METU Studies in Development, 30 (June), 2003, 19-34

Robustness of unit root tests when the series are I(2)

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Abstract

This paper examines the testing for unit roots when the macroeconomic series are integrated of order two, I(2), rather than of order one, I(1). Via an example we demonstrate that neither the Augmented Dickey-Fuller test, nor the autocorrelation and partial autocorrelation functions are robust in the presence of double unit roots. Empirically, the Dickey-Pantula sequential unit root method indicates that the Turkish money stock, GNP, and price data are I(2), while autocorrelation and partial autocorrelation functions provide evidence in favor of I(1). The paper thus recommends that the possibility of I(2)-ness should be seriously considered in econometric modeling.

1. Introduction

Although most time series seem to be best approximated as integrated processes of order one, there are some series, especially nominal time series like prices, wages, GNP, money balances, and the like, that appear to be more smooth and more slowly changing than what is normally observed for I(1) variables. Such series may be potentially integrated of order two. If the series are log-transformed, the growth rates will therefore be I(1). A shock to the series in one period will have an ever lasting influence (explosive effect) on both future growth rates and the

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levels of the series, and since the latter is the accumulation of the past growth rates, the processes will be extremely smooth.

One should also make an effort to elaborate on the economic meaning of finding a double unit root in macroeconomic variables. This makes intuitive sense in periods of high inflation. When an inflation spiral has gathered momentum the cost of not anticipating future inflationary changes becomes increasingly high. Agents, therefore, quickly learn that a shock (for example an expansion in monetary aggregates, income or a wage increase) is likely to cause further acceleration of the inflation rate and adjust their expectations accordingly. When expectations are self-fulfilling it is extremely difficult to stop an accelerating inflation rate without very drastic measures, such as a price freeze and a wage freeze.

When there is a unit root in the data, differencing is one way to handle the stationarity. If there is more than one unit root, an additional differencing is needed. Various econometric problems might arise while a regression is run with different orders of integrated variables. To avoid these problems, the first thing to do is to identify the correct order of integration of each variable. For that reason, testing for the number of unit roots present in the data is necessary for time series modeling. To test for a single unit root in the data, the augmented Dickey-Fuller (ADF) procedure is a commonly used method applied to the differenced series. However, the Dickey-Fuller (1981) test is based on the assumption of a single unit root. That is, applying Dickey-Fuller to the second differenced series may cause some statistical problems (See Dickey and Pantula 1987). Since the standard ADF test is based on the assumption of one unit root at most, at least the first few tests in this sequence would not be theoretically justified in case the series had more than one unit root. ADF-type tests for a single unit root have excessive density in the explosive region of the distribution and thus produce misleading results if the series are I(2) (see Haldrup and Lildholdt, 2002).

For the presence of additional unit roots, Dickey and Pantula (1987) investigate the effectiveness of the standard Dickey-Fuller test and the double unit roots test suggested by Hazsa and Fuller (1979)[1]. Dickey and Pantula conducted a Monte Carlo experiment to show the problems described above. Their simulation study shows that if the series has three unit roots, several things occur: First, the 5% level Dickey-Fuller test rejects the null of a single unit root in favor of stationarity 9% of the time. Second, the 5% level Hazsa and Fuller test rejects the null of double unit

[1] There is also some other literature focusing on univariate testing for double unit root, Hazsa and Fuller (1979), Sen and Dickey (1987), Shin and Kim (1999), Haldrup (1994, 1998) and Haldrup and Lildholdt (2002).

roots in favor of a single unit root and two stationary roots 9.2% of the time[2].

If there are more unit roots, the test for less unit roots indicates that the series needs to be differenced, and therefore the null hypothesis will be rejected less than 5% of the time. Given the above findings, however, the simulation study by Dickey and Pantula (1987) does not support the previous statement. To address this problem, Dickey and Pantula (1987) have proposed a univariate testing procedure, the so-called sequential unit root test. According to Dickey and Pantula, when the ADF test is applied to a time series with more than one unit root, it is possible to obtain stationary time series. This is frequently observed in empirical modeling where I(2)-ness is ignored as opposed to the I(1) alternative. Haldrup and Lildholdt (2002) recommend that the possibility of I(2)-ness in the data should be seriously considered.[3]

Motivated by the findings of Dickey and Pantula, this study demonstrates the analytical results and some of the implications of the ADF test. The sequential unit root method is then applied to some Turkish macroeconomic aggregates, namely nominal broad money (M2), nominal GNP, CPI and WPI that are commonly used in modeling the Turkish broad money demand, the dynamics of inflation and inflation uncertainty in Turkey. This study shows that while Turkish macroeconomic series have generally been modeled as I(1) based on the conventional tests mentioned above, they must indeed be modeled as I(2) (see Metin and Muslu, 1999; Berüment *et al,*2002).

