TESTING FOR UNIT ROOT IN TIME SERIES DATA: EVIDENCE FROM EUROPEAN UNION LONG-TERM INTEREST RATES

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ABSTRACT

Testing for the presence of unit root in economic or financial time series data is an important precondition prior to further statistical analysis. This paper investigates the order of integration of long-term interest rates series for 23 European countries using two commonly used unit root tests in applied work: augmented Dickey-Fuller (ADF) test and generalized least squares Dickey-Fuller (DF-GLS).We compare rejection rate of unit root hypothesis under different lag selection techniques. Of particular interest is influence of the choice of optimal lag-length on the outcome of stationarity test, we provide empirical evidence that show that the outcome of unit root test is crucially dependent on appropriate choice of lag structure.

**Keywords:** Unit root test, ADF test, DF-GLS test, optimal lag-length, information criteria, stationarity, order of integration.

**1. INTRODUCTION**

Unit root testing is a very important research direction in time series analysis that has attracted a huge literature because of its significance to further statistical analysis of economic and financial time series data which are generally known to be non-stationary(i.e. it contains a unit root). Unit root tests are commonly used in empirical analysis to investigate the stationarity properties of series which is the same as determination of the order of integration of series denoted as  ,where  represents the number of differencing required to induce stationarity. Series that become stationary after being differenced once are referred to as  series. Similarly, series that become stationary after being differenced twice are referred to as  and so on like that. There is also a class of time series data that is fractionally integrated. The order of integration of this class of time series is denoted by  where  and such series is said to exhibit long memory or long-range dependence .Stationarity of series is a core issue in different areas of time series analysis. For example, it is a very crucial precondition to residual-based Engle-Granger cointegration methodology as well as Johansen multivariate cointegration technique since variables entering the cointegrating space must be integrated of the same order (Engle and Granger 1987, Johansen, 1988 and 1991). Similarly, in estimation and forecasting ,stationarity are required for reliable estimation and accurate prediction(see Diebold and Kilian,1999, Mahadeva and Robinson,2004).However, it is often observed that the main criticism of commonly used unit root tests such as ADF family of unit root tests as well as DF-GLS unit root test is the problem of low power that could make these unit root tests suggest wrongly that a stationary series is non-stationary when it is in fact stationary but close to being a unit root. In applied work, most unit root tests are conducted using either ADF proposed by Said and Dickey (1984) or DF-GLS unit root test introduced by Elliot et al (1996).In view of the popularity and dominance of these two unit root tests in applied work, it has become most imperative to investigate the influence of lag selection on the performance of these two tests since they have become the most commonly used tests by applied researchers.

Early studies on stationary properties of interest rate series includes the work of Rose (1988) that investigated the presence of unit roots in short-term nominal interest rates and inflation rates using monthly data covering 1947-1986 for 18 countries in the Organization for Economic Co-operation and Development (OECD).Rose (1988) finds that augmented Dickey-Fuller (ADF) tests fail to reject the null hypothesis of a unit root in short-term nominal interest rates, but they can consistently reject presence of unit root for inflation rates. A number of other authors like Kings et al. (1991), Mishkin(1992), Gali (1992), Wallace and Warner (1993), Mishkin and Simon(1995), Engsted(1995),Crowder and Hoffman(1996),Koustas and Serletis(1999), Bierens(2000), Rapach(2003), Rapach and Weber(2004) and Rapach and Wohar(2004) as reported in Neely and Rapach(2008) have equally investigated stationarity properties of nominal interest rate series. However, previous studies have mainly focused on investigating the effects of structural break and non-linearities on empirical power properties of standard augmented Dickey-Fuller test which is the most commonly applied unit root test in applied work but with little attention focused on the issue of mis-specification of lag-length which is a very important model specification decision that cannot be under-estimated. Similarly, a number of authors have also studied the presence of unit root in various classes of short-term and long-term interest rates series for European countries.Fountas and Wu(1998) show that long-term interest rate series for 8 European countries are integrated of order 1 i.e they are difference-stationary .Afonso and Rault(2005) established that long-term interest rate series and its determinants in OECD countries are individually integrated of order 1.Following this empirical findings, Afonso and Rault(2005) used panel cointegration to investigate existence of long-run relationship between long-term interest rate series and its potential determinants in OECD countries .Bruggemann and Lutkepohl(2005) analyzed US and European short and long-term interest rate series and showed that the series are cointegrated.

