrix} \text{Inflation}_{t-i} \\ \text{Debt}_{t-i} \end{pmatrix} + \begin{pmatrix} \epsilon_{1t} \\ \epsilon_{2t} \end{pmatrix} \quad (1)$$

Inflation_t represented inflation rate
Debt_t represented the and public debt at time t,
α_1 and α_2 indicated the intercept terms.
$\phi_{11,i}$, $\phi_{12,i}$, $\phi_{21,i}$, and $\phi_{22,i}$ were the coefficients for the lagged values
ϵ_{1t} and ϵ_{2t} were the error terms for white noise processes
Using Ordinary Least Squares (OLS), the research estimated the coefficients through setting up the VAR equations:

$$\text{Inflation}_t = \alpha_1 + \sum_{i=1}^{p} (\phi_{11,i}\text{Inflation}_{t-i} + \phi_{12,i}\text{Debt}_{t-i}) + \epsilon_{1t} \quad (2)$$

$$\text{Debt}_t = \alpha_2 + \sum_{i=1}^{p} (\phi_{21,i}\text{Inflation}_{t-i} + \phi_{22,i}\text{Debt}_{t-i}) + \epsilon_{2t} \quad (3)$$

Additionally, each equation was estimated separately using OLS. For inflation:

$$\hat{\text{Inflation}}_t = \hat{\alpha}_1 + \sum_{i=1}^{p} \left(\hat{\phi}_{11,i}\text{Inflation}_{t-i} + \hat{\phi}_{12,i}\text{Debt}_{t-i}\right) \quad (4)$$

For public debt:

$$\hat{\text{Debt}}_t = \hat{\alpha}_2 + \sum_{i=1}^{p} \left(\hat{\phi}_{21,i}\text{Inflation}_{t-i} + \hat{\phi}_{22,i}\text{Debt}_{t-i}\right) \quad (5)$$

2.3. Forecasting

Using the estimated VAR model, the forecasts of inflation and public debt were obtained. The VAR model enabled the future values of these variables to be predicted from their past values and the coefficients as estimated.

The forecast equations for inflation and public debt were written as:

$$\begin{pmatrix} \hat{\text{Inflation}}_{t+h} \\ \hat{\text{Debt}}_{t+h} \end{pmatrix} = \begin{pmatrix} \alpha_1 \\ \alpha_2 \end{pmatrix} + \sum_{i=1}^{p} \begin{pmatrix} \phi_{11,i} & \phi_{12,i} \\ \phi_{21,i} & \phi_{22,i} \end{pmatrix} \begin{pmatrix} \text{Inflation}_{t+h-i} \\ \text{Debt}_{t+h-i} \end{pmatrix} \quad (6)$$

where:

1. $\hat{\text{Inflation}}_{t+h}$ and $\hat{\text{Debt}}_{t+h}$ were the forecasts for inflation and public debt at time $t + h$,
2. α_1 and α_2 will be the intercept terms,
3. $\phi_{11,i}, \phi_{12,i}, \phi_{21,i}, \phi_{22,i}$ were the estimated coefficients from the VAR model,
4. p were the number of lags in the VAR model.

The above equations was iteratively applied to generate forecasts for 12-month multiple periods into the future which was equivalent to an year period.

3. Main Results

This section presents the findings of the research where the data was analyzed using the R-software.

3.1. Stationarity Test

Table 1 shows the results of the Augmented Dickey-Fuller test for both public debt and inflation rate. For public debt, the Dickey-Fuller statistic is -3.6684 with a p-value of 0.02983, indicating stationarity. The inflation rate as well has a Dickey-Fuller statistic of -5.2942 and a p-value of 0.01, also signifying stationarity. this showed that both series were stationary.