The organization of the paper is as follows: In section 2, the Dickey and Pantula (1987) sequential unit root testing procedure is explained. In section 3, an example is used to prove that the ADF-type unit root testing and the autocorrelation and partial autocorrelation functions are not robust in determining the I(2)-ness of the series. In section 4, the sequential unit root testing procedure is applied to Turkish macroeconomic variables. The results of the test indicate that all of the variables are I(2), while their autocorrelation and partial autocorrelation functions provide evidence to the contrary. Finally, section 5 concludes with a discussion of issues that arise when I(2)-ness is disregarded and the variables are treated as I(1), which is a frequent occurrence in empirical modeling.

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2 See Maddala and Kim (1998: 343).

3 Haldrup (1998) provides excellent survey on recent advances in the theoretical literature on double unit roots.

2. Dickey-Pantula sequential unit root testing procedure

Dickey and Pantula (1987) propose a sequential procedure based on the *pseudo-t statistic*, $t^*_{i,n}(p)$, to check whether a given time series may include more than one unit root. Here *i*, *n* and (*p*) are respectively the number of unit roots, the number of observations, and the orders of the AR of the procedure. $t^*_{i,n}(p)$ is the value of *t-statistic* for the coefficient of $(1-B)^{i-1}Y_{t-1}$ in the regression of $(1-B)^p Y_t$ on $(1-B)^{i-1}Y_{t-1}$, $(1-B)^{i-1}Y_t$, ... , $(1-B)^{p-1}Y_{t-1}$ where *t* stands for time. Then, the test statistic $t^*_{i,n}(p)$ is used to test the null hypothesis of *i* unit roots against the alternative of $i-1$ unit roots. If the null hypothesis of *i* unit roots is rejected, the next step is to test the null hypothesis of $i-1$ unit roots against the $i-2$ unit roots alternative. This continues until the null hypothesis is not rejected. For illustrative purposes, let's take $p = 3$ and consider the following model :

$$Y_t = \alpha_1 Y_{t-1} + \alpha_2 Y_{t-2} + \alpha_3 Y_{t-3} + e_t \tag{1}$$

where e_t is a sequence of *iid* random variables with mean zero and variance σ^2 and without loss of generality, $\sigma^2 = 1$. Let m_1, m_2 and m_3 denote the roots of the characteristic equation

$$m^3 - \alpha_1 m^2 - \alpha_2 m - \alpha_3 = 0$$

where $1 \geq |m_1| \geq |m_2| \geq |m_3|$. Consider the following four hypotheses.

(i)	$H_0 : \lvert m_1\rvert < 1$	(Model is stationary)
(ii)	$H_1 : m_1 = 1, \lvert m_2\rvert < 1$	(Nonstationary with 1 unit root)
(iii)	$H_2 : m_1 = m_2 = 1, \lvert m_3\rvert < 1$	(Nonstationary with 2 unit roots)
(iv)	$H_3 : m_1 = m_2 = m_3 = 1$	(Nonstationary with 3 unit roots)

The model can be written as

$$X_t = \theta_1 Y_{t-1} + \theta_2 Z_{t-1} + \theta_3 W_{t-1} + e_t \, . \tag{2}$$

Let $Z_t = \nabla Y_t = Y_t - Y_{t-1}$,

$$W_t = \nabla^2 Y_t = Y_t - 2Y_{t-1} + Y_{t-2}$$

$$X_t = \nabla^3 Y_t = Y_t - 3Y_{t-1} + 3Y_{t-2} - Y_{t-3}$$

where Δ, Δ^2, Δ^3 represent the first, second and the third difference of the series of interest, respectively. The θ parameters are:

$\theta_1 = -(1-m_1)(1-m_2)(1-m_3)$,
$\theta_2 = -2\theta_1 - (1-m_1)(1-m_2) - (1-m_2)(1-m_3) - (1-m_3)(1-m_1)$,
$\theta_3 = m_1 m_2 m_3 - 1$.

