International Journal of Management and Commerce Innovations ISSN 2348-7585 (Online)
Vol. 6, Issue 1, pp: (1487-1508), Month: April - September 2018, Available at: www.researchpublish.com

# AN EMPIRICAL ANALYSIS OF THE DETERMINANTS OF INFLATION IN RWANDA (2006-2015)

Noella Nyishimente, Dr. Jaya Shukla, Dr. Patrick Mulyungi

Jomo Kenyatta University of Agriculture and Technology

*Abstract:* **It is now widely agreed among economists, policy makers and central banks that the main objective of monetary policy is to keep low inflation rate which is regarded as a measure of macroeconomic stability. To achieve this objective, inflation has to be well managed and a need to understand its determinants is at utmost important. *Monetary policy and financial stability report* (2016). As in other countries, the findings in Rwanda reveal mixed results on inflation and its determinants. This is mainly due to a range of conventional views about the appropriate measure of inflation and also due to a disparity between countries (developed and developing countries). This raises concern among policy makers and requires an investigation as to why inflation continue to increase despite their efforts to control main drivers of inflation in order maintain price stability. Given this backdrop, there is need to establish the determinants of inflation in Rwanda. This has form the general objective of the study. The specific objectives of this study were to examine the effects of money supply on inflation; to investigate the effects of exchange rate on inflation; to determine the effects of GDP on inflation and to establish the effects of oil prices on inflation. Findings clearly suggest that a unit change in Money supply increases the inflation; a unit change in Exchange rate decreases the inflation; a unit change in GDP certainly and significantly increases the inflation and that a unit change in the Oil price decreases the inflation by certain measures. Though the econometric model used had been found to fit the data, (with R-square = 94.45%), all along, serial correlation or simply heteroskedasticity of the error terms has been found to exist for the time series that were used. With respect to the level of elasticity of the variables under study, both exchange rate and money supply had larger coefficients that the GDP and Oil price. Unit root test performed also suggested stationarity at different lags for each time series. Particularly the money supply time series was found to be more stable than any of the three remaining; GDP time series was stationary only at lag 0 and at lag one; inflation and oil price time series were found to be stationary only at lag 7 and 17 respectively. Interestingly, at lag 18, all-time series considered in the model had an explosive behavior. Through the Vector autoregressive test, impulse-response dynamics of the time series in the model was performed. Findings suggest strongly the shocks on inflation causes responses of different magnitude on the independent variables. When considering shocks from the predictors, it has been found particularly that shocks from exchange rate causes a huge oil price response. This is in line with the economic dynamism that has been observed in Rwanda. Stability of VAR model under study has also been examined and findings revealed a rather non-stable VAR model, if the natural logarithm of the economic variable is considered. When transformed into their difference state, finding reveals a completely stable VAR model. Co-integration has been also performed. Findings suggested existence of only two possible co-integration vectors that can explain the long run economic effects, namely the inflation and money supply. Thus, not neglecting other factors, findings of the current research strongly suggest that at the fore front of the determinants of inflation is primarily money supply in the economy. Hence, sound an adequate monetary policy has evidently more impact on inflation than any other determinant considered in this work.**

*Keywords:* **Money Supply, exchange rate, Inflation, Gross Domestic Product, Consumer Price Index.**

## 1. INTRODUCTION

Inflation is an inevitable property of any economy in the world and has been a critical issue since the early 1970s when oil prices soared to record high figures. Ever since, controlling inflation rate has been a high priority of many countries especially those with small open economies. Inflation results in a decrease of purchasing power of the national currency and can also lead to uncertainty to domestic and foreign investors to invest in the economy. In an open economy, however, the cost of inflation is even higher, overstated prices worsen the country's terms of trade by making domestic goods expensive on regional and world markets making it increasingly difficult to compete in world trade and hence causing a poor trade balance. Lipsey et al (1982).

In recent years, experiences in both developed and developing countries have shown that rise in the price of essential commodities; particularly food and oil items affected almost all the countries in the world. The policy makers believe that, when inflation crosses a reasonable limit in the economy it can adversely affect other macroeconomic variables and in turn weakens its steady level of the economy. However, to overcome the hindrance of inflation in economy, most of central banks in developed and developing countries have the core objective to keep inflation at minimum rate for achieving high economic growth. In the same way, National Bank of Rwanda (BNR) aims to keep price stability towards sustainable economic development. The concern with maintaining price stability stems not only from the need to maintain overall macroeconomic stability, but also from the fact that price stability allow market participants, both domestic and foreign, to make informed decisions and adjust their decisions about spending, saving and investing in welfare enhancing ways. Thus, it is necessary to maintain price stability through controlling its channels or sources that are responsible for inflationary impulse. Gichondo(2012).

## 2. STATEMENT OF THE PROBLEM

High inflation level poses a serious threat to macroeconomic stability around the world and it continues to be a central debate to many central banks and policy makers. This is because high varying inflation rate may have social and economic shocks on the economy as a result of its negative effect on price stability, savings and investment. Several studies have been carried out on factors that may affect inflation on both developed and developing countries but findings proven different results (Kesavarajah (2010); Laura Papi (1997); Bashir et al., (2011), Dlaminiet al., (2001), Wema, (2009), Francis Gyebi (2013), Gichondo and Kimenyi (2012), Martin Ruzima (2015) among others). From these studies, the determinants of inflation were not specific and results drawn were not consistent.

However, the focus of central banks is therefore, primarily to be narrowed to the pursuit of low inflation. Despite its efforts to ensure price stability, maintaining the inflation rate below the target has for most years remained elusive and the rise in prices (inflation) has been an issue for central banks, policy makers and the general public, indeed. Gichuki et al. (2013).Given the efforts by central bank, the failure to achieve the inflation target and lack of consent on the causes of rise in inflation in order to ensure its management, discovery of its determinants is of utmost importance. The purpose of this study was therefore meant to analyze the determinants of inflation in Rwanda and to determine the extent to which each determinant affects inflation.

## 3. OBJECTIVES OF THE STUDY

The aim of this study was to establish the determinants of inflation in Rwanda using vector autoregressive model on time series data.

### 3.1 Specific objectives

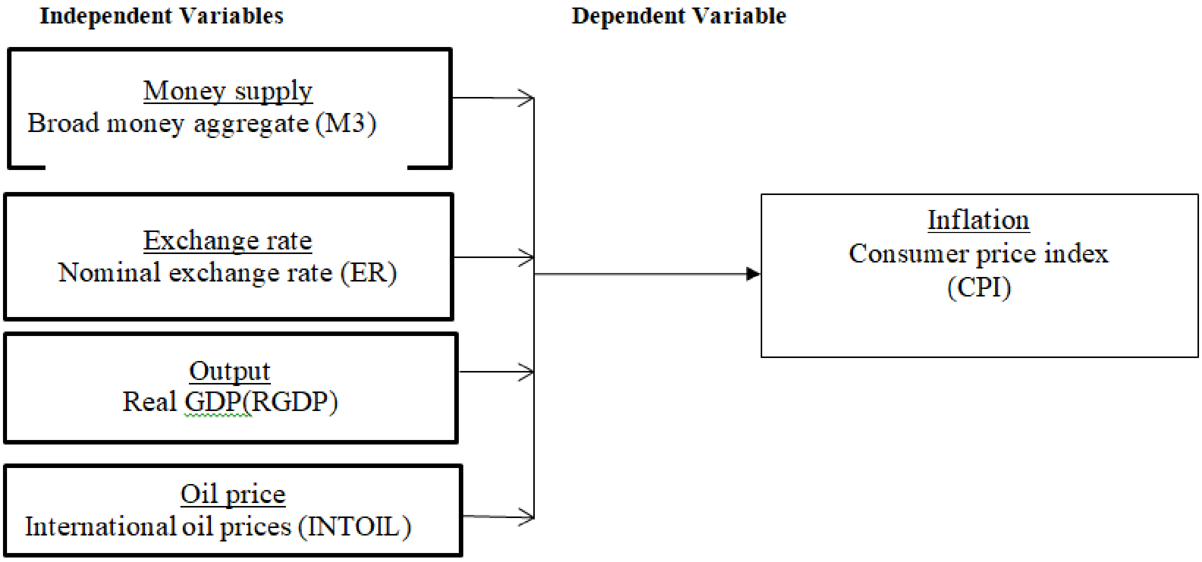
i. To examine the effects of money supply (broad money) on inflation;

ii. To investigate the effects change in exchange rate on inflation;

iii. To determine the effects of Gross Domestic product (GDP) on inflation;

iv. To establish the effects of oil prices on inflation

## 4. CONCEPTUAL FRAMEWORK




## 5. RESEARCH METHODOLOGY

### 5.1 Research Design

Research design is the blue print for the collection, measurement, analysis of data and a plan to obtain answers to research questions (Coopers & Schindler, 2006). This research used quantitative research because this study was systematic empirical investigation of observable phenomena via statistical, mathematical or numerical data or computational techniques. The objective of quantitative research is to develop and employ econometric models, theories and/or hypotheses pertaining to phenomena. This study utilized quantitative research design because it involves systematic empirical investigation of observable phenomena via statistical or numerical data. This study aims at analyzing the interdependence relationship between inflation and its determinants in Rwanda.

The measurement process is the key to quantitative research because it provides the fundamental connection between empirical observation and mathematical expression of quantitative relationships. Most quantitative research falls into two areas: studies that describe events and studies aimed at discovering inferences or causal relationships. Descriptive studies are aimed at finding out "what is". Descriptive research is unique in the number of variables employed. Like other types of research, descriptive research can include multiple variables for analysis, yet unlike other methods, it requires only one variable (Borg & Gall, 1989). For instance, a descriptive study might employ methods of analyzing correlations between multiple variables by using tests such as Pearson's Product Moment correlation, regression, or multiple regression analysis which suits this research because the study used multi-variate time series data. Studies that have been undertaken in the area of research by (Armeshand, 2010) in Iran, (Acute et al,2001 ) in Swaziland, (Khan et al, 2007) in Pakistan, (Dacosta and Greenidge,2008) in Caribbean countries, (Bandara, 2011) in Srilanka, (Akhtaruzzan,2005) in Bangladesh, (Odusolaand Akinbobola, 2001) in Nigeria, (Enu and Havi, 2014) in Ghana and (Gichondo and Kimenyi,2012) in Rwanda among others, justify the use of these research designs.

### 5.2 Data collection and procedure

#### 5.2.1 Type of data

This study used secondary data from the National Bank of Rwanda (BNR) data base to estimate the estimate the determinants of inflation in Rwanda. These include data on money supply, nominal exchange rate, real GDP, oil prices and consumer price index (CPI) using time series data. All data are time series on quarterly basis from 2006 to 2015. Several previous researchers who carried out a study on determinants of inflation have utilized time series secondary data though the time frame and location area was different from one researcher to another as shown in the empirical literature review. This study was therefore consistent with the previous researches.

### 5.2.2 Variables measurements

According to National Institute of Statistics of Rwanda, CPI uses a Modified Laspeyres formula to calculate the index. In Rwanda, inflation is established through the Consumer Price Index (CPI).Hence, this study used consumer price indices as proxies for inflation rates. Same have been used by Gichondo and Kimenyi, 2012.The nominal effective exchange rate (NEER) index was used as a proxy to capture movements in the exchange rate. Same have been used by Gichondo and Kimenyi (2012).In addition, money supply (M3) was used to capture monetary policy effect on the price level. Furthermore, GDP at constant prices (real) rather than GDP at current prices was used as a proxy of output. Finally, oil price was used as a proxy for fluctuations in the world price of crude oil (including Brent oil, WTI and Dubai).

### 5.3 Descriptive Data analysis and statistical tests

The study addresses two objectives. The analysis of effects requires testing for the relationship between the variables under study. This was achieved by carrying out multivariate co-integration test and granger causality test. To analyze the effects macroeconomic variables such as money supply (M3), Exchange rate, gross domestic product (GDP) and oil prices on inflation. This study applied Vector Autoregressive (VAR) technique and subsequently the impulse response analysis and variance decomposition analysis.