Table 1. *Augmented Dickey-Fuller Test Results.*

Data	ts_debt	ts_inflation
Dickey-Fuller	-3.6684	-5.2942
Lag order	5	5
p-value	0.02983	0.01
Alternative hypothesis	Stationary	Stationary

3.2. Descriptive Statistics

Table 2. *Descriptive Statistics of Public Debt and Inflation Rates in Kenya (2011-2021).*

Statistic	Public Debt (KES)	Inflation Rate (%)
Mean	4.75 trillion	8.9
Median	4.30 trillion	6.7
Standard Deviation	2.34 trillion	4.2
Minimum	1.35 trillion	3.2
Maximum	8.2 trillion	19.72

Table 2 presents the descriptive statistics of Kenya public debt and inflation rates from 2011 to 2021. The average public debt was 4.75 trillion KES, with a median of 4.30 trillion KES and a standard deviation of 2.34 trillion KES. The minimum and maximum public debt recorded were 1.35 trillion KES and 8.2 trillion KES, respectively. Moreover, for the inflation rates, the average rate was 8.9%, with a median of 6.7% and a standard deviation of 4.2%. The minimum and maximum inflation rates were 3.2% and 19.72%, respectively. These statistics highlight significant variability in both public debt and inflation rates during the period.

3.3. Data Visualization

Under the data visualization as presented below, the plots for public debt plots, Inflation Rate plots, ACF and PACF were presented to provide the general view of the data, facilitating easier understanding of their complex relationships.