In terms of θ's the above hypotheses are equivalent to

$$
\begin{aligned}
&\text{(a)} : H_0 : \theta_1 < 0,\ \theta_2 < 0,\ \theta_3 < 0 \\
&\text{(b)} : H_1 : \theta_1 = 0,\ \theta_2 < 0,\ \theta_3 < 0 \\
&\text{(c)} : H_2 : \theta_1 = \theta_2 = 0,\ \theta_3 < 0 \\
&\text{(d)} : H_3 : \theta_1 = \theta_2 = \theta_3 = 0.
\end{aligned}
$$

Then to check for the number of unit roots present in the data, the following testing procedure should be followed:

Step 1: We test

$H_3 : \theta_1 = \theta_2 = \theta_3 = 0$ against $H_2 : \theta_1 = \theta_2 = 0,\ \theta_3 < 0$

Then, H_3 will be rejected if $t^*_{3,n}(3) \le \tau_{n,\alpha}$ where $t^*_{3,n}(3)$ is the value of the *pseudo t-statistic* (t^* statistic from the regression of X_t on W_{t-1} for testing whether the coefficient of W_{t-1} is zero), and $\tau_{n,\alpha}$ is the critical value for sequential test reported in Dickey and Pantula (1987), where α is the level of significance. If H_3 is not rejected, then the procedure stops and it is concluded that the series include three unit roots. But, if H_3 is rejected, we go to step 2.

Step 2: When H_3 is rejected, we test

$H_2 : \theta_1 = \theta_2 = 0,\ \theta_3 < 0$ against $H_1 : \theta_1 = 0,\ \theta_2 < 0,\ \theta_3 < 0$.

The null hypothesis H_2 will be rejected if $t^*_{2,n}(3) \le \tau_{n,\alpha}$ where $t^*_{2,n}(3)$ is the value of the *pseudo t-statistic* (t^* statistic in the regression of X_t on Z_{t-1} and W_{t-1} for testing whether the coefficient of Z_{t-1} is zero). If H_2 is not rejected, then the procedure stops. It is concluded that the series include two unit roots. If, however, the null hypothesis is rejected we go to step 3.

Step 3: When H_2 is rejected in Step 2, we test

$H_2 : \theta_1 = \theta_2 = 0,\ \theta_3 < 0$ against $H_0 : \theta_1 < 0,\ \theta_2 < 0,\ \theta_3 < 0$

This is simply testing for a unit root and the standard Dickey Fuller test can be applied. The null hypothesis H_1 will be rejected if

$t^*_{1,n}(3) \le \tau_{n,\alpha}$, where $t^*_{1,n}(3)$ is the value of the t-statistic in the regression of X_t on Y_{t-1}, Z_{t-1} and W_{t-1} for testing whether the coefficient of Y_{t-1} is equal to zero). If H_1 is not rejected, then the procedure stops and it is concluded that the series include one unit root. Otherwise, the conclusion is that the process is stationary.

3. An example

In this sub section we provide an example[4] to show that the ADF-type unit root testing and the autocorrelation and partial autocorrelation functions are not robust for the determination of the I(2)-ness of the series. We consider a third order autoregressive, AR(3), time series model given by,

$$Y_t = 2.8Y_{t-1} - 2.6Y_{t-2} + 0.8Y_{t-3} + e_t \text{ [5]} \tag{3}$$

where $e_t \sim WN(0,\sigma^2)$. The characteristic equation for this model is

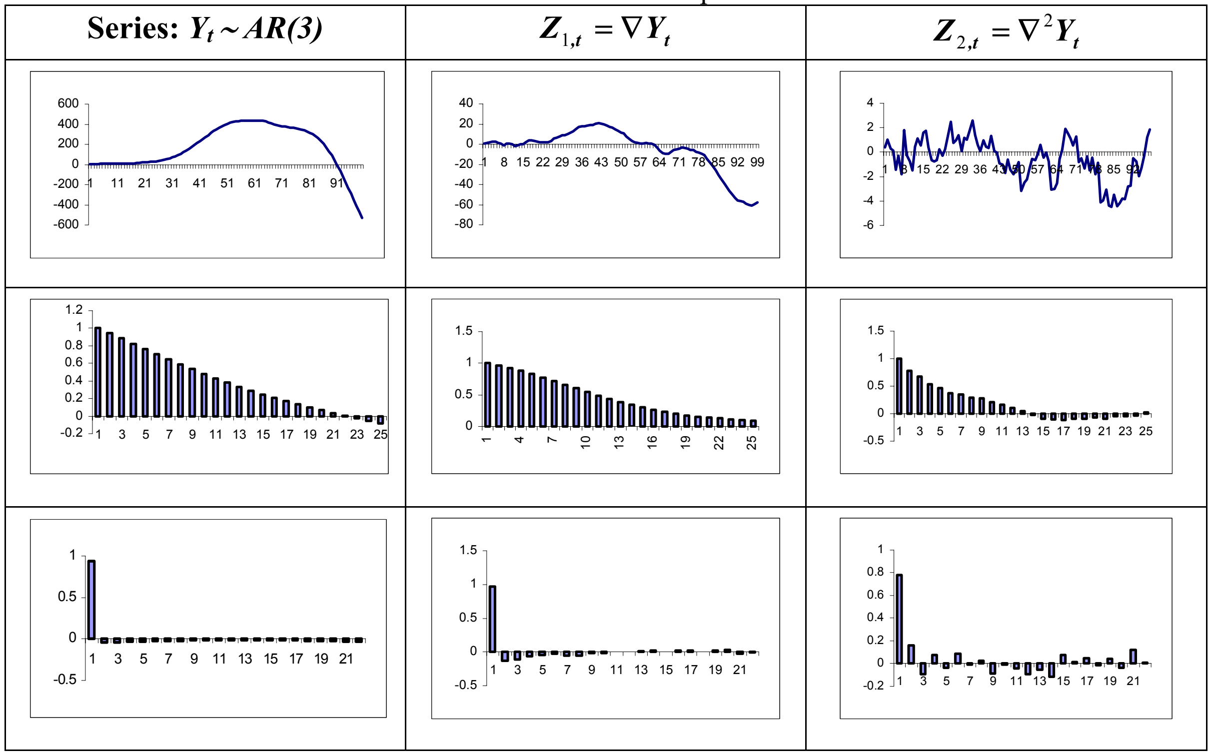
$$m^3 - 2.8m^2 + 2.6m - 0.8 = 0$$

The roots of the characteristic equations are: $m_1 = m_2 = 1$ and $m_3 = 0.8$. That is, the theoretical model is nonstationary. In line with the model, 100 observations are generated, assuming that errors are normally distributed random variables. The data and its identification plots are given in Figure 1. Without checking for the number of unit roots, the identification plots may imply incorrect orders for the models. For example, when we look at the identification of the plots, the autocorrelations decay slowly and the partial autocorrelations cut off after lag 1, which implies that the model is a first order autoregressive time series. However, the series is generated from a third order autoregressive model. This shows that the determination of the number of unit roots is important for detecting the order of autoregressive models. According to the identification plots, the series looks like a second order integrated process because the second differenced series looks stationary.

[4] A simulation (Power Study) was done by Dickey and Pantula (1987: 459-60). (Also see Power Study of 10,000 replications to compare the various proposed tests in terms of their respective powers).

[5] Parameters 2.8, -2.6 and 0.8 are selected as to make the roots of the characteristic equation (3) are two unit roots and 0.8.

Figure 1
Monte Carlo Example



When a third order autoregressive model is fit to this series the following equation is obtained:

$$\begin{aligned}\hat{Y}_t &= 2.74Y_{t-1} - 2.47Y_{t-1} + 0.73Y_{t-2} \\ &\quad (0.077) \quad (0.157) \quad (0.081)\end{aligned} \tag{4}$$

where the standard errors of the parameters are given in parantheses. Since the summation of all estimated parameters is equal to one, the process is obviously nonstationary.

Dickey and Pantula (1987) suggests that when the ADF test is applied to a time series with more than one unit root, it is possible to obtain a stationary time series. In fact, when ADF is applied to the generated data by regressing ΔY_t on Y_{t-1}, ΔY_{t-1} and ΔY_{t-2}, the following results are obtained: [6]

$$\begin{aligned}\Delta Y_t &= -0.001054Y_{t-1} + 1.739852\Delta Y_{t-1} - 0.734878\Delta Y_{t-2} \\ &\quad (-2.246) \qquad (22.707) \qquad (-9.119)\end{aligned} \tag{5}$$

Here, the value of the ADF test statistic, given in parantheses, is –2.246, which is smaller than the critical value of the ADF test, $\tau_{\alpha,n}$, where $n = 100$, $\alpha = 0.05$, so that the null hypothesis of a unit root is not rejected.[7] That is, contrary to the above findings, the process is stationary.

Next, we show that the series is nonstationary with two unit roots by applying the Dickey-Pantula sequential unit root procedure to the same data set. Using Equation (2), the following results are obtained for the sequential unit root procedure:

Hypotheses	**$T^*_{i,n}(3)$**	**$T_{0.05,100}$**	**Conclusion**
H_3 vs. H_2	-3.049	-1.95	Reject H_3: 3 unit roots
H_2 vs. H_1	-0.38	-1.95	Fail to reject H_2: 2 unit roots (procedure stops)
H_1 vs. H_0	–	–	–

That is, the series clearly have two unit roots, as expected.

6 The optimum lag structure and lag order is determined by using the Akaike Information Criterion and Schwarz Bayesian Criterion.

7 We replicated the same ADF test with constant (t = -2.18) and also with constant and trend (t = -1.01). Both ADF test statistics given in the respective parentheses are smaller than the critical value of the ADF test, $\tau\alpha$, n, while n =100, α = 0.05, so that the null hypothesis of a unit root is not rejected.

4. An Empirical Example

In this section, the order of integration for some for Turkish annual economic variables (M2–Turkish nominal Money Supply, CPI–Consumer Price Index, WPI–Wholesale Price Index and nominal GNP–National Income) for the period of 1970-2001 is investigated. Using alternative AR and autoregressive moving average (ARMA) specifications for each variable of interest, two model selection criteria, namely the Akaike Information Criteria (AIC) and the Schwarz Bayesian Criteria (SBC) are calculated. The model specifications and the values of AIC and SBC are reported in Table 1 for each of the variables of interest.[8] Using the minimum of both AIC and SBC, the data is modeled as an AR(3) and specification is given below:

$$(Y_t - \mu) = \alpha_1 (Y_{t-1} - \mu) + \alpha_2 (Y_{t-2} - \mu) + \alpha_3 (Y_{t-3} - \mu) + e_t . \qquad (6)$$

where $e_t \sim WN(0, \sigma^2)$. Y_t represents M2, WPI, CPI and GNP, respectively. The OLS estimates of the parameters are reported as below:

	$\hat{\alpha}_1$	$\hat{\alpha}_2$	$\hat{\alpha}_3$
M2	1.46	0.07	-0.54
WPI	1.41	-0.10	-0.31
CPI	1.64	-0.30	-0.34
GNP	1.32	-0.07	-0.25

Since summation of all estimated α parameters is equal to one, the series includes at least one unit root[9]. Therefore, differencing is required to achieve stationarity.

Table 1

Model Selection Criteria of the Several AR and ARMA Specifications for the Variables of Interest

		AR(1)	AR(2)	AR(3)	ARMA(3,1)	ARMA(3,2)	ARMA(3,3)
M2	*AIC*	71.03	53.56	***-26.48***	84.40	84.49	81.00
	SBC	73.95	57.96	***-20.48***	91.73	93.28	91.27
WPI	*AIC*	64.66	48.63	***19.49***	72.56	79.28	78.54
	SBC	67.59	53.02	***25.35***	79.88	88.08	88.00
CPI	*AIC*	65.45	46.54	***2.79***	73.81	78.26	72.74
	SBC	68.38	50.94	***8.65***	81.13	87.05	83.00
GNP	*AIC*	69.60	47.39	***-41.85***	76.84	85.22	78.22
	SBC	72.53	51.79	***-35.99***	84.17	94.01	88.49

8 ARMA(1,1), ARMA(1,2), ARMA(1,3), ARMA(2,1), ARMA(2,2) ARMA(2,3) are also tried however, not reported in Table 1 to save the space.

9 After some ignorable rounding, $\alpha1+ \alpha2+ \alpha3 =1$.

The sequential procedure explained in section 2 is applied to determine the order of differencing necessary to achieve a stationary series. The results of the Dickey and Pantula sequential procedure for double unit roots are given in Table 2. Consider the M2 variable; when testing for three unit roots against two unit roots, the value of the test statistic obtained from the regression of X_t on W_{t-1} is –9.23. Since $t^*_{3,32} = -9.23$ is smaller than the critical value (-1.95) reported in Dickey and Pantula (1987) at $\alpha = 0.05$, the null hypothesis of three unit roots (H_3) is rejected against the alternative of two unit roots. Similarly, testing for two unit roots against a single unit root, the value of the test statistic obtained from the regression of X_t on Z_{t-1} and W_{t-1} is –0.34. Since the value of the pseudo $t^*_{2,32}$ statistic is greater than the 5% critical value (–1.95), we fail to reject the null hypothesis of two unit roots and the procedure stops. That is, the M2 series has two unit roots. Similar results are obtained for the two price series and the GNP data; that is, they all have two unit roots.

Table 2
Testing for Double Unit roots by Using the Dickey and Pantula Sequential Procedure

		$\hat{\theta}_3$	$\hat{\theta}_2$	$\hat{\theta}_1$	$t^*_{i,32}(3)$	$\tau_{32,0.05}{}^*$	*Conclusion*
	H_3 vs. H_2	-1.51			-9.23	-1.95	Reject H_3
M2	H_2 vs. H_1		-0.02		***-0.34******	-1.95	Fail to reject
	H_1 vs. H_0			-0.016	1.36	-1.95	
	H_3 vs. H_2	-1.24			-6.77	-1.95	Reject H_3
WPI	H_2 vs. H_1		-0.03		***-0.39******	-1.95	Fail to reject
	H_1 vs. H_0			0.015	1.26	-1.95	
	H_3 vs. H_2	-1.25			-6.8	-1.95	Reject H_3
CPI	H_2 vs. H_1		-0.039		***-0.55******	-1.95	Fail to reject
	H_1 vs. H_0			0.01	0.82	-1.95	
	H_3 vs. H_2	-0.86			-4.50	-1.95	Reject H_3
GNP	H_2 vs. H_1		-0.02		***-0.51******	-1.95	Fail to reject
	H_1 vs. H_0			-0.012	1.81	-1.95	

* $\tau_{n,\alpha}$ is changing with different values of n and α. Here, with good coincidence, -1.95 also corresponds to the Dickey-Fuller $\alpha = 0.05$ value.

The order of integration for M2, WPI, CPI and GNP is also investigated by using their identification plots. The time series and identification plots of the variables of interest are given in Figures 2 to 5. According to the identification plots, the series look like second order integrated processes because the second differenced series appear stationary. The plots of M2 in Figure 2 indicate that the autocorrelations decay slowly and the partial autocorrelations are cut off after lag 1, which implies that the model is a first order autoregressive time series.

Figure 2: M2

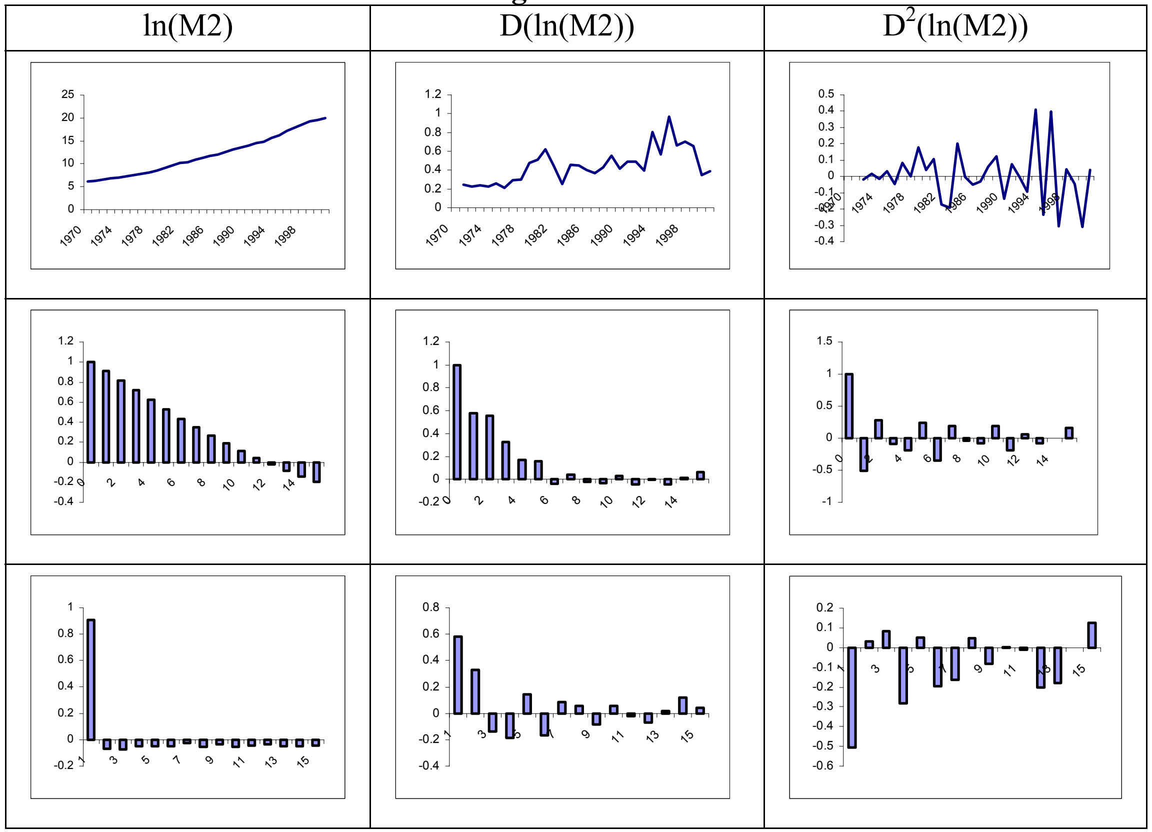


Figure 3: WPI

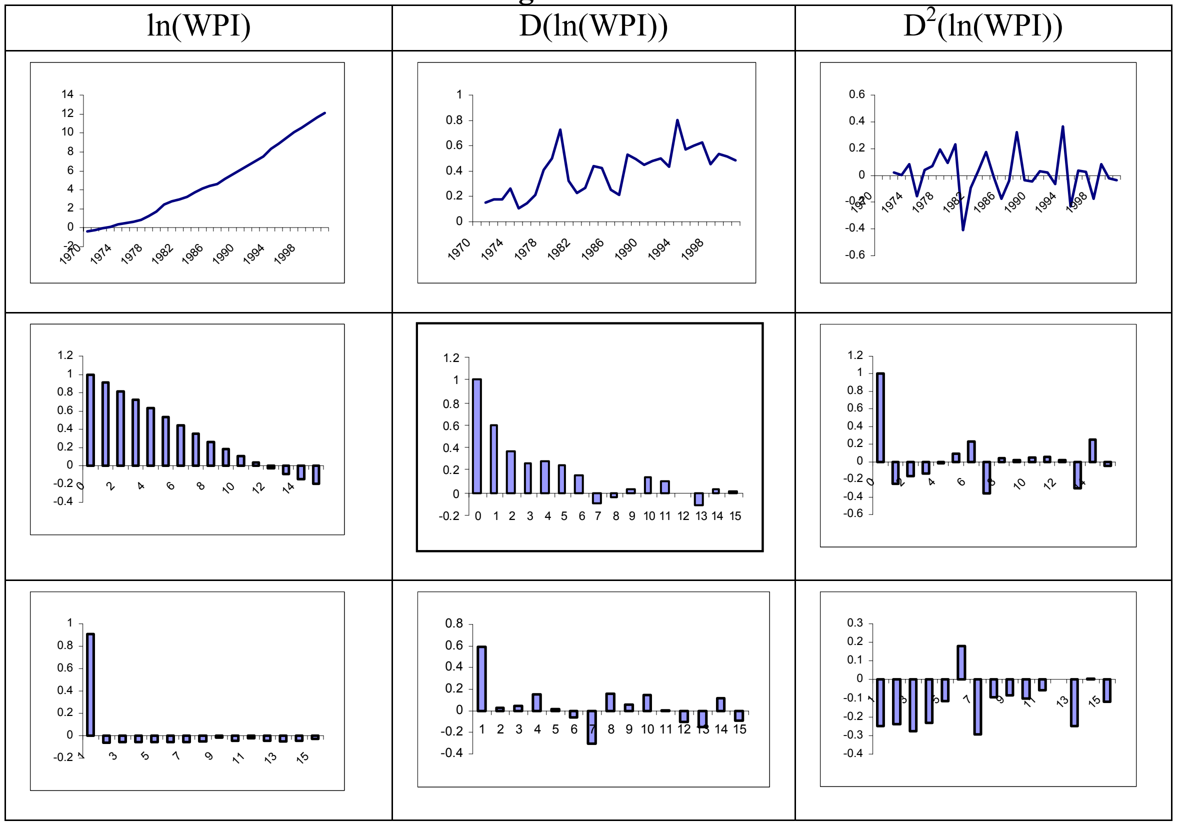


Figure 4: CPI