### 5.3.1 Model Specification

The first and the most important steps we have to take in attempting the study of any relationship between variables, was to express this relationship in mathematical form that is to specify the model, with which the economic phenomenon was explored empirically. This is called specification of the model or formation of the maintained hypothesis. Various functional models can be used in multiple regression analysis. Functional analysis was used to reveal the quantitative relations between variables and set of explanatory variables to determine the effects of the various factors such as money supply (M3), Exchange rate, gross domestic product (GDP) and oil prices on inflation (price level). Thus, the model is written as follows: $CPI = f(M3, ER, GDP, OILP)$(3.1). Whereby, $CPI$= a measure of inflation;$M3$ = money supply (broad money); $NER$ =Nominal exchange rate; $GDP =$ Gross domestic product; $OILP =$ oil prices. This model can be specified as follows: $y = \beta 0 + \beta 1M3 + \beta 2ER + \beta 3GDP + \beta 4OIL + \varepsilon t$(3.2) This study applied log transformation for all variables in order to determine elasticity for each variable under study.

### 5.3.2 Time Series property of the data

Given the fact that this study uses time series data, stationarity and co- integration tests were used to avoid the rejection of hypothesis. In empirical analysis, non-stationarity of time series data is a persistent problem. To avoid spurious results, the study used standard estimation of time series model as per (Verbeek, 2004). According to Chris Brooks (2008), a stationary series can be defined as one in which mean, variance and autocovariances are constant for each given lag. For this, the study was, therefore, employed augmented Dickey Fuller (ADF) to test stationarity of variables under study.

### 5.4. Testing for unit root

This study applied the Augmented Dickey-Fuller (ADF) test in order to test the presence of a unit root. It was recommended to use this test under the assumption that the error terms have to be uncorrelated. The ADF test includes the lagged values of the dependent variable. The advantage of using the Augmented Dickey-Fuller test is the ability to include enough terms so that the error term becomes uncorrelated. This study applied log transformation variables to remove the degree of heterogeneity of error terms. Small letters of these variables indicate, therefore, transformed variables into natural logarithms.

$$\Delta \mathrm{CPI}_t = \mathrm{a}_1 + \gamma \mathrm{cpi}_{t-1} + \mathrm{a}_2 \mathrm{t} + \sum_{i=1}^{k} \alpha_i \mathrm{cpi}_{t-1} + \varepsilon_t \quad (3.3)$$

Where: $a_1$is intercept, t is linear time trend, k is the number of lagged first differences, and $\varepsilon_t$ is error term. The null hypothesis is unit root and the alternative hypothesis is level stationarity (Enders, 2004). If the coefficient of $cpi_{t-1}$(i.e $\gamma$) is significantly different from zero, then the null hypothesis will be rejected. Otherwise it will be accepted. Similar tests for stationarity were applied to all variables under study.

### 5.5 Testing for co-integration

This study employed Johansen co-integration test and error correction approaches to test for long and short terms relationship. From one hand, co-integration has gained remarkable considerations in analyzing time series data in order to avoid spurious regression. In the case, where the individual variable exhibit stochastic process, the technique is appropriate for choosing coefficient for stationary. From the other hand, Vector Error Correction Models are the basic VAR, with an error correction term incorporated into the model. VECM framework was used to distinguish between shocks with permanent and transitory effects.

### 5.6 VectorAutoregressive (VAR)

Vector autoregressive (VAR) models have a long tradition as tools for multiple time series analysis. Vector autoregressive models became popular for economic analysis when Sims (1980) advocated them as alternatives to simultaneous equations. One of the critics of the model is that it has no theory foundation. VAR is a theoretical model that uses observed time series properties of the data to forecast economic variables.

The general form of VAR is the following:

$$\propto_t = \sum_{i=1}^{k} A_i \propto_{t-1} + \varepsilon_t$$

Where, $\propto_t$: is column vector of observations at time "*t*" on all the variables in the model.

Σ: summation of endogenous variables at time "*t*", $\propto_{t-1}$: Lag of endogenous variables and $\varepsilon_t$: are the impulses or shocks.Under vector autoregressive (VAR) model all variables are treated symmetrically; each variable has an equation explaining its evolution based on its own lags and the lags of all other variables in the models.

Specifically, for this study we will test the following model:

$CPI_t = \propto_0 + \sum_{i=1}^{k} \propto_{1i} CPI_{t-1} \sum_{i}^{k} \propto_{2i} M3_{t-1} \sum_{i=1}^{k} \propto_{3i} ER_{t-1} + \sum_{i}^{k} \alpha_{4i} GDP_{t-1} + \sum_{i}^{k} \alpha_{5i} OILP_{t-1}\ v_i (3.4)$

Where: bCPI: Consumer price index, $\mathrm{M3{:}\ money\ supply(broad\ money), ER{:}\ exchange\ rate,}$ GDP: gross domestic product, OILP: oil price and $V_1$: the impulses or shocks and k: lag length. All variables are transformed in natural logarithms. Although, VAR model deals with several endogenous variables together, each endogenous variable is explained by its lagged, or past, values and the lagged values of all other endogenous variables in the model; usually, there are no exogenous variables in the model. When estimating vector autoregressive model or conducting Granger causality tests, the test can be sensitive to the lag length of the VAR. This study used Akaike Information Criterion for lag length selection.

## 6. SUMMARY OF RESEARCH FINDINGS

### Description of data

Data used in this study have been sourced from the National Bank of Rwanda and cover eightyears spelled in quarters, that is, from 2006 to 2015. This is a time series data and contains quantitative data points observed in time. Five variables surveyed having complete data points are used. These include M3, CPI (end), ER, RGDP and OIL (end), where M3 is the money supply, CPI is the consumer price index end measures, ER is the exchange rate quoted by the National Bank of Rwanda, RGDP is the prevailing Gross Domestic Product and OIL (end) is the oil prices. In view of the model displayed in both equations (3.1) and (3.2), on page 20, it is clear that CPI is used as dependent on M3, ER, GDP and OIL price variables.

The transformation of these variables into their natural logarithm, for the study of their individual elasticity, leads to the following visualization of their correlation matrix in table and in figure as well.

```
. correl  ln_cpiend ln_m3 ln_er ln_rgdp ln_ioilend
(obs=40)
```

| | ln_cpi~d | ln_m3 | ln_er | ln_rgdp | ln_ioi~d |
|---|---|---|---|---|---|
| ln_cpiend | 1.0000 | | | | |
| ln_m3 | 0.9517 | 1.0000 | | | |
| ln_er | 0.8492 | 0.9411 | 1.0000 | | |
| ln_rgdp | 0.9646 | 0.9872 | 0.9290 | 1.0000 | |
| ln_ioilend | 0.1732 | 0.1260 | -0.0793 | 0.1053 | 1.0000 |

**Table 6.1:** The current table depicts the correlation measure among variables that are used in the econometric model of the project understudy.

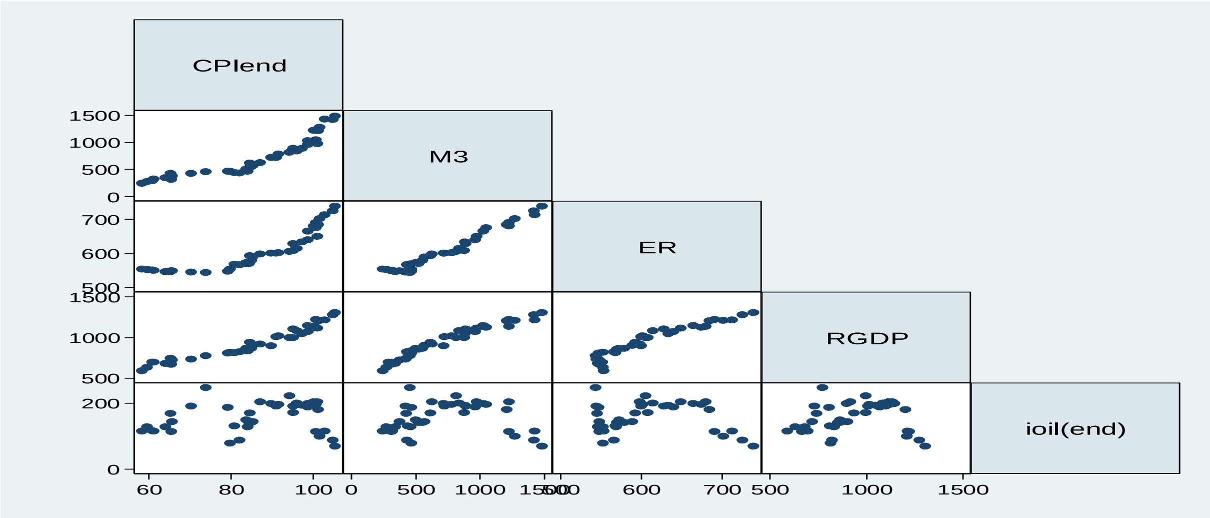



**Figure 6.1:**The above figure displays correlation matrix the relationship between the variables of the econometric model used, after variables are transformed into their natural logarithm measures.

A closer look on the figure above reveals, particularly on the first row, that definitely CPI is highly and positively correlated with M3, ER and GDP. Same observation can be done someone uses Table 4.1 in the first column. In the first row, and in the first cell in column five in the above figure, it is also clear that OIL price is less correlated with CPI, a measure of 0.1 unit. Observe that the last column and the last row display how OIL price depart from other variables, in terms of their relationship.

**Empirical analysis of the economic model**

In this section, the regression analysis, computation and interpretation of elasticity of each independent variable are discussed. Moreover, the Ramsey RESET test is used to investigate any misspecification of the model under study.

**Regression Analysis**

In this section, the attention is laid on studying the effectiveness of the empirical model suggested in this project. As proposed on page 20, the variables in the model are transformed into their natural logarithm and used as follows:

$$\ln(CPI) = \ln(\beta 0) + \beta_1 \ln(M3) + \beta_2 \ln(ER) + \beta_3 \ln(GDP) + \beta_4 \ln(OIL) + \varepsilon \qquad (3.5)$$

```
. regress ln_cpiend ln_m3 ln_er ln_rgdp ln_ioilend
```

| Source | SS | df | MS |
|---|---|---|---|
| Model | 1.20454463 | 4 | .301136159 |
| Residual | .064252914 | 35 | .001835798 |
| Total | 1.26879755 | 39 | .03253327 |

| | |
|---|---|
| Number of obs = | 40 |
| F( 4, 35) = | 164.04 |
| Prob > F = | 0.0000 |
| R-squared = | 0.9494 |
| Adj R-squared = | 0.9436 |
| Root MSE = | .04285 |

| ln_cpiend | Coef. | Std. Err. | t | P>\|t\| | [95% Conf. | Interval] |
|---|---|---|---|---|---|---|
| ln_m3 | .1386806 | .101141 | 1.37 | 0.179 | -.0666467 | .3440078 |
| ln_er | -.830395 | .2709603 | -3.06 | 0.004 | -1.380474 | -.2803163 |
| ln_rgdp | .8192819 | .2023049 | 4.05 | 0.000 | .4085811 | 1.229983 |
| ln_ioilend | -.0075601 | .0276666 | -0.27 | 0.786 | -.0637263 | .0486061 |
| _cons | 3.304394 | 1.799922 | 1.84 | 0.075 | -.3496408 | 6.95843 |

**Table 6.2:** The current table displays the output related to the econometric model in equation (3.5) above.

The first concern that one needs to ask is whether the econometric model used in (3.5) or in (3.1) fit the data that are used in this project. To that end, the confirmation is underlined by the result above, Prob> F = 0.0000. Higher quality of the model used is underpinned by the measure obtained in R-squared = 0.9494. This signifies that 94.4 % of variation in the variable CPI, thus inflation is being explained by the model and only 5.6% of variation in CPI is unaccounted for. The difference observed between R-squared (0.9494) and Adj. R-squared (0.9436) which of 0.58% reveals that variables used as independent, that (M3, ER, GDP, OIL) behave independently vis-à-vis the Consumer Price Index.

From the second column, one reconstructs easily the parameter estimates of the model (3.5) above. Formally, equation (3.5) is written as follows:

$$\ln(CPI) = 3.304394 + 0.1386806\ln(M3) - 0.830395\ln(ER) + 0.8192819\ln(GDP) - 0.0060175\ln(OIL)$$
(3.6)

From this equation, it appears that the variable GDP has the highest influence in the consumer price index or the inflation. A change of a unit in the GDP increases CPI by 0.8192819 units, keeping all other variables constant. Similar interpretation follows for other variables. It is quite interesting to point out how changes in oil price affect insignificantly consumer price index. From individual statistical significance point of view, it appears that GDP and ER have quite a significant impact on the consumer price index as compared to M3 and OIL price. Their p-values are 0.0000 and 0.004 respectively. This is 99.9 % confidence level of significance. The variable M3 is however slightly significant at 10% level. The oil price p-value of 0.786 is not significant at all. This confirms results that were displayed in the matrix picture above in which oil price exhibited a weaker correlation with the rest of the economic variables used. Observe that all the parameter estimates in equation (3.6) answer each specific objective forwarded in chapter one.

**Computation of elasticity of independent variables**

At this point, the elasticity of each variable is investigated, and one considers results depict in the following table.

```
. mfx, eyex

Elasticities after regress
      y  = Fitted values (predict)
         =  4.4351868
```

| variable | ey/ex | Std. Err. | z | P>\|z\| | [ 95% C.I. ] | | X |
|---|---|---|---|---|---|---|---|
| ln_m3 | .2019803 | .14731 | 1.37 | 0.170 | -.086735 | .490696 | 6.4596 |
| ln_er | -1.198741 | .39116 | -3.06 | 0.002 | -1.96539 | -.432087 | 6.40254 |
| ln_rgdp | 1.260252 | .3112 | 4.05 | 0.000 | .650313 | 1.87019 | 6.82238 |
| ln_ioi~d | -.0085327 | .03123 | -0.27 | 0.785 | -.069734 | .052669 | 5.00578 |

**Table 6.3:** The above table displays elasticity measures for each independent variable in the model. From the above table, on the column entitled **ey/ex** exhibits the elasticity of each independent variable. As expected from the record of the coefficient estimates in Table 4.1, ER and GDP variables are more and opposing level of elasticity , (ey/ex = -1.198741) for ER and (ey/ex = 1.260252) for GDP. Other variables are not elastic per se. In proportional terms, this implies that any increase in GDP has as higher effect on CPI as 1.260252. Similarly, an increase in ER has a negative direction, as higher effect on CPI as 1.198741 units.

**Investigation of misspecificationof the model**

To test any misspecification of the model in equation (3.5), ones perform an equivalent of the Wald test, which is Ramsey RESET test and obtains the following results:

```
. estat ovtest

Ramsey RESET test using powers of the fitted values of ln_cpiend
       Ho:  model has no omitted variables
                 F(3, 32) =      13.70
                 Prob > F =       0.0000

. estat ovtest, rhs

Ramsey RESET test using powers of the independent variables
       Ho:  model has no omitted variables
                F(12, 23) =       3.97
                 Prob > F =       0.0022
```

Given Prob> F = 0.0000 in the first Ramsey RESET test where powers of the fitted values of the natural log of CPI are used, the null hypothesis therein is rejected in favour of the alternative at alpha = 0.001 level of significance. Similarly, in the second Ramsey RESET test, where the powers of the independent variables are used to investigate any misspecification, the null hypothesis therein is rejected in favour of the alternative at alpha = 0.001 level of significance. This result has been forthcoming, given that the R-square as in Table 4.2 exhibited excellent result of 94.49 % justification of the belle-fit of the model.

**Testing Heteroskedasticity in the model error**

It is common practice in econometrics to perform a test investigating how the error in the model (3.2) is distributed. Constant variance as per assumption is the only criterion that is being tested. To this end, the Breusch-Pagan/Cook-Weisberg test is used and results are displayed in lines that follow.

```
. estat hettest, iid

Breusch-Pagan / Cook-Weisberg test for heteroskedasticity
         Ho: Constant variance
         Variables: fitted values of ln_cpiend

         chi2(1)      =     6.61
         Prob > chi2  =   0.0102

. estat hettest  ln_m3 ln_er ln_rgdp ln_ioilend, iid

Breusch-Pagan / Cook-Weisberg test for heteroskedasticity
         Ho: Constant variance
         Variables: ln_m3 ln_er ln_rgdp ln_ioilend

         chi2(4)      =     7.00
         Prob > chi2  =   0.1359
```

While value of Prob> chi2 = 0.0102 indicates certain level of heteroskedasticity in the conditional mean square of the disturbances in the model, the value of Prob> chi2 = 0.1359 points to fairly low level of heteroskedasticity in the model. This revelation makes it imperative to conduct a "serial correlation test" of the residuals in the model.

**Serial correlation test**

In this work, the Durbin and Watson test are used alongside the Breusch –Godfrey LM test for autocorrelation. Both tests use the model AR(p). In general, an AR(p) serial correlation process is of the form

$$u_t = \rho_1 u_{t-1} + \cdots + \rho_p u_{t-p} + \varepsilon_t \qquad (3.7)$$

Where $\varepsilon_t$ is i.i.d. with variance $\sigma^2$ but is not assumed or required to be normal for the test. The null hypothesis of Durbin' alternative test is formally labelled as

$$H_0 : \rho_1 = 0, \cdots, \rho_p = 0 \qquad (3.8)$$

and the alternative is that at least on $\rho$ 's is not zero. The following exhibits display both tests.

```
. estat durbinalt, small

Durbin's alternative test for autocorrelation
```

| lags(p) | F | df | Prob > F |
|---|---|---|---|
| 1 | 10.489 | ( 1, 34 ) | 0.0027 |

```
H0: no serial correlation
```

At lag 1, with Prob> F = 0.0027, the Durbin and Watson test reveals serial correlation among the residuals.

```
. estat bgodfrey, lag(5)

Breusch-Godfrey LM test for autocorrelation
```

| lags(p) | chi2 | df | Prob > chi2 |
|---|---|---|---|
| 5 | 16.569 | 5 | 0.0054 |

```
H0: no serial correlation

. estat bgodfrey, lag(6)

Breusch-Godfrey LM test for autocorrelation
```

| lags(p) | chi2 | df | Prob > chi2 |
|---|---|---|---|
| 6 | 16.569 | 6 | 0.0110 |

```
H0: no serial correlation
```

Similarly, at lag 5, and 6, for instance as displayed in the above results, the Breusch-Godfrey LM test for autocorrelation reveals serial correlation in the residuals. Both tests reject categorically the null hypothesis, at alpha = 0.05 level of significance.

In summary, the performance of the model under investigation reveals that there is a measurable impact of M3, ER, GDP and OIL price, taken in their natural log on the log of CPI. Residuals of the model appear to be heteroskedastic and serially correlated.

**Testing for the unit root**

The test is meant to investigate stationarity property of the consumer price index (CPI), M3, ER, GDP and OIL price in their natural log. In differentiating CPI, stationarity of the model (3.3) is assessed.

In investigating stationarity of log(CPI), the following results occurred:

```
. dfuller ln_cpiend, trend regress lags(7)
```

Augmented Dickey-Fuller test for unit root  Number of obs = 32

| | Test Statistic | Interpolated Dickey-Fuller 1% Critical Value | 5% Critical Value | 10% Critical Value |
|---|---|---|---|---|
| Z(t) | -4.238 | -4.316 | -3.572 | -3.223 |

MacKinnon approximate p-value for Z(t) = 0.0039

| D.ln_cpiend | Coef. | Std. Err. | t | P>\|t\| | [95% Conf. | Interval] |
|---|---|---|---|---|---|---|
| ln_cpiend | | | | | | |
| L1. | -.3538581 | .083488 | -4.24 | 0.000 | -.5270016 | -.1807145 |
| LD. | .1006331 | .1487781 | 0.68 | 0.506 | -.2079137 | .40918 |
| L2D. | .0327275 | .1516462 | 0.22 | 0.831 | -.2817675 | .3472225 |
| L3D. | -.0290358 | .1490852 | -0.19 | 0.847 | -.3382197 | .280148 |
| L4D. | .058638 | .1384072 | 0.42 | 0.676 | -.228401 | .345677 |
| L5D. | -.1464064 | .1323005 | -1.11 | 0.280 | -.4207808 | .127968 |
| L6D. | .1133264 | .1308169 | 0.87 | 0.396 | -.1579713 | .384624 |
| L7D. | -.154332 | .1263238 | -1.22 | 0.235 | -.4163115 | .1076475 |
| _trend | .0032746 | .001217 | 2.69 | 0.013 | .0007506 | .0057985 |
| _cons | 1.529349 | .3460986 | 4.42 | 0.000 | .8115846 | 2.247114 |

Findings are good. The time series difference of log(CPI) is stationary only at lag 7, non- stationary at lags i=1,2,3,4,5,6,8,9,…,17, and at lag 18, it becomes explosive as shown in the following graph.

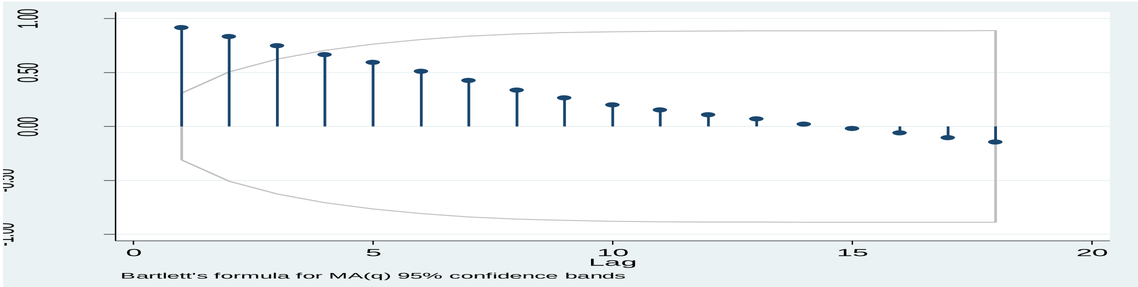



**Figure 6.2:** This figure displays the non-stationarity of the first difference of the time series CPI at lag 18 where it behaves in a way that is explosive.

In light of these results, equation (3.3) can now be written with all the coefficient estimates as

$$\begin{aligned}\Delta\ln(CPI)_t = {} & 1.529349 + 0.0032746t - 0.3538581\ln(CPI)_{t-1} + 0.1006331\Delta\ln(CPI)_{t-1} \\ & + 0.0327275\Delta\ln(CPI)_{t-2} - 0.0290358\Delta\ln(CPI)_{t-3} + 0.058638\Delta\ln(CPI)_{t-4} \\ & - 0.1464064\Delta\ln(CPI)_{t-5} + 0.1133264\Delta\ln(CPI)_{t-6} - 0.154332\Delta\ln(CPI)_{t-7}\end{aligned}$$

Since Test statistic, say $t_{stat}$ = -4.238 <$Z_{stat}$ = -3.572, it follows that the difference series is stationary at lag 7. Also, observe that the p-value for Z(t) = 0.0039 < 0.05, which implies rejection of the null hypothesis in favour of the alternative.

In investigating stationarity of the first difference of the time series **ln(M3),** findings reveal that the time series is stationary at lag 4, 6, 8, 9, 10, 11, 12 and 17. Results that follow display its stationarity at lag 4.

```
. dfuller ln_m3, trend regress lags(4)
```

Augmented Dickey-Fuller test for unit root  Number of obs = 35

| | Test Statistic | 1% Critical Value | 5% Critical Value | 10% Critical Value |
|---|---|---|---|---|
| | | Interpolated Dickey-Fuller | | |
| Z(t) | -4.545 | -4.288 | -3.560 | -3.216 |

MacKinnon approximate p-value for Z(t) = 0.0013

| D.ln_m3 | Coef. | Std. Err. | t | P>\|t\| | [95% Conf. | Interval] |
|---|---|---|---|---|---|---|
| ln_m3 | | | | | | |
| L1. | -.7308772 | .1608008 | -4.55 | 0.000 | -1.060263 | -.4014916 |
| LD. | .3752645 | .1678793 | 2.24 | 0.034 | .0313794 | .7191497 |
| L2D. | .3478456 | .1452316 | 2.40 | 0.024 | .0503522 | .645339 |
| L3D. | .1370403 | .1446956 | 0.95 | 0.352 | -.1593553 | .4334359 |
| L4D. | .6260722 | .1338873 | 4.68 | 0.000 | .3518164 | .900328 |
| _trend | .0312176 | .0069103 | 4.52 | 0.000 | .0170626 | .0453727 |
| _cons | 4.063569 | .8857481 | 4.59 | 0.000 | 2.249196 | 5.877942 |

Reconstructing equation (3.3) for the unit root test, one has the following

$$\Delta\ln(M3)_t = 4.063569 + 0.312176t - 0.7308772\ln(M3)_{t-1} + 0.3752645\ln(M3)_{t-1} + 0.3478456\Delta\ln(M3)_{t-2} + 0.1370403\ln(M3)_{t-3} + 0.6260722\Delta\ln(M3)_{t-4}$$

The Mackinnon approximate p-value for Z(t) = 0.0013 < 0.05 confirms stationarity of the time series under study. Observe that Δln(M3) behaves in a way that is explosive at lag 18 as reported in the following figure.

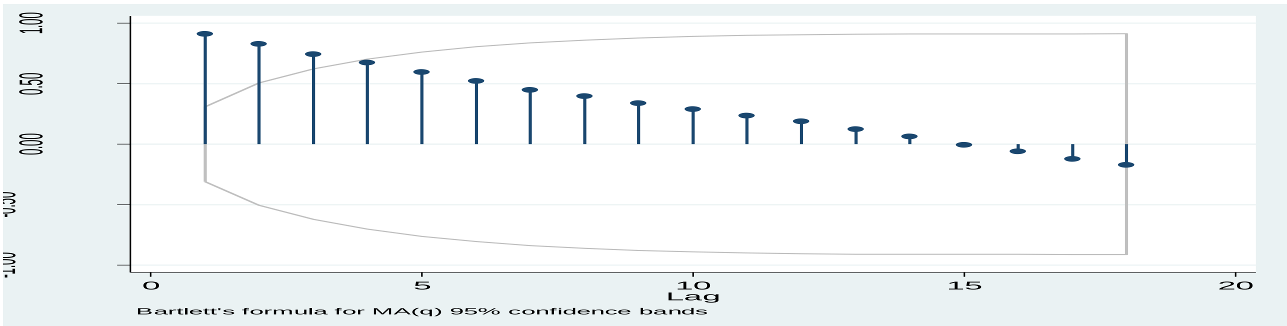



**Figure 6.3** Displays how explosive the time series Δln(M3) behaves at lag 18**.**

Investigating stationarity of Δln(ER) the following results have been occurring. The time series displays stationarity at each and every lag. At lag {0, 1, 2, 3}, the Mackinnon approximate p-value for Z(t) < 0.05 which confirms stationarity of the time series under study.

```
. dfuller d_lnER, trend regress lags(1)
```

Augmented Dickey-Fuller test for unit root  Number of obs = 37

| | Test Statistic | 1% Critical Value | 5% Critical Value | 10% Critical Value |
|---|---|---|---|---|
| | | Interpolated Dickey-Fuller | | |
| Z(t) | -3.956 | -4.270 | -3.552 | -3.211 |

MacKinnon approximate p-value for Z(t) = 0.0102

| D.d_lnER | Coef. | Std. Err. | t | P>\|t\| | [95% Conf. | Interval] |
|---|---|---|---|---|---|---|
| d_lnER | | | | | | |
| L1. | -.8030425 | .2030192 | -3.96 | 0.000 | -1.216088 | -.3899969 |
| LD. | .1601525 | .1723115 | 0.93 | 0.359 | -.1904177 | .5107228 |
| _trend | .0003754 | .0001305 | 2.88 | 0.007 | .0001099 | .000641 |
| _cons | -.001131 | .0021322 | -0.53 | 0.599 | -.0054691 | .003207 |

Reconstructing equation (3.3) for the unit root test, one has the following

$$\Delta\ln(ER)_t = -0.001131 + 0.0003754t - 0.8030425\ln(ER)_{t-1} + 0.1601525\Delta\ln(ER)_{t-1}$$

For any lag greater or equal to 4, the difference of the log of exchange rate is non-stationary, displaying the Mackinnon approximate p-value for Z(t) > 0.05.

Investigation stationarity of the time series Δln(GDP), it is found that the time series is stationary only at lag 0 and at lag 1, as displayed in the following results.

```
. dfuller ln_rgdp, trend regress lags(0)

Dickey-Fuller test for unit root                   Number of obs   =        39

                               ---------- Interpolated Dickey-Fuller ---------
                  Test         1% Critical       5% Critical      10% Critical
               Statistic           Value             Value             Value
------------------------------------------------------------------------------
 Z(t)             -5.614            -4.251            -3.544            -3.206
------------------------------------------------------------------------------
MacKinnon approximate p-value for Z(t) = 0.0000

------------------------------------------------------------------------------
D.ln_rgdp    |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
     ln_rgdp |
         L1. |  -.7901015   .1407372    -5.61   0.000     -1.07553   -.5046733
      _trend |   .0140106   .0025894     5.41   0.000     .0087591    .0192621
       _cons |   5.123448   .9077077     5.64   0.000     3.282531    6.964364
------------------------------------------------------------------------------
```

```
. dfuller ln_rgdp, trend regress lags(1)

Augmented Dickey-Fuller test for unit root         Number of obs   =        38

                               ---------- Interpolated Dickey-Fuller ---------
                  Test         1% Critical       5% Critical      10% Critical
               Statistic           Value             Value             Value
------------------------------------------------------------------------------
 Z(t)             -7.602            -4.260            -3.548            -3.209
------------------------------------------------------------------------------
MacKinnon approximate p-value for Z(t) = 0.0000

------------------------------------------------------------------------------
D.ln_rgdp    |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
     ln_rgdp |
         L1. |  -1.227272     .16144    -7.60   0.000    -1.555357   -.8991864
         LD. |    .476751   .1215829     3.92   0.000     .2296647    .7238372
      _trend |   .0218851   .0029228     7.49   0.000     .0159453    .0278249
       _cons |    7.93658   1.040955     7.62   0.000     5.821106    10.05206
------------------------------------------------------------------------------
```

In both cases, the Mackinnon approximate p-value for Z(t)= 0.0000 < 0.05 which confirms stationarity of the time series under study.

Given both results, equation (3.3) can now be formally written as follows. At lag 0, one has

$$\Delta\ln(GDP)_t = 5.123442 + 0.10150t - 0.7501015\ln(GDP)_{t-1}$$

At at lag one, equation (3.3) becomes

$$\Delta\ln(GDP)_t = 7.93658 + 0.218851t - 1.227272\ln(GDP)_{t-1} + 0.476751\Delta\ln(GDP)_{t-1}$$

as it were.

At other lags, it is non-stationary, particularly at lag 18, it explodes as well, as displayed in the following figure.

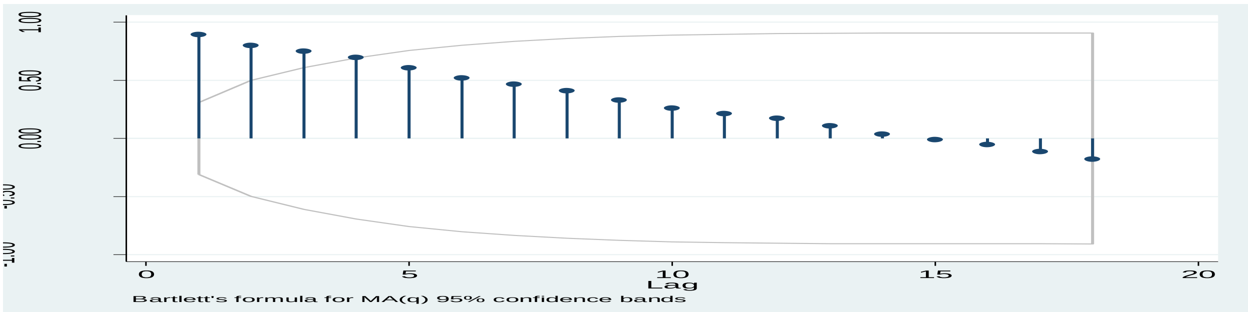



**Figure 6.5** Display the behaviour of the series Δln(GDP) at lag 18 when it explodes**.**

Investigation stationarity of the time series Δln(OIL), the findings are as follows. The difference time series under study is non-stationary at every lag, except at lag 17, where as shown in the results bellow, it displayed stationarity.

```
. dfuller ioilend, trend regress lags(17)

Augmented Dickey-Fuller test for unit root         Number of obs   =        22
```

| | | Interpolated Dickey-Fuller | | |
|---|---|---|---|---|
| | Test Statistic | 1% Critical Value | 5% Critical Value | 10% Critical Value |
| Z(t) | -6.121 | -4.380 | -3.600 | -3.240 |

MacKinnon approximate p-value for Z(t) = 0.0000

| D.ioilend | Coef. | Std. Err. | t | P>\|t\| | [95% Conf. | Interval] |
|---|---|---|---|---|---|---|
| ioilend | | | | | | |
| L1. | -37.87762 | 6.18828 | -6.12 | 0.026 | -64.50364 | -11.2516 |
| LD. | 37.71356 | 6.236126 | 6.05 | 0.026 | 10.88168 | 64.54544 |
| L2D. | 37.57607 | 6.191485 | 6.07 | 0.026 | 10.93626 | 64.21588 |
| L3D. | 38.24558 | 6.344189 | 6.03 | 0.026 | 10.94873 | 65.54242 |
| L4D. | 40.03309 | 6.577757 | 6.09 | 0.026 | 11.73129 | 68.3349 |
| L5D. | 35.53479 | 5.847678 | 6.08 | 0.026 | 10.37426 | 60.69532 |
| L6D. | 28.50688 | 4.680691 | 6.09 | 0.026 | 8.367487 | 48.64627 |
| L7D. | 24.75047 | 3.996934 | 6.19 | 0.025 | 7.553053 | 41.94789 |
| L8D. | 21.5036 | 3.467421 | 6.20 | 0.025 | 6.584494 | 36.42271 |
| L9D. | 19.1432 | 3.108096 | 6.16 | 0.025 | 5.770139 | 32.51625 |
| L10D. | 16.96786 | 2.719524 | 6.24 | 0.025 | 5.26669 | 28.66903 |
| L11D. | 14.4833 | 2.318611 | 6.25 | 0.025 | 4.507118 | 24.45947 |
| L12D. | 13.44943 | 2.166351 | 6.21 | 0.025 | 4.128376 | 22.77049 |
| L13D. | 11.02759 | 1.756776 | 6.28 | 0.024 | 3.468789 | 18.58639 |
| L14D. | 8.767101 | 1.40346 | 6.25 | 0.025 | 2.7285 | 14.8057 |
| L15D. | 5.299426 | .8237802 | 6.43 | 0.023 | 1.754986 | 8.843866 |
| L16D. | 3.025649 | .5246292 | 5.77 | 0.029 | .7683518 | 5.282946 |
| L17D. | 2.924324 | .4319848 | 6.77 | 0.021 | 1.065643 | 4.783004 |
| _trend | 126.516 | 21.48947 | 5.89 | 0.028 | 34.05422 | 218.9777 |
| _cons | 2692.09 | 419.4907 | 6.42 | 0.023 | 887.1678 | 4497.013 |

Reading the coefficients from these results in the second column, equation (3.3) can formally be written as

$$\Delta\ln(ioilend)_t = 2692.09 + 126.516t - 37.87762\ln(ioilend)_{t-1} + 37.73156\Delta\ln(ioilend)_{t-1} \\ + 37.57607\Delta\ln(ioilend)_{t-2} + \cdots + 3.025649\Delta\ln(ioilend)_{t-16} + 2.924324\Delta\ln(ioilend)_{t-17}$$

while omitting other middle terms. In this instance, as it is observe in the results above, the Mackinnon approximate p-value for Z(t)= 0.0000 < 0.05 and this confirms loudly stationarity of the time series under study. At lag 18, the time series Δln(OIL) explodes.

In summary, one characteristic that has been observed for all deference time series under investigation, is that at lag 18, they all exhibit explosive behaviour. Only one of them, particularly, the time series Δln(ER) had been found to be non-stationary at every lag. Moreover Δln(ioilend) is also non-stationary everywhere except at lag 17. Given the non-uniformity of the time series Δln(CPI) which did not completely meet the behaviour of stationarity, it is then imperative to examine the VAR measurements of time series at hand.

**Vector Autoregressive (VAR) test**

The current analysis is centred on the behaviour of the model displayed in equation (3.5) above. Far from reconstructing equation (3.5), the focus is laid on investigating the impulse responses of economic variables under study among themselves on shocks experienced by the markets. Reaction of five variables on shocks is being investigated. For clarity and ease of interpretation of the result, this assignment is done in a 2-variable system.

**(a) Impact of CPI shocks on the time-path of M3 variable and vice-versa**

The impulse of CPI shocks on the time-path of M3 variable and the impulse of M3 shocks on the time-path of CPI at lag 8 are both displayed in the following results.

```
. varbasic ln_cpiend ln_m3, lags(1/2) step(8) irf

Vector autoregression

Sample:  3 - 40                                 No. of obs      =        38
Log likelihood =  156.1545                      AIC             = -7.692341
FPE            =  1.57e-06                      HQIC            = -7.539014
Det(Sigma_ml)  =  9.24e-07                      SBIC            = -7.261397

Equation           Parms      RMSE     R-sq      chi2     P>chi2
----------------------------------------------------------------
ln_cpiend            5     .020893   0.9856   2597.591   0.0000
ln_m3                5     .054354   0.9885   3256.051   0.0000
----------------------------------------------------------------

------------------------------------------------------------------------------
             |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
ln_cpiend    |
   ln_cpiend |
         L1. |   .7336902   .1638078     4.48   0.000     .4126328    1.054748
         L2. |   .1406303   .1493971     0.94   0.347    -.1521826    .4334432
       ln_m3 |
         L1. |   .1036981   .0602443     1.72   0.085    -.0143785    .2217748
         L2. |  -.0744417   .0646385    -1.15   0.249    -.2011307    .0522474
       _cons |   .3825228    .154183     2.48   0.013     .0803296    .6847159
-------------+----------------------------------------------------------------
ln_m3        |
   ln_cpiend |
         L1. |   .1823173    .426155     0.43   0.669    -.6529311    1.017566
         L2. |  -.3049267   .3886647    -0.78   0.433    -1.066696    .4568422
       ln_m3 |
         L1. |   .6729767   .1567288     4.29   0.000     .3657938    .9801595
         L2. |   .3563201   .1681605     2.12   0.034     .0267316    .6859085
       _cons |   .4115298   .4011155     1.03   0.305    -.3746421    1.197702
------------------------------------------------------------------------------
```

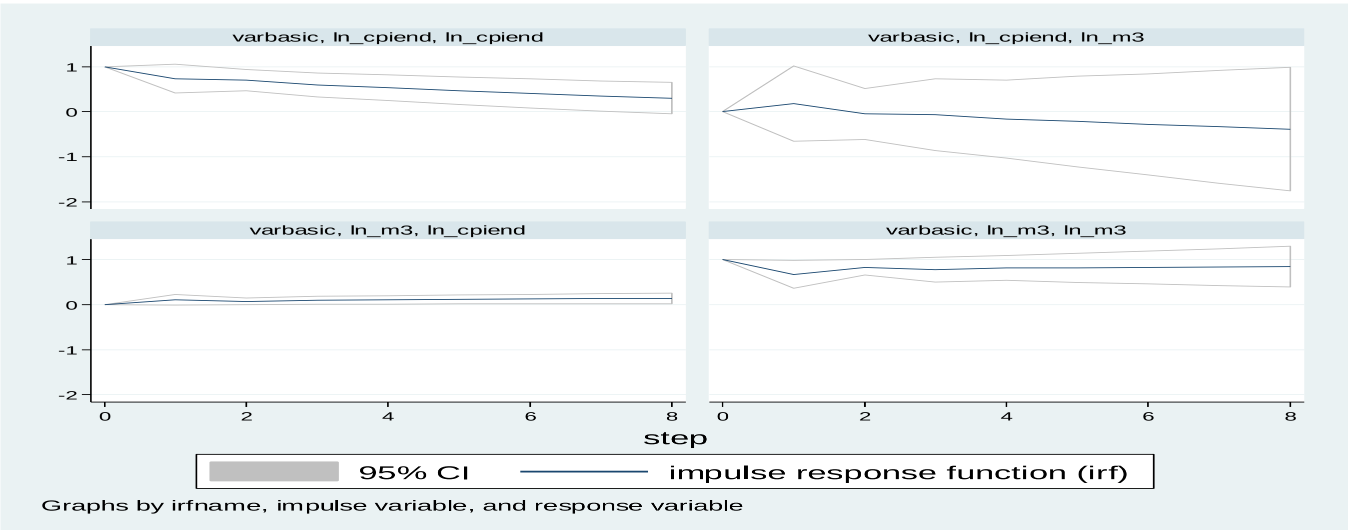
From these results, the impulse of CPI shocks on the time-path of M3 is formally given by equation:

$$\ln(CPI)_t = 0.3825228 + 0.7336902\ln(CPI)_{t-1} + 0.1406303\ln(CPI)_{t-2} + 0.1036981\ln(M3)_{t-1} - 0.0744417\ln(M3)_{t-2}$$
(eq.1)

And the impulse of M3 shocks on the time-path of CPI is described by the equation

$$\ln(M3)_t = 0.4115298 + 0.1823173\ln(CPI)_{t-1} - 0.3049267\ln(CPI)_{t-2} + 0.6729767\ln(M3)_{t-1} + 0.3563201\ln(M3)_{t-2}$$
(eq.2)

To have a complete sense of mutual impulse-response impact, the figure bellow is used. Of interest are the panels top-corner right and bottom-corner left. On the top-corner right, the impulse of CPI shocks, over time impacts M3 severely. On the bottom-left, it can be observed that the impulse of M3 shocks on the time-path of CPI, however, does not exert heavy weight on the consumer price index. This is expected in the economic state of the country. Shocks from Consumer Price index, which is just the inflation, affect badly M3, but the same influence is not felt is the reverse happens.

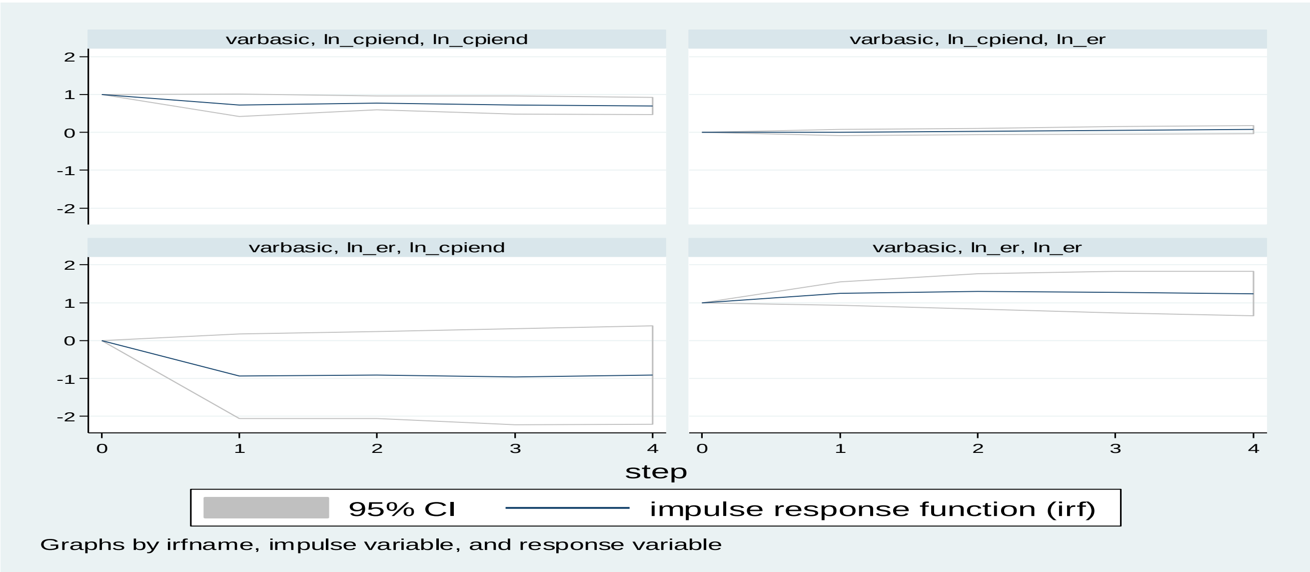


**(b) Impact of CPI shocks on the time-path of ER variable and vice-versa**

The impulse of CPI shocks on the time-path of ER and vice-versa in figure is displayed in the following results.

```
. varbasic ln_cpiend  ln_er, lags(1/2) step(4) irf

Vector autoregression

Sample:  3 - 40                                 No. of obs      =        38
Log likelihood =   238.637                      AIC             = -12.03353
FPE            =  2.04e-08                      HQIC            =  -11.8802
Det(Sigma_ml)  =  1.20e-08                      SBIC            = -11.60258

Equation           Parms      RMSE     R-sq      chi2     P>chi2
----------------------------------------------------------------
ln_cpiend             5     .021406   0.9849   2472.821   0.0000
ln_er                 5     .005907   0.9964   10579.13   0.0000
----------------------------------------------------------------

------------------------------------------------------------------------------
             |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
ln_cpiend    |
   ln_cpiend |
         L1. |   .7173376   .1515692     4.73   0.000     .4202675    1.014408
         L2. |    .258691   .1501137     1.72   0.085    -.0355265    .5529084
       ln_er |
         L1. |  -.9399282   .5691647    -1.65   0.099     -2.05547     .175614
         L2. |   .9339718   .5710535     1.64   0.102    -.1852725    2.053216
       _cons |   .1701217   .3585807     0.47   0.635    -.5326835    .8729269
-------------+----------------------------------------------------------------
ln_er        |
   ln_cpiend |
         L1. |  -.0036018   .0418263    -0.09   0.931    -.0855799    .0783763
         L2. |   .0297788   .0414247     0.72   0.472    -.0514121    .1109697
       ln_er |
         L1. |   1.243268    .157064     7.92   0.000     .9354285    1.551108
         L2. |  -.2503444   .1575853    -1.59   0.112    -.5592059    .0585171
       _cons |  -.0645729   .0989523    -0.65   0.514    -.2585158    .1293699
------------------------------------------------------------------------------
```

The figurebelow display in a picture the impulse-response to shocks expected over time from each other in the market.




While the impulse of CPI shock on the time-path depicts little (see top-right panel) influence on ER (Exchange Rate), the impulse of ER on the time-path of CPI is great (see bottom left panel) and this is quite persistent. The impulse of CPI shock on the time-path upon itself can grow with the same magnitude (see top left panel) while the impulse of ER shock upon itself over time is quite increasing as the time passes (see bottom right panel).

Both impulse-response dynamics are formally represented by the following system of equations

$$\begin{bmatrix}\ln(CPI)_t\\ \ln(ER)_t\end{bmatrix} = \begin{pmatrix}0.1701217\\ -0.0643729\end{pmatrix} + \begin{pmatrix}0.717376 & 0.258691\\ -0.003601 & 0.0297788\end{pmatrix}\begin{pmatrix}\ln(CPI)_{t-1}\\ \ln(CPI)_{t-2}\end{pmatrix} + \begin{pmatrix}-0.939928 & 0.9339718\\ 1.243268 & -0.2503444\end{pmatrix}\begin{pmatrix}\ln(ER)_{t-1}\\ \ln(ER)_{t-2}\end{pmatrix} \quad \text{(eq.3)}$$

**(c) Impact of CPI shocks on the time-path of GDP variable and vice-versa**

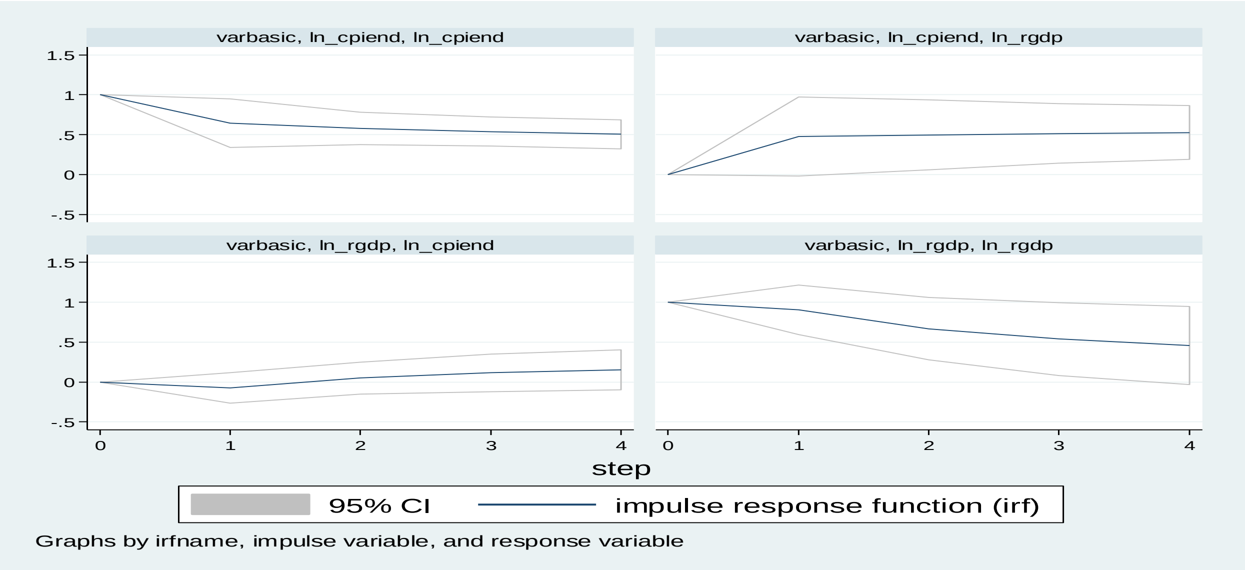
The impulse of CPI shocks on the time-path of GDP and vice-versa observed is displayed in the following results from which the following system of VAR equations are deduced.

$$\begin{bmatrix}\ln(CPI)_t\\ \ln(GDP)_t\end{bmatrix} = \begin{pmatrix}0.1202242\\0.4037654\end{pmatrix} + \begin{pmatrix}0.6449897 & 0.1956665\\0.4763433 & -0.2404273\end{pmatrix}\begin{pmatrix}\ln(CPI)_{t-1}\\ \ln(CPI)_{t-2}\end{pmatrix} + \begin{pmatrix}-0.0738154 & 0.1629638\\0.9040845 & -0.1147827\end{pmatrix}\begin{pmatrix}\ln(GDP)_{t-1}\\ \ln(GDP)_{t-2}\end{pmatrix} \quad \text{(eq.4)}$$

```
. varbasic ln_cpiend ln_rgdp, lags(1/2) step(4) irf

Vector autoregression

Sample:  3 - 40                                 No. of obs      =        38
Log likelihood =  171.8838                      AIC             = -8.520201
FPE            =  6.86e-07                      HQIC            = -8.366874
Det(Sigma_ml)  =  4.04e-07                      SBIC            = -8.089257
```

| Equation | Parms | RMSE | R-sq | chi2 | P>chi2 |
|---|---|---|---|---|---|
| ln_cpiend | 5 | .021196 | 0.9852 | 2522.645 | 0.0000 |
| ln_rgdp | 5 | .034572 | 0.9727 | 1356.245 | 0.0000 |

| | Coef. | Std. Err. | z | P>\|z\| | [95% Conf. | Interval] |
|---|---|---|---|---|---|---|
| **ln_cpiend** | | | | | | |
| ln_cpiend | | | | | | |
| L1. | .6449897 | .1546943 | 4.17 | 0.000 | .3417945 | .9481849 |
| L2. | .1956665 | .1543436 | 1.27 | 0.205 | -.1068413 | .4981744 |
| ln_rgdp | | | | | | |
| L1. | -.0738154 | .09755 | -0.76 | 0.449 | -.2650099 | .117379 |
| L2. | .1629638 | .0968814 | 1.68 | 0.093 | -.0269203 | .3528478 |
| _cons | .1202242 | .1522691 | 0.79 | 0.430 | -.1782178 | .4186663 |
| **ln_rgdp** | | | | | | |
| ln_cpiend | | | | | | |
| L1. | .4763433 | .252314 | 1.89 | 0.059 | -.0181831 | .9708697 |
| L2. | -.2404273 | .2517421 | -0.96 | 0.340 | -.7338327 | .2529781 |
| ln_rgdp | | | | | | |
| L1. | .9040845 | .1591089 | 5.68 | 0.000 | .5922369 | 1.215932 |
| L2. | -.1147827 | .1580184 | -0.73 | 0.468 | -.4244931 | .1949276 |
| _cons | .4037654 | .2483586 | 1.63 | 0.104 | -.0830084 | .8905392 |




From the top right panel, it can be observed that the impulse of CPI shocks on GDP response is quite huge as compare to the impulse of GDP shocks on the response of the CPI (see bottom left panel). These two economic variables appear to share impulse-response dynamics in the economic arena.

**(d) The Impact of CPI shocks on the time-path of OIL price variable and vice-versa**

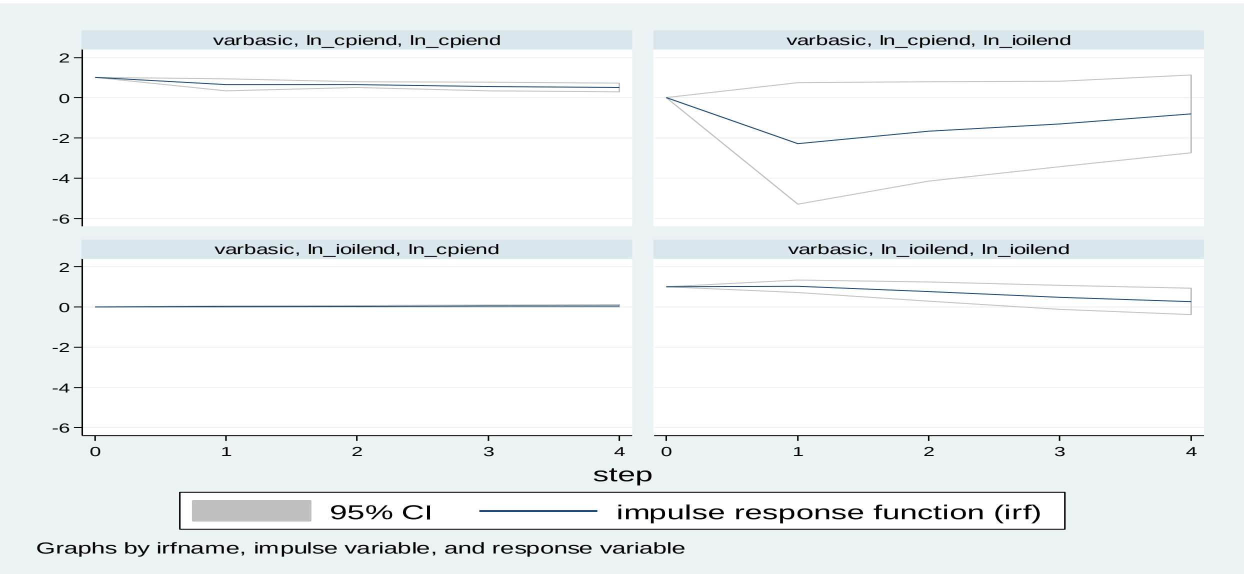
Results below depict the impulse-response exhibited when CPI experiences shocks and OIL price responds to those economic shocks.

```
. varbasic ln_cpiend ln_ioilend, lags(1/2) step(4) irf

Vector autoregression

Sample:  3 - 40                               No. of obs      =        38
Log likelihood =   103.836                    AIC             = -4.938734
FPE            =  .0000246                    HQIC            = -4.785408
Det(Sigma_ml)  =  .0000145                    SBIC            =  -4.50779

Equation           Parms      RMSE     R-sq      chi2     P>chi2
----------------------------------------------------------------
ln_cpiend             5     .021066   0.9853   2554.351   0.0000
ln_ioilend            5     .208896   0.6132   60.24544   0.0000
----------------------------------------------------------------

------------------------------------------------------------------------------
             |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
ln_cpiend    |
   ln_cpiend |
         L1. |   .6430856   .1551468     4.15   0.000     .3390035    .9471677
         L2. |   .2879015   .1475179     1.95   0.051    -.0012283    .5770312
  ln_ioilend |
         L1. |   .0187507   .0159063     1.18   0.238    -.0124252    .0499265
         L2. |   .0069252   .0177177     0.39   0.696    -.0278008    .0416512
       _cons |   .1964783   .0926132     2.12   0.034     .0149597    .3779969
-------------+----------------------------------------------------------------
ln_ioilend   |
   ln_cpiend |
         L1. |  -2.278037   1.538448    -1.48   0.139    -5.293339     .737266
         L2. |   2.120281   1.462799     1.45   0.147    -.7467528    4.987314
  ln_ioilend |
         L1. |   1.023049   .1577286     6.49   0.000      .713907    1.332192
         L2. |  -.2430063   .1756898    -1.38   0.167    -.5873521    .1013394
       _cons |   1.825341   .9183604     1.99   0.047      .025388    3.625294
------------------------------------------------------------------------------
```

From these results, the following VAR equations can be deduced:

$$\begin{bmatrix}\ln(CPI)_t\\ \ln(IOIL)_t\end{bmatrix} = \begin{pmatrix}0.1202242\\ 0.4037654\end{pmatrix} + \begin{pmatrix}0.6449897 & 0.1956665\\ 0.4763433 & -0.2404273\end{pmatrix}\begin{pmatrix}\ln(CPI)_{t-1}\\ \ln(CPI)_{t-2}\end{pmatrix} + \begin{pmatrix}0.0187507 & 0.0069252\\ 1.023049 & -0.2430063\end{pmatrix}\begin{pmatrix}\ln(IOIL)_{t-1}\\ \ln(IOIL)_{t-2}\end{pmatrix} \quad \text{(eq.5)}$$

The picture below explains the impulse-response between these economic variables. What can be observed right in the top-left panel is that the Oil price responds with higher magnitude to CPI shocks. This observation makes sense economically. Any increase or decrease in the CPI is a signal of a change in whichever direction in Oil price.




**(e) The impact of CPI shocks on the time-path of M3, ER, GDP and Oil price and vice-versa**

In this section, the interest is on observing what the shocks of CPI produces as a response on all other economic variables under study. The following figure displays pictorially responses coming from M3, ER, GDP and OIL price in the presence of CPI shocks but also impulse-response dynamics among themselves.

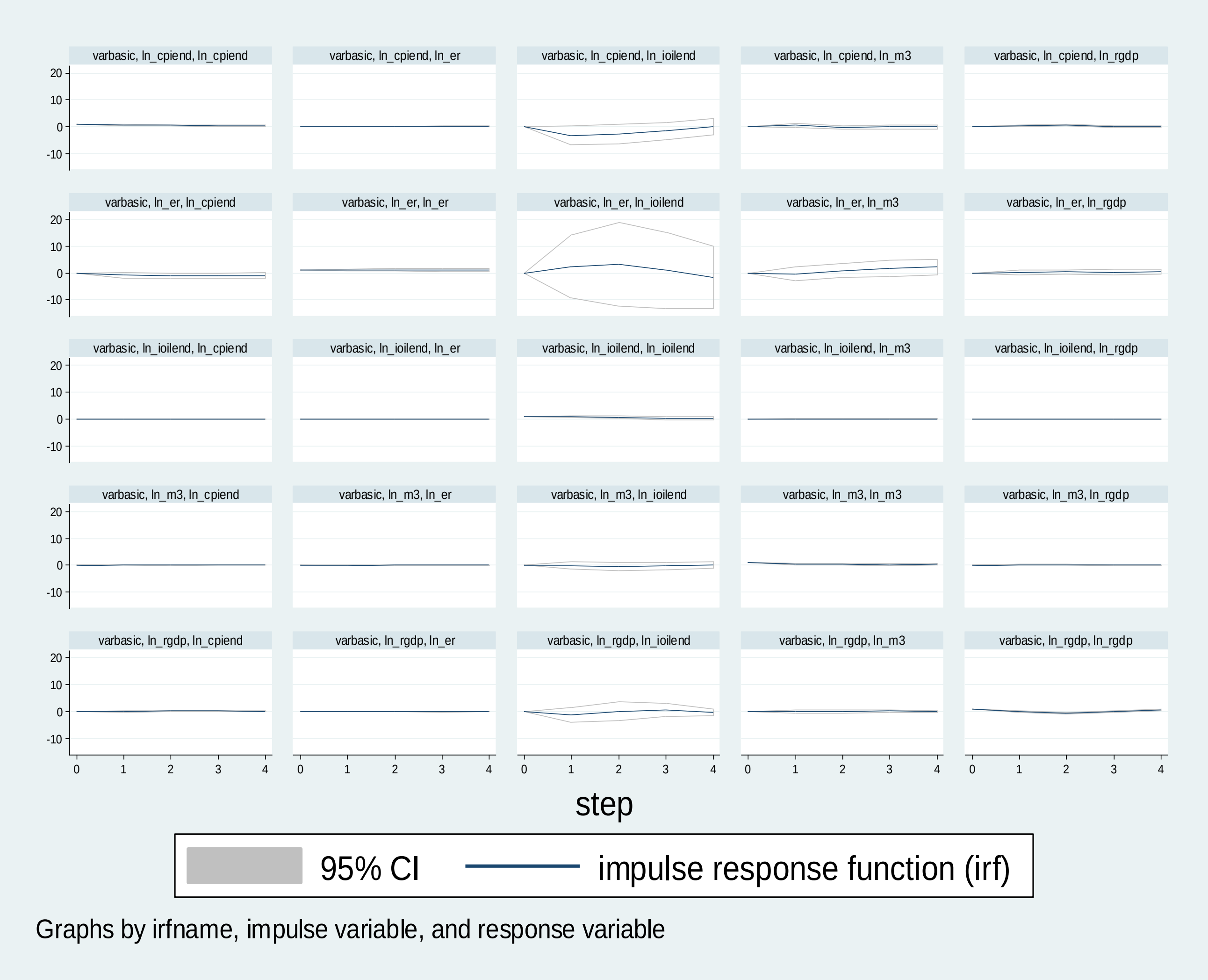



**Figure 6.6:** Impulse variable and response variables

A quick observation on this matrix picture reveals that shocks on CPI produces a fairly response on Oil price (first row, third column), shocks coming from ER will produce considerable response in Oil price (second row, third column), shocks on ER will absolutely have an impact on M3 and shocks from GDP will trigger a reasonable response in the Oil price. There other observations that can be made in the above summary picture and this are left to the discretion of a reader who wants to know each and every detail in the picture. The VAR equation representing the above observation is huge, and it has been omitted in this work.

**Selection of the order of VAR(p)**

In this work, it is intended to select the order of the Vector autoregressive that has been used using the AIC criteria. Recall that

$$AIC = -2L + 2(k + 2kp)$$

where L is the log-likelihood for the model. Select the model with the smallest AIC among others.

```
. varsoc ln_cpiend ln_m3  ln_er ln_rgdp ln_ioilend, maxlag(4)

   Selection-order criteria
   Sample:  5 - 40                              Number of obs      =        36
```

| lag | LL | LR | df | p | FPE | AIC | HQIC | SBIC |
|---|---|---|---|---|---|---|---|---|
| 0 | 201.584 | | | | 1.2e-11 | -10.9213 | -10.8446 | -10.7014 |
| 1 | 392.75 | 382.33 | 25 | 0.000 | 1.2e-15 | -20.1528 | -19.6922 | -18.8332* |
| 2 | 424.821 | 64.141 | 25 | 0.000 | 9.1e-16 | -20.5456 | -19.7012 | -18.1263 |
| 3 | 450.095 | 50.55 | 25 | 0.002 | 1.1e-15 | -20.5609 | -19.3327 | -17.0419 |
| 4 | 491.288 | 82.384* | 25 | 0.000 | 7.6e-16* | -21.4604* | -19.8484* | -16.8418 |

```
   Endogenous:  ln_cpiend ln_m3 ln_er ln_rgdp ln_ioilend
    Exogenous:  _cons
```

The finding for testing various lags, it is revealed that taking p=4 do produce a VAR with expected economic impulse-reaction of variables under investigation. The order p = 4 is used by default. An in-depth search of p from various samples reveals that the time series under study requires the value of p to be equal to 2 as displays in the following results

```
. varsoc

   Selection-order criteria
   Sample:  3 - 40                                  Number of obs      =        38
```

| lag | LL | LR | df | p | FPE | AIC | HQIC | SBIC |
|---|---|---|---|---|---|---|---|---|
| 0 | 203.571 | | | | 2.0e-11 | -10.4511 | -10.3745 | -10.2357 |
| 1 | 411.349 | 415.55 | 25 | 0.000 | 1.3e-15 | -20.071 | -19.611 | -18.7781* |
| 2 | 448.684 | 74.67* | 25 | 0.000 | 7.5e-16* | -20.7202* | -19.8769* | -18.35 |

```
   Endogenous:  ln_cpiend ln_m3 ln_er ln_rgdp ln_ioilend
    Exogenous:  _cons
```

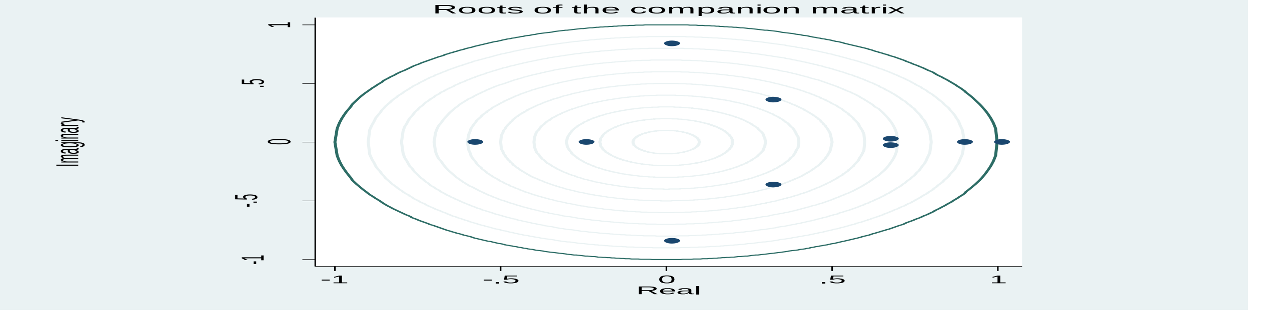
The measure of AIC = -20.7202* indicates maximum lag that is required. In studying stability of VAR(2), results below indicate that it is not stable, at all.

```
. varstable, graph

   Eigenvalue stability condition
```

| Eigenvalue | Modulus |
|---|---|
| 1.014052 | 1.01405 |
| .9030719 | .903072 |
| .01788803 + .8403911*i* | .840581 |
| .01788803 - .8403911*i* | .840581 |
| .6786326 + .02672206*i* | .679158 |
| .6786326 - .02672206*i* | .679158 |
| -.5762365 | .576237 |
| .3239564 + .3620477*i* | .485825 |
| .3239564 - .3620477*i* | .485825 |
| -.2395726 | .239573 |

```
   At least one eigenvalue is at least 1.0.
   VAR does not satisfy stability condition.
```

In picture, this is represented by the following diagram

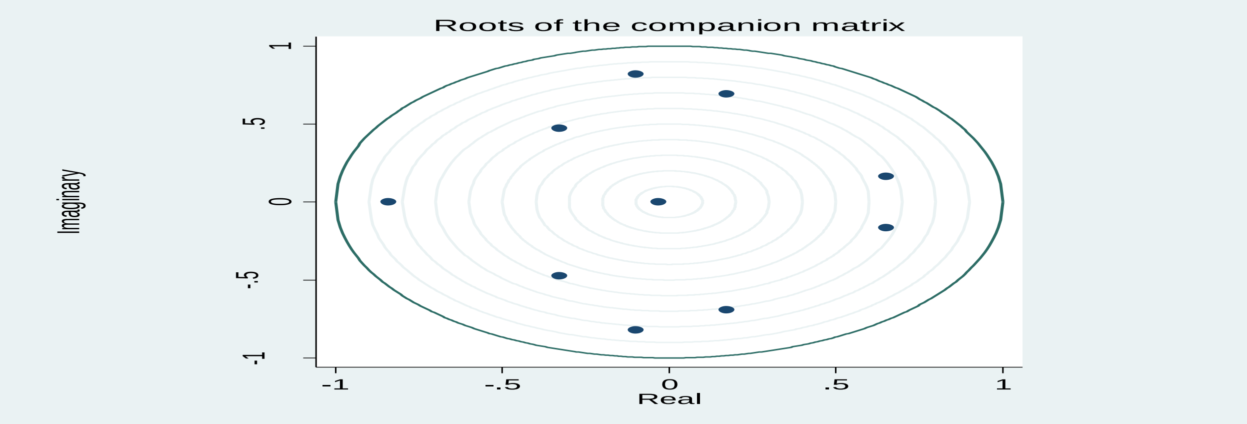



The dot that is out of a unit circle as depicted in the above diagram signals that the time series that is the main subject of this study is not stable. Testing the VAR model that consider the first difference for each variable, stability is quite guaranteed as shown in the following results and graph:

```
. varstable, graph

   Eigenvalue stability condition
```

| Eigenvalue | Modulus |
|---|---|
| -.8410944 | .841094 |
| -.100184 + .8200552*i* | .826152 |
| -.100184 - .8200552*i* | .826152 |
| .1736652 + .6926388*i* | .714078 |
| .1736652 - .6926388*i* | .714078 |
| .6521569 + .1647841*i* | .672653 |
| .6521569 - .1647841*i* | .672653 |
| -.3275362 + .4727607*i* | .575137 |
| -.3275362 - .4727607*i* | .575137 |
| -.03081124 | .030811 |

```
   All the eigenvalues lie inside the unit circle.
   VAR satisfies stability condition.
```




Since all points, i.e. eigenvalues are inside a unit circle, there are evidences that the VAR which uses the first difference of the natural log of the variable under study is more stable than the model which considered only the natural log of the variable under study.

**Testing co-integration**

In previous section, the impulse-response of variables under study laid foundation for the section. In this section, it is intended to examine or distinguish between shocks and transitory effect observed early in the study of impulse-response. Using the VECM frame in STATA, the following results were obtained.

```
. vecrank ln_cpiend ln_m3 ln_er ln_rgdp ln_ioilend, trend(constant) lags(4)

                       Johansen tests for cointegration
Trend: constant                                         Number of obs =      36
Sample:  5 - 40                                                  Lags =       4
-------------------------------------------------------------------------------
                                                              5%
maximum                                         trace    critical
  rank    parms       LL        eigenvalue    statistic    value
    0      80     441.89075          .         98.7937     68.52
    1      89     463.82364      0.70432       54.9279     47.21
    2      96      477.3181      0.52749       27.9390*    29.68
    3     101      485.2202      0.35532       12.1348     15.41
    4     104      491.0176      0.27536        0.5400      3.76
    5     105     491.28758      0.01489
-------------------------------------------------------------------------------
```

The trace statistic with a star indicates maximum number of co-integrating vector that is possible at determined lag. Given the trace statistic of 27.9390* at lag 2, one rejects the null hypothesis of 0, 1 co-integrating vectors in favour of greater than 1. In conclusion, at lag 4, there are two co-integrating vectors. Also, using VEC frame confirms that there are only two co-integrating vectors that are possible, from a set of five time series under study (see results below).

```
Cointegrating equations

Equation           Parms    chi2     P>chi2
-------------------------------------------
_ce1                   3   270.3825   0.0000
_ce2                   3   849.4046   0.0000
-------------------------------------------

Identification:  beta is exactly identified
                 Johansen normalization restrictions imposed

------------------------------------------------------------------------------
        beta |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
_ce1         |
   ln_cpiend |          1          .        .       .            .           .
       ln_m3 |  -1.11e-16          .        .       .            .           .
       ln_er |   2.099407   .2898457     7.24   0.000     1.531319    2.667494
     ln_rgdp |  -1.638651   .1501329   -10.91   0.000    -1.932907   -1.344396
  ln_ioilend |   .0900443   .0375833     2.40   0.017     .0163823    .1637062
       _cons |  -7.172741          .        .       .            .           .
-------------+----------------------------------------------------------------
_ce2         |
   ln_cpiend |  (dropped)
       ln_m3 |          1          .        .       .            .           .
       ln_er |  -2.126515   .5736719    -3.71   0.000    -3.250891   -1.002139
     ln_rgdp |  -1.674601   .2971478    -5.64   0.000       -2.257   -1.092202
  ln_ioilend |  -.1476948   .0743861    -1.99   0.047     -.293489   -.0019007
       _cons |   19.35156          .        .       .            .           .
------------------------------------------------------------------------------
```

From these results, it is easy to deduce co-integration equations as follows:

$$\ln(CPI)_t = 1.11e - 16\ln(M3)_t - 2.099407\ln(ER)_t + 1.638651\ln(GDP)_t - 0.0900443\ln(OIL)_t - Z_{1t}$$

where the coefficients in the right hand side of the equation indicate the levels of elasticity of the associated predictors and $-Z_{1t}$ is the $I(1)$ error term. The second equation is the following

$$\ln(M3)_t = 2.126515\ln(ER)_t + 1.674601\ln(GDP)_t + 1.1476948\ln(OIL)_t - Z_{2t}$$

Where, once again, the coefficients on the right-hand side are the levels of elasticity of each associated predictor and $-Z_{2t}$ is the $I(1)$ error term.

## 7. CONCLUSIONS AND RECOMMENDATIONS

### 7.1 Conclusion

The current work has been centred on assessing the determinants of inflation in Rwanda. The main determinants under the radars include M3, exchange rate (ER), gross domestic production (GDP) and the oil price (OIL). To assess and measure the influence of the latter on inflation in Rwanda, a regression model (3.5) has been used. Results suggested a model is a belle-fit since 94.45 % measure of variation in the inflation have been captured. Among the determinants considered, it has been revealed through findings that GDP and ER exercise a statistically significant influence on inflation. A unit change in ER would decrease the inflation by as much as units as 0.8303905, while keeping other determinants constant. Also a change in GDP would increase the inflation by 0.8192819 units, keeping other predictors constant. An interesting part of this study is that, using Durbin-Watson and Breusch-Godfred LM tests, findings indicated that the error terms in the model (3.5) are serially correlated. This is in line with the behaviour of economic variables considered in the model.

A unit root test has been performed to determine stationarity of the five series under study. These include the natural log of CPI, M3, ER, GDP and OIL price. Using Dicket-Fuller test, findings revealed that CPI is stationary only at lag 7 and non-stationary at other lags. M3 had better performance. It has been found to be stationary at lag 4, 6, 8, 9, 10, 11, 12, and 17. The variable GDP was stationary at lags 0 and 1, Oil price was stationary only at lag 17 and Exchange Rate was found to be non-stationary. An interesting characteristic shared by all the five time series is that at lag 18 they all exhibit an explosive behaviour.

Testing impulse-response dynamic among all economic variables used in this work has been performed through VAR test. Precisely, an examination of the impulse of CPI in its natural log has been observed on the time-path of each predictor in the model. In general, shocks from Inflation (CPI) create detectable response in M3, ER, GDP and in Oil price each with different magnitude. Of particular interest were, firstly, a considerable magnitude response observed from Oil price in the presence of ER shocks over time, secondly, a remarkable response observed from Oil price in the presence of GDP shocks. Both dynamics are economically verifiable. As compared to other major currencies, it is an observable fact that Rwandan currency has been weaker and weaker over time. This economic phenomenon has been provoking hikes in oil pricing. Shocks from any economic variable used had, over time, a fairly response from other variables.

Testing co-integration has been performed through VECM framework. Given the five time series under study in this project, it has been found that two co-integrating vectors exists, expressing shocks that create rather permanent effects on other economic variables, precisely, shocks from CPI and from M3.

### 7.2 Recommendations

Areas that need complete attention from the decision makers include the following

(a) Increase export that takes on board both services and products, particularly in the region. This will reduce exclusiveness and pronounced dependence on the US dollars which dictate direction of the consumer price index.

(b) Stabilize exchange rate through appropriate monetary policies which are consistent with the strength of the Rwandan franc vis-à-vis foreign currencies.

(c) Introduction and exploitation of wind energy which definitely and effectively reduces the consumption of oil in energy production.

### 7.3 Further areas of research

Interesting further econometric research that appears to be imperative for the Rwandan scientific community in the area of economic studies including the following:

(a) Determining stability conditions of the all economic variables used in the model (3.5)

(b) Studying both fixed and random effects models involving the five economic variables used in this work.

## REFERENCES

[1] Ahmed, F. R. (2013). Determinant of inflation in Pakistan: An econometrics analysis, using Johansen co-integration approach. *European Journal of Business and Management*, , 5, 115-122.

[2] Armesh, H., Rad, A. A., Azadavar, R., Zarezadeh, S., & Saeidinia, M. (2011). Inflation in the Islamic Republic of Iran: Apply univariate and multivariate co-integration analysis. *International Journal of Business and Social Science* , 2-12.

[3] Bashir, F., Nawaz, S., Yasin, K., Khursheed, U., Khan, J., & Qureshi, M. J. (2011). Determinants of inflation in Pakistan: An econometric analysis using Johansen cointegration approach. *Australian Journal of Business and Management Research*, 1, 71-82.

[4] BNR. ( 2012 ). *monetary policy and financial stability.*

[5] BNR. (2004). *Economic review n°001, June.*

[6] BNR. (2008). *Economic review n°002, November.*

[7] BNR. (2016). *Monetary policy and financial stability.*

[8] Brooks, C. (2014). *Introductory econometrics for finance.* Cambridge university press.

[9] Budina, N., Maliszewski, W., De Menil, G., & Turlea, G. (2006). Money, inflation and output in Romania, 1992–2000. *Journal of International Money and Finance*, 25,330-347.

[10] Busari, D. (2007). *the determinants of inflation in Nigeria: 1980 – 2003.* Central Bank of Nigeria Economic and Financial Review. Vol. 45(1): 35 – 56.

[11] Canetti, E. and Greene. (1991). *Monetary growth and exchange rate depreciations as causes of inflation in African countries: an empirical analysis. Center for economic research on Africa research monograph series.*

[12] Chibber, A. and Shafik, N. (1990). *Exchange reform, parallel markets and inflation in Africa: the case of Ghana.*

[13] Dickey, D. A., & Fuller, W. A. (1981). Likelihood ratio statistics for autoregressive time series with a unit root Econometrica. *Journal of the Econometric Society*, 1057-1072.

[14] Diouf, M. A. (2007). *modelling inflation for Mali.* IMF working paper.

[15] Dlamini, A. D. (2001). *A Cointegration analysis of the Determinants of Inflation in Swaziland.*

[16] Durevall, D. and N.S. Ndung'u. (1999). *"A dynamic model of inflation for Kenya". IMF Working Paper99/77. International Monetary Fund.* Washington, D.C.

[17] Enders, W. (2008). *Applied econometric time series.* John Wiley & Sons.

[18] Engle, R. F., & Granger, C. W. (1987). Co-integration and error correction: representation, estimation, and testing. Econometrica. *Journal of the Econometric Society,*, 251-276.

[19] Friedman, M. (1971). *The Keynesian challenge to the quantity theory. National Bureau of Economic Research,*. 15-29.

[20] Gichondo and Kimenyi. ((2012). *Modeling inflation in Rwanda.*

[21] Gichuki, J.K. & Moyi, E.D. (2013). *Monetary Conditions Index for Kenya. Research in applied Economics. Macrothink Institute. ISSN 1948-5433, Vol.5, No.4.*

[22] Gyebi, F., & Boafo, G. K. (2013). Macroeconomic determinants of inflation in Ghana from 1990–2009. *International Journal of Business and Social Research*, 81- 93.

[23] Imimole, B. and Enoma, A. (2011). Exchange rate depreciation and inflation in Nigeria (1986 – 2008). *Business and economics journal,* , Vol. BEJ-28.1-12.

[24] Johansen, S. (1991). Estimation and hypothesis testing of cointegration vectors in Gaussian vector autoregressive models. Econometrica. *Journal of the Econometric Society,* , 1551-1580.

[25] Keynes, J. M. (1936). *The General Theory of Employment, Interest, and Money.*

[26] Khan, R. E. (2010). Determinants of inflation: A case of Pakistan (1970-2007). . *Journal of Economics*, , 45-51.

[27] Kigabo, R. (2008). *Money and inflation in Rwanda.* Kigali: BNR Economic Review, 3,75-109.

[28] Laryea, S. A., & Sumaila, U.R. (2001). *Determinants of Inflation in Tanzania. CMI Working Papers. Chr. Michelsen Institute, Development Studies and Human Rights.* .

[29] Lipsey, R., P Steiner and D. Purvis. (1982). *Economics, 7th Edition,.* New York : Harper: Collins Pub.Inc.

[30] Mankiew, N. G. (1997). *Macroeconomics, 3rd Edition,.* New York: Worth Publishers, Inc.

[31] Mishkin, F. S. (2004). *The economics of money, banking and financial markets (7th. Ed.).* Addison-Wesley, U.S.

[32] Mortaza, G. (2006). *Sources of inflation in Bangladesh.* Recent Macroeconomic Experience.

[33] Qayyum, A. (2006). *Money, Inflation, and Growth in Pakistan. The Pakistan Development Review 45: 2 pp.203–212.*

[34] Sowa, N. a. (1991). *Inflationary trends and Control in Ghana", AERC Research Report: Nairobi.*

[35] Ubide, Ange. (1997). *"Determinants of Inflation in Mozambique",.* Washington D.C.: IMF Working Paper WP/97/145, International Monetary Fund.