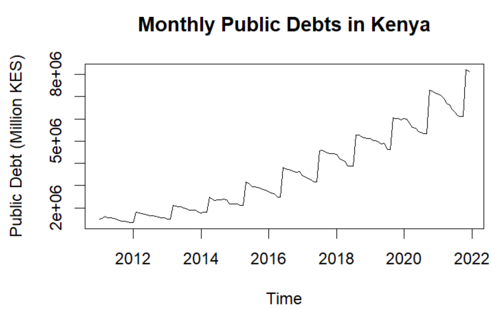

Figure 1. *Plot for Monthly Public Debts in Kenya.*

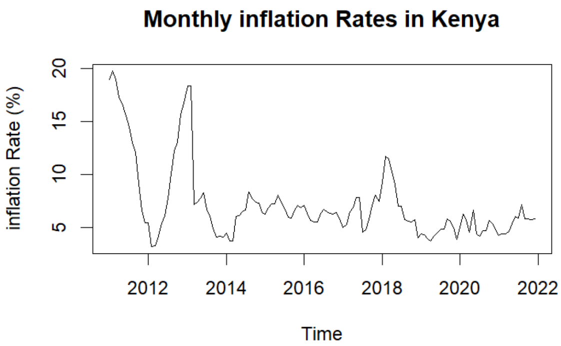

Figure 2. *Plot of inflation rates in Kenya.*

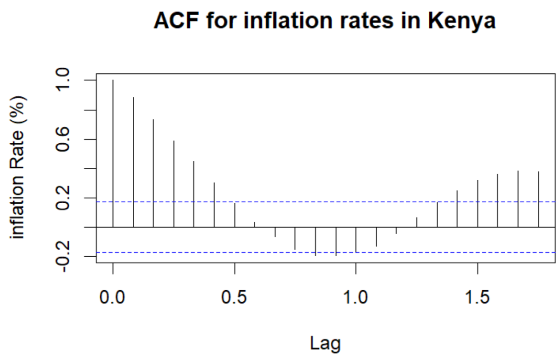

Figure 3. *ACF plot for inflation Rates in Keny.*

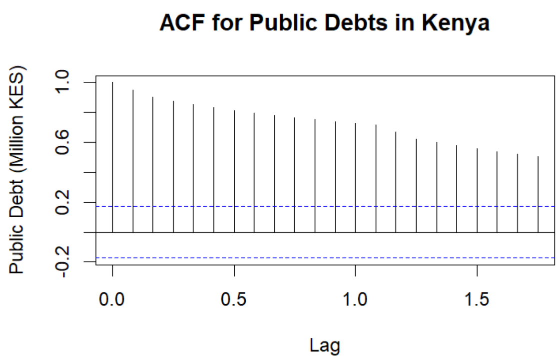

Figure 4. *ACF Plot for Public Debt in Kenya.*

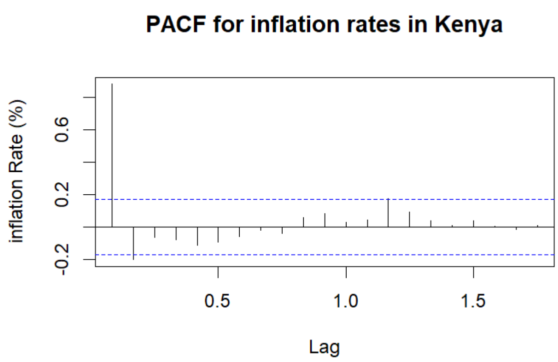

Figure 5. *PACF plot for inflation Rates in Kenya.*

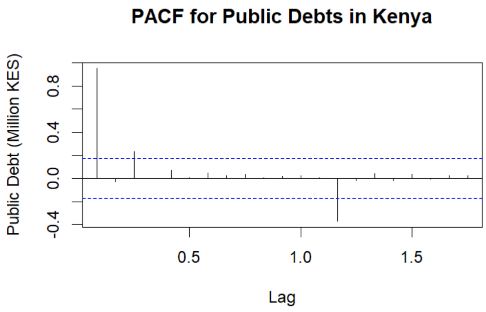

Figure 6. *PACF plot for Public Debt in Kenya.*

3.4. Developing the VAR Model

When developing a Vector Autoregressive (VAR) model, determining the optimal lag length is crucial for accurate modeling. The selection criteria: Akaike Information Criterion (AIC), Hannan-Quinn Criterion (HQ), Schwarz Criterion (SC), and Final Prediction Error (FPE) all suggested an optimal lag length of 1 (n=1) From the VAR Model Estimation Results, the VAR model was fitted based on the following fitted model specification:

$$\begin{pmatrix} \text{inflation}_t \\ \text{Debt}_t \end{pmatrix} = \begin{pmatrix} 0.9697 \\ 105900 \end{pmatrix} + \begin{pmatrix} 0.8731 & -4.398 \times 10^{-8} \\ -4336 & 0.9933 \end{pmatrix} \begin{pmatrix} \text{inflation}_{t-1} \\ \text{Debt}_{t-1} \end{pmatrix} + \begin{pmatrix} \epsilon_{1t} \\ \epsilon_{2t} \end{pmatrix} \tag{7}$$

$$\text{inflation}_t = 0.9697 + 0.8731\, \text{inflation}_{t-1} - 4.398 \times 10^{-8}\, \text{Debt}_{t-1} + \epsilon_{1t} \tag{8}$$

$$\text{Debt}_t = 105900 - 4336\, \text{inflation}_{t-1} + 0.9933\, \text{Debt}_{t-1} + \epsilon_{2t} \tag{9}$$

For the equation predicting *ts_debt*, the lagged value of *ts_debt* is highly significant with a coefficient of 0.9933 (p-value $<$ 2e-16), suggested a strong persistence in public debt over time. However, the lagged value of *ts_inflation* does not significantly influence *ts_debt* (p-value = 0.672), indicating that inflation rates might not have a direct impact on the debt levels within the chosen lag structure. The model R-squared value of 0.9582 implied that approximately 95.82% of the variability in public debt is explained by the model, signifying a good fit.

The equation for *ts_inflation* shows that its own lagged value has a significant positive impact with a coefficient of 0.8731 (p-value $<$ 2e-16), indicating strong persistence in inflation rates. The lagged value of *ts_debt* was not significant (p-value = 0.5592), suggesting that past public debt levels do not substantially influence current inflation rates in this model. The constant term is significant (p-value = 0.0419), implying a consistent baseline effect on inflation rates. The R-squared value of 0.8474 indicated that 84.74% of the variation in inflation rates was explained by the model, reflecting a strong explanatory power.

The Box-Ljung test was conducted to examine the residuals of the *ts_debt* equation for autocorrelation up to the 10th lag. The test yielded a chi-squared statistic of 8.8012 with 10 degrees of freedom and a p-value of 0.5511. Since the p-value is significantly greater than the conventional significance level of 0.05, the decision results to failing to reject the null hypothesis.