Our present study focuses on lag selection and unit root testing for long-term interest rate series for 23 European countries. Of particular interest is the issue of lag selection using commonly used standard information criteria such as Akaike information criterion proposed by Akaike(1973), modified Akaike information criterion(MAIC) developed by Ng and Perron(2000), Bayesian information criterion(BIC) introduced by Schwarz(1978) and Hannan-Quinn information criterion(HQIC) developed by Hannan and Quinn(1978).Our objective is to compare and contrast the outcome of ADF and DF-GLS unit root tests under different optimal lag structure suggested by standard information criteria.

## 2. The source and the relevance of data used for this study

We use monthly data of nominal long-term interest rate series for 23 European countries: Austria, Belgium, Cyprus, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Slovakia, Spain, Sweden and United Kingdom. The sample starts in January, 2001 and ends in October, 2011 covering 130months.Both ADF and DF-GLS unit root tests are implemented for the long-term interest rate series in order to determine the order of integration of each series.

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## 3. Preliminary investigation of stationarity properties of long-term interest rates

We employed both line graphs and unit root tests to investigate stationarity properties of the long-term interest rate series.The line graphs of the levels of long-term interest rate series indicated that series are non-stationary at level as the series do not fluctuate around a constant mean.The line graphs of the first difference of long-term interest rate series show evidence of stationarity since it has no persistent trend and it fluctuates around a constant mean which suggests that each of the series might be integrated of order 1. We employed information-based lag selection criteria such as AIC,MAIC,BIC and HQIC for selection of optimal lag-length required for the implementation of unit root testing using ADF and DF-GLS unit root tests.All empirical analysis were carried out using Eviews statistical package

## 4.Testing stationarity properties of long-term interest rates

In this study, we employed two commonly used unit root tests in applied work: augmented Dickey–Fuller (ADF) and generalized least squares Dickey-Fuller (DF-GLS).The augmented Dickey-Fuller (ADF) test is implemented based on the following regressions:

ADF Model I: (1)

ADF Model II:  (2)

ADF Model III:  (3)

Where  is a difference operator,  is the drift term,  is the trend component,  is unit root parameter and there is a unit root if ,  is the optimal lag-length to be determined empirically, are lagged differences of the original series  which are included to control for serial correlation in error term so that  becomes a white noise process .Equation (1) to (3) tests the null hypothesis of a unit root against a trend stationary alternative which may be stated as:

 i.e. Series has a unit root

Against the alternative hypothesis which says,  , i.e. Series is stationary

The generalized least squares Dickey-Fuller (DF-GLS) unit root test is a modified version of an augmented Dickey–Fuller(ADF) test except that the original series is transformed via a generalized least squares (GLS) regression. Elliot et al.(1996) demean or detrended the data as follows:

 (4)

Where  and  are used for detrending and demeaning respectively. Following the proposition of Wolters (2003), the demeaned or detrended series  is then employed in the ADF regression without any deterministic regressors in the following test regression:

 (5)

While are lagged differences of the GLS-detrended series  which are included to control for serial correlation in error term so that  becomes a white noise process, other parameters are as defined as in (3) .Similarly, equation (5) tests the null hypothesis of a unit root against a trend stationary alternative. The choice of DF-GLS unit root test is informed by the fact that local-to-unity detrending enhances the empirical power properties of ADF test. In this present study, the assumption of no deterministic linear time trend for long-term interest rate series as proposed by Wolters(2003) and adapted in Bruggemann and Lutkepohl (2005) is relaxed in ADF model III by allowing for the presence of deterministic linear time trend for the level of long-term interest rate series . Since the time series data under investigation are monthly dataset ,the maximum lag-length is set at 12 and autoregressive models of order 1 to 12 were fitted to the long-term interest rate series for the 23 European countries .In order to determine optimal lag-length required for the implementation of these unit root tests, the particular lag that minimizes each of the information-based lag selection criteria is selected as optimal truncation lag for the particular series and the empirical results are presented in table 1 through table 4 below:

**Table 1: Lag selection and Unit root Testing by ADF MODEL I**

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | Countries | ADF I |  | ADF I |  | ADF I |  | ADF I |  |
| 1. | Austria | -8.4364\* | 0 | -8.4364\* | 0 | -8.4364\* | 0 | -8.4364\* | 0 |
| 2. | Belgium | -5.6599\* | 2 | -8.7122\* | 0 | -8.7122\* | 0 | -8.7122\* | 0 |
| 3. | Cyprus | -8.4582\* | 0 | -4.1557\* | 3 | -8.4582\* | 0 | -8.4582\* | 0 |
| 4. | Czech | -5.4784\* | 2 | -2.7231\* | 10 | -8.0168\* | 1 | -5.4784\* | 2 |
| 5. | Denmark | -5.5058\* | 6 | -5.1169\* | 2 | -8.4074\* | 0 | -8.4074\* | 0 |
| 6. | Finland | -8.2757\* | 0 | -8.2757\* | 0 | -8.2757\* | 0 | -8.2757\* | 0 |
| 7. | France | -7.6609\* | 1 | -8.4656\* | 0 | -8.4656\* | 0 | -8.4656\* | 0 |
| 8. | Germany | -8.1059\* | 0 | -5.3645\* | 2 | -8.1059\* | 0 | -8.1059\* | 0 |
| 9. | Greece | -0.7731 | 9 | -0.5973 | 10 | -9.3814\* | 0 | -0.7731\* | 9 |
| 10. | Hungary | -6.3756\* | 2 | -8.7644\* | 0 | -10.383\* | 1 | -6.3756\* | 2 |
| 11. | Ireland | -4.3551\* | 10 | -2.6377\* | 7 | -8.8869\* | 0 | -4.1409\* | 8 |
| 12. | Italy | -9.2907\* | 0 | -1.7346 | 11 | -9.2907\* | 0 | -9.2907\* | 0 |
| 13. | Latvia | -2.7124 | 12 | -1.7270 | 9 | -8.1533\* | 0 | -8.1533\* | 0 |
| 14. | Lithuania | -4.7094\* | 10 | -4.5117\* | 2 | -5.3642\* | 1 | -5.3642\* | 1 |
| 15. | Luxembourg | -7.3916\* | 0 | -2.0761\* | 12 | -7.3916\* | 0 | -7.3916\* | 0 |
| 16. | Malta | -7.8173\* | 0 | -7.8173\* | 0 | -7.8173\* | 0 | -7.8173\* | 0 |
| 17. | Netherlands | -8.4448\* | 0 | -8.4448\* | 0 | -8.4448\* | 0 | -8.4448\* | 0 |
| 18. | Poland | -4.8585\* | 2 | -2.7263\* | 8 | -6.9025\* | 0 | -4.8585\* | 2 |
| 19. | Portugal | -0.8074 | 7 | -0.0073 | 9 | -3.9226\* | 2 | -3.9226\* | 2 |
| 20. | Slovakia | -6.3632\* | 0 | -6.3632\* | 0 | -6.3632\* | 0 | -6.3632\* | 0 |
| 21. | Spain | -8.8577\* | 1 | -9.0309\* | 0 | -8.8577\* | 1 | -8.8577\* | 1 |
| 22. | Sweden | -8.1188\* | 0 | -5.1588\* | 2 | -8.1188\* | 0 | -8.1188\* | 0 |
| 23. | United Kingdom | -6.6718\* | 5 | -7.5378\* | 0 | -7.5378\* | 0 | -7.5378\* | 0 |

1. \*indicates significance at 5% level
2. Table 1 reports the results of the ADF model I test conducted to determine the order of integration of long-term interest rate series for 23 European countries. The optimal lag order  was selected using four information-based lag selection criteria. Using the optimal lag structure suggested by AIC lag selection criterion, the unit root hypothesis is consistently rejected for the first difference of long-term interest rate series for 21 countries at the 5% significance level with exception of long-term interest rate series for Greece and Portugal that were not rejected at conventional level of significance thereby indicating non-stationarity after first difference which suggest that these series might be  series. With MAIC lag selection criterion, the unit root hypothesis is consistently rejected for the first difference of long-term interest rate series for 19 countries at the 5% significance level with exception of long-term interest rate series for Greece, Italy, Latvia and Portugal that were not rejected at conventional level of significance thereby indicating non-stationarity after first difference which suggest that these series might be  series. With BIC lag selection criterion, the unit root hypothesis is consistently rejected for the first difference of long-term interest rate series for all countries at the 5% significance level indicating that all series are stationary after first difference which implies that all series are  series. With HQIC lag selection criterion, the unit root hypothesis is consistently rejected for the first difference of long-term interest rate series for 22 countries at the 5% significance level with exception of long-term interest rate series for Greece that was not rejected at conventional level of significance thereby indicating non-stationary after first difference which suggest that Greece series might be  series. In summary, the unit root hypothesis for the first difference of long-term interest rate series was consistently rejected for most of the European countries at the 5% significance level using ADF Model I test.However, the difference in lag structure specifications suggested by conventional lag selection criteria explains the discrepancies in the rejection rate recorded by ADF model I test.
3. Table 2: Lag selection and Unit root Testing by ADF MODEL II

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | Countries | ADF II |  | ADF II |  | ADF II |  | ADF II |  |
| 1. | Austria | -8.4685\* | 0 | -8.4685\* | 0 | -8.4685\* | 0 | -8.4685\* | 0 |
| 2. | Belgium | -5.6565\* | 2 | -8.6887\* | 0 | -8.6887\* | 0 | -8.6887\* | 0 |
| 3. | Cyprus | -8.4278\* | 0 | -4.1369\* | 3 | -8.4278\* | 0 | -8.4278\* | 0 |
| 4. | Czech | -5.5499\* | 2 | -7.8449\* | 0 | -8.0868\* | 1 | -5.5499\* | 2 |
| 5. | Denmark | -5.7348\* | 6 | -5.2236\* | 2 | -8.4678\* | 0 | -8.4678\* | 0 |
| 6. | Finland | -8.3282\* | 0 | -8.3282\* | 0 | -8.3282\* | 0 | -8.3282\* | 0 |
| 7. | France | -7.6886\* | 1 | -8.4807\* | 0 | -8.4807\* | 0 | -8.4807\* | 0 |
| 8. | Germany | -5.8966\* | 6 | -8.1650\* | 0 | -8.1650\* | 0 | -8.1650\* | 0 |
| 9. | Greece | -1.1209 | 9 | -0.9206 | 10 | -9.7078 | 0 | -1.1209\* | 9 |
| 10. | Hungary | -6.3517\* | 2 | -8.7304\* | 0 | -10.343\* | 1 | -6.3517\* | 2 |
| 11. | Ireland | -4.4018\* | 10 | -2.6648 | 7 | -8.8758\* | 0 | -4.1784\* | 8 |
| 12. | Italy | -9.2654\* | 0 | -1.6849 | 11 | -9.2654\* | 0 | -9.2654\* | 0 |
| 13. | Latvia | -2.6972 | 12 | -1.7256 | 9 | -8.1289\* | 0 | -8.1289\* | 0 |
| 14. | Lithuania | -4.6912\* | 10 | -4.4965\* | 2 | -5.3465\* | 1 | -5.3465\* | 1 |
| 15. | Luxembourg | -7.4317\* | 0 | -2.1627 | 12 | -7.4317\* | 0 | -7.4317\* | 0 |
| 16. | Malta | -6.1040\* | 4 | -7.8688\* | 0 | -7.8688\* | 0 | -7.8688\* | 0 |
| 17. | Netherlands | -8.4958\* | 0 | -8.4958\* | 0 | -8.4958\* | 0 | -8.4958\* | 0 |
| 18. | Poland | -4.9365\* | 2 | -2.7596 | 8 | -6.9454\* | 0 | -6.9454\* | 0 |
| 19. | Portugal | -1.0003 | 7 | -0.2055 | 9 | -4.0401\* | 2 | -4.0401\* | 2 |
| 20. | Slovakia | -6.4256\* | 0 | -6.4256\* | 0 | -6.4256\* | 0 | -6.4256\* | 0 |
| 21. | Spain | -8.8233\* | 1 | -8.9955\* | 0 | -8.8233\* | 1 | -8.8233\* | 1 |
| 22. | Sweden | -8.1787\* | 0 | -5.2571\* | 2 | -8.1787\* | 0 | -8.1787\* | 0 |
| 23. | United Kingdom | -6.7973\* | 5 | -7.5538\* | 0 | -7.5538\* | 0 | -7.5538\* | 0 |

\*denotes significance at 5% level

1. Table 2 reports the results of the ADF model II test conducted to determine the order of integration of long-term interest rate series rates for 23 European countries. The optimal lag order  was selected using four information-based lag selection criteria. Using AIC lag selection criterion, 20 out of 23 null hypotheses of unit root were rejected for the first difference of long-term interest rate series at 5% level with exception of long-term interest rate series for Greece, Latvia and Portugal that were not rejected at conventional level of significance thereby indicating non-stationarity after first difference which suggest that these series might be  series. With MAIC lag selection criterion, 19 out of 23 null hypotheses of unit root were rejected for the first difference of long-term interest rate series at 5% level with exception of long-term interest rate series for Greece ,Ireland, Italy, Latvia, Luxembourg, Poland and Portugal that were not rejected at conventional level of significance thereby indicating non-stationarity after first difference which suggest that long-term interest rates for the seven countries might be  series. With BIC lag selection criterion, all the 23 null hypotheses of unit root for the first difference of long-term interest rate series were rejected at 5% level indicating that all series are stationary after first difference which implies that all series are  series. With HQIC lag selection criterion, 22 out of 23 null hypotheses of unit root were rejected for the first difference of long-term interest rate series at 5% level with exception of long-term interest rate series for Greece that was not rejected at conventional level of significance thereby indicating non-stationary after first difference which suggest that Greece series might be  series. The unit root hypothesis for the first difference of long-term interest rate series was consistently rejected for most of the European countries at the 5% significance level using ADF Model II test. However, the difference in lag structure specifications suggested by conventional lag selection criteria explains the discrepancies in the rejection rate recorded by ADF model II test.

1. Table 3: Lag selection and Unit root Testing by ADF MODEL III

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | Countries | ADF III |  | ADF III |  | ADF III |  | ADF III |  |
| 1. | Austria | -8.4294\* | 0 | -8.4294\* | 0 | -8.4294\* | 0 | -8.4294\* | 0 |
| 2. | Belgium | -5.7289\* | 2 | -8.7141\* | 0 | -8.7141\* | 0 | -8.7141\* | 0 |
| 3. | Cyprus | -8.7901\* | 0 | -5.1622\* | 2 | -8.7901\* | 0 | -8.7901\* | 0 |
| 4. | Czech | -5.5379\* | 2 | -7.8247\* | 0 | -8.0718\* | 1 | -5.5379\* | 2 |
| 5. | Denmark | -5.7133\* | 6 | -5.2149\* | 2 | -8.4491\* | 0 | -8.4491\* | 0 |
| 6. | Finland | -8.2991\* | 0 | -8.2991\* | 0 | -8.2991\* | 0 | -8.2991\* | 0 |
| 7. | France | -7.6552\* | 1 | -8.4397\* | 0 | -8.4397\* | 0 | -8.4397\* | 0 |
| 8. | Germany | -5.8797\* | 6 | -8.1519\* | 0 | -8.1519\* | 0 | -8.1519\* | 0 |
| 9. | Greece | -2.1867 | 9 | -2.0829 | 10 | -10.863\* | 0 | -10.863\* | 0 |
| 10. | Hungary | -6.3510\* | 2 | -8.7072\* | 0 | -10.325\* | 1 | -6.3510\* | 2 |
| 11. | Ireland | -4.8155\* | 10 | -8.9228\* | 0 | -8.9228\* | 0 | -4.8155\* | 10 |
| 12. | Italy | -9.5209\* | 0 | -2.2165 | 11 | -9.5209\* | 0 | -9.5209\* | 0 |
| 13. | Latvia | -2.6519 | 12 | -1.6950 | 9 | -8.0980\* | 0 | -8.0980\* | 0 |
| 14. | Lithuania | -4.6631\* | 10 | -4.4774\* | 2 | -5.3242\* | 1 | -5.3242\* | 1 |
| 15. | Luxembourg | -7.4010\* | 0 | -2.1401 | 12 | -7.4010\* | 0 | -7.4010\* | 0 |
| 16. | Malta | -6.2409\* | 4 | -7.8800\* | 0 | -7.8800\* | 0 | -7.8800\* | 0 |
| 17. | Netherlands | -8.4716\* | 0 | -8.4716\* | 0 | -8.4716\* | 0 | -8.4716\* | 0 |
| 18. | Poland | -5.0942\* | 2 | -2.8287 | 8 | -7.0237\* | 0 | -7.0237\* | 0 |
| 19. | Portugal | -4.1701\* | 5 | -0.3875 | 12 | -10.774\* | 0 | -10.774\* | 0 |
| 20. | Slovakia | -6.5387\* | 0 | -6.5387\* | 0 | -6.5387\* | 0 | -6.5387\* | 0 |
| 21. | Spain | -8.9725\* | 1 | -9.0857\* | 0 | -8.9725\* | 1 | -8.9725\* | 1 |
| 22. | Sweden | -8.1899\* | 0 | -5.2745\* | 2 | -8.1899\* | 0 | -8.1899\* | 0 |
| 23. | United Kingdom | -6.8056\* | 5 | -7.5559\* | 0 | -7.5559\* | 0 | -7.5559\* | 0 |

1. \* denotes significance at 5% level
2. Table 3 reports the results of the ADF III test conducted to determine the order of integration of long-term interest rate series rates for 23 European countries. The optimal lag order  was selected using four information-based lag selection criteria. Using AIC lag selection criterion, 21 out of 23 null hypotheses of unit root were rejected for the first difference of long-term interest rate series at 5% level with exception of long-term interest rate series for Greece and Latvia that were not rejected at conventional level of significance thereby indicating non-stationarity after first difference which suggest that the long-term interest rates for the two countries might be  series. With MAIC lag selection criterion, 17 out of 23 null hypotheses of unit root were rejected for the first difference of long-term interest rate series at 5% level with exception of long-term interest rate series for Greece ,Italy, Latvia, Luxembourg, Poland and Portugal that were not rejected at conventional level of significance thereby indicating non-stationarity after first difference which suggest that the long-term interest rates for the six countries might be  series. With BIC and HQIC lag selection criteria, all the 23 null hypotheses of unit root for the first difference of long-term interest rate series were rejected at 5% level indicating that all series are stationary after first difference which implies that all series are  series. The unit root hypothesis for the first difference of long-term interest rate series was consistently rejected for all the European countries at the 5% significance level using ADF Model III test when lag-length are selected by BIC and HQIC.

Table 4: Lag selection and Unit root Testing by DF-GLS Test

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | Countries | DF-GLS |  | DF-GLS |  | DF-GLS |  | DF-GLS |  |
| 1. | Austria | -8.2950\* | 0 | -5.3743\* | 2 | -8.2949\* | 0 | -8.2950\* | 0 |
| 2. | Belgium | -5.4512\* | 2 | -2.2273 | 12 | -8.5288\* | 0 | -8.5288\* | 0 |
| 3. | Cyprus | -8.6643\* | 0 | -4.3753\* | 3 | -8.6643\* | 0 | -8.6643\* | 0 |
| 4. | Czech | -4.4118\* | 2 | -1.5162 | 10 | -4.4117\* | 2 | -4.4118\* | 2 |
| 5. | Denmark | -5.5845\* | 6 | -5.1536\* | 2 | -8.4215\* | 0 | -8.4215\* | 0 |
| 6. | Finland | -8.2881\* | 0 | -8.2881\* | 0 | -8.2881\* | 0 | -8.2881\* | 0 |
| 7. | France | -8.2160\* | 0 | -8.2160\* | 0 | -8.2159\* | 0 | -8.2160\* | 0 |
| 8. | Germany | -5.7495\* | 6 | -5.3970\* | 2 | -8.1221\* | 0 | -8.1221\* | 0 |
| 9. | Greece | -1.9753 | 9 | -1.8121 | 10 | -10.710\* | 0 | -10.710\* | 0 |
| 10. | Hungary | -5.6096\* | 2 | -8.2931\* | 0 | -5.6096\* | 2 | -5.6096\* | 2 |
| 11. | Ireland | -4.3064\* | 10 | -2.6156 | 7 | -8.8711\* | 0 | -4.1014\* | 8 |
| 12. | Italy | -9.4460\* | 0 | -2.1161 | 11 | -9.4460\* | 0 | -9.4460\* | 0 |
| 13. | Latvia | -2.7005 | 12 | -1.7615 | 9 | -8.0240\* | 0 | -8.0240\* | 0 |
| 14. | Lithuania | -4.3112\* | 10 | -4.2997\* | 2 | -5.1313\* | 1 | -5.1313\* | 1 |
| 15. | Luxembourg | -7.4077\* | 0 | -2.1083 | 12 | -7.4077\* | 0 | -7.4077\* | 0 |
| 16. | Malta | -6.0405\* | 4 | -7.8454\* | 0 | -7.8454\* | 0 | -7.8454\* | 0 |
| 17. | Netherlands | -8.4873\* | 0 | -8.4874\* | 0 | -8.4874\* | 0 | -8.4874\* | 0 |
| 18. | Poland | -5.1063\* | 2 | -4.1996\* | 6 | -7.0111\* | 0 | -7.0111\* | 0 |
| 19. | Portugal | -1.9863 | 7 | -0.9794 | 12 | -10.695\* | 0 | -4.5920\* | 2 |
| 20. | Slovakia | -6.5872\* | 0 | -6.5873\* | 0 | -6.5873\* | 0 | -6.5873\* | 0 |
| 21. | Spain | -8.7849\* | 1 | -8.9791\* | 0 | -8.7849\* | 1 | -8.7849\* | 1 |
| 22. | Sweden | -8.1989\* | 0 | -5.2675\* | 2 | -8.1989\* | 0 | -8.1989\* | 0 |
| 23. | United Kingdom | -6.8017\* | 5 | -7.5874\* | 0 | -7.5874\* | 0 | -7.5874\* | 0 |

1. \* denotes significance at 5% level
2. Table 4 reports the results of the DF-GLS test conducted to determine the order of integration of long-term interest rate series rates for 23 European countries. The optimal lag order  was selected using four information-based lag selection criteria. Using AIC lag selection criterion, 20 out of 23 null hypotheses of unit root were rejected for the first difference of long-term interest rate series at 5% level with exception of long-term interest rate series for Greece, Latvia and Portugal that were not rejected at conventional level of significance thereby indicating non-stationarity after first difference which suggest that the long-term interest rates for the three countries might be  series. With MAIC lag selection criterion, 15 out of 23 null hypotheses of unit root were rejected for the first difference of long-term interest rate series at 5% level with exception of long-term interest rate series for Belgium, Czech, Greece, Ireland, Italy, Latvia, Luxembourg and Portugal that were not rejected at conventional level of significance thereby indicating non-stationarity after first difference which suggest that the long-term interest rates for the eight countries might be  series. With BIC and HQIC lag selection criterion, all the 23 null hypotheses of unit root for the first difference of long-term interest rate series were rejected at 5% level indicating that all series are stationary after first difference which implies that all series are  series. The unit root hypothesis for the first difference of long-term interest rate series was consistently rejected for all the European countries at the 5% significance level using DF-GLS test when lag-length are selected by BIC and HQIC.
3. **6.Conclusion**

This paper has investigated stationarity properties of European countries’ long-term interest rate series based on monthly dataset for the period covering January, 2001 to October, 2011. For both ADF and DF-GLS tests, it was discovered that both BIC and HQIC out-performed AIC and MAIC in selecting the best optimal lag-length. Similarly, our empirical findings also demonstrate that inclusion of deterministic linear time trend for the level of the long-term interest rate series does not increase evidence of stationarity for the first difference of the long-term interest rate series but the choice of lag-length does .The robustness of the rejection of unit root hypothesis across different optimal lag-lengths suggested by standard lag selection criteria suggests that the performance of ADF and DF-GLS could be enhanced when appropriate optimal lag order is selected. However, the difference in lag structure specifications suggested by conventional lag selection criteria explains non-rejection of unit root hypothesis for the first difference of long-term interest rate series for some countries as shown under tables 1 to 4 above.

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**APPENDIX**

Figure 1: Line graph for the level of long-term interest rate for Group A



Figure 2: Line graph for the level of long-term interest rate for Group B



Figure 3: Line graph for the level of long-term interest rate for Group C



Figure 4: Line graph for the level of long-term interest rate for Group D



Figure 5: Line graph for the level of long-term interest rate for Group E



Figure 6: Line graph for the first difference of long-term interest rate for Group A



Figure 7: Line graph for the first difference of long-term interest rate for Group B



Figure 8: Line graph for the first difference of long-term interest rate for Group C



Figure 9: Line graph for the first difference of long-term interest rate for Group D



Figure 10: Line graph for the first difference of long-term interest rate for Group E



From fig.1 to 5, it is clearly seen that the levels of long-term interest rate series are non-stationary. Similarly, from fig.6 to fig.10, we can observe that the first difference of long-term interest rate series fluctuate around a constant mean for various countries showing evidence of stationarity after first difference.