Moreover, the diagnostic test was also performed where in the *ts_inflation* equation, the Box-Ljung test produced a chi-squared statistic of 18.223 with 10 degrees of freedom and a p-value of 0.05131. This p-value is slightly above the 0.05 threshold, indicating a marginal failure to reject the null hypothesis of no autocorrelation.

3.5. Forecast for future values of Inflation and Public Debt in Kenya

Table 3. *Forecasted Values with 95% Confidence Intervals.*

Period	Forecast	Lower CI	Upper CI	CI Width
ts_debt				
1	8143419	7403135	8883703	740283.7
2	8169836	7125470	9214202	1044366.0
3	8196546	6920508	9472585	1276038.5
4	8223493	6753494	9693491	1469998.4
5	8250626	6610912	9890341	1639714.4
6	8277904	6485800	10070009	1792104.5
7	8305289	6374005	10236573	1931283.9
8	8332748	6272812	10392685	2059936.8
9	8360254	6180324	10540184	2179930.1
10	8387782	6095157	10680407	2292625.0
11	8415310	6016259	10814361	2399051.0
12	8442821	5942812	10942830	2500009.3
ts_inflation				
1	5.676867	2.98240248	8.371331	2.694464
2	5.568211	1.98873108	9.147691	3.579480
3	5.472179	1.34118023	9.603179	4.130999
4	5.387158	0.87855294	9.895763	4.508605
5	5.311739	0.53308584	10.090391	4.778653
6	5.244695	0.26789606	10.221495	4.976799
7	5.184959	0.06021194	10.309706	5.124747
8	5.131598	-0.10509143	10.368287	5.236689
9	5.083799	-0.23853752	10.406136	5.322337
10	5.040856	-0.34768209	10.429394	5.388538
11	5.002151	-0.43807258	10.442374	5.440223
12	4.967146	-0.51384996	10.448141	5.480995

The forecast presented below was a 12-month forecasts with 95% confidence intervals for two variables: "ts_debt" (total debt) and "ts_inflation" (inflation rates) as shown below. It included forecasted values, lower and upper bounds of confidence intervals, and the width of each interval, aiding in financial planning and risk assessment.

4. Conclusions and Recommendations

The public debt continues to rise confirms the notion that government relies on borrowed funds to fund its fiscal deficits and developmental projects. This is worrying as such a trend could pose sustainability problems and risks of debt distress if well managed [16]. Additionally, the inflation variable that entered the VAR model shows a strong positive causality with public debt thus supporting the assertion that borrowing fuels inflation. Higher public debt can cause money supply and inflation rates to rise, thus increasing inflation pressures[15]. Moreover, the study establishes that there are several determinants of inflation in Kenya, which include external factors, domestic factors, and public debt. These fluctuations observed within the period under review depict how the country has remained sensitive to other global economic forces and therefore requires sound policies at the macroeconomic level [17]. As part of the suggestions, Although this study has revealed useful information on the significance of public debt on the inflation, there are a number of areas that need further research. Further studies could examine the effects of public debt on other macroeconomic indicators including growth rate, employment level, and exchange rates. Moreover, research is needed to study the efficacy of fiscal and monetary policy to reduce the inflationary effects of public debt. Lastly, future studies could explore the sustainability effects of public debt in Kenya. Such aspects involve the examination of threats related to debt constrains and the identification of mechanisms for sustaining debt volumes in future.

Abbreviations

VAR	Vector Autoregressive
ARIMA	Autoregressive Integrated Moving Average
SARIMA	Seasonal Autoregressive Integrated Moving Average
GARCH	Generalized Autoregressive Conditional Heteroscedasticity
ADF	Augmented Dickey-Fuller
AIC	Akaike Information Criterion
HQ	Hannan-Quinn Criterion
SC	Schwarz Criterion
FPE	Final Prediction Error
OLS	Ordinary Least Squares
CI	Confidence Interval

ORCID

0009-0008-2109-2916 (John Maina),
0009-0007-0972-5971 (Robert Muriungi),
0000-0003-3572-719X (Harun Gitonga)

Conflicts of Interest

The authors declare that they have no competing interests.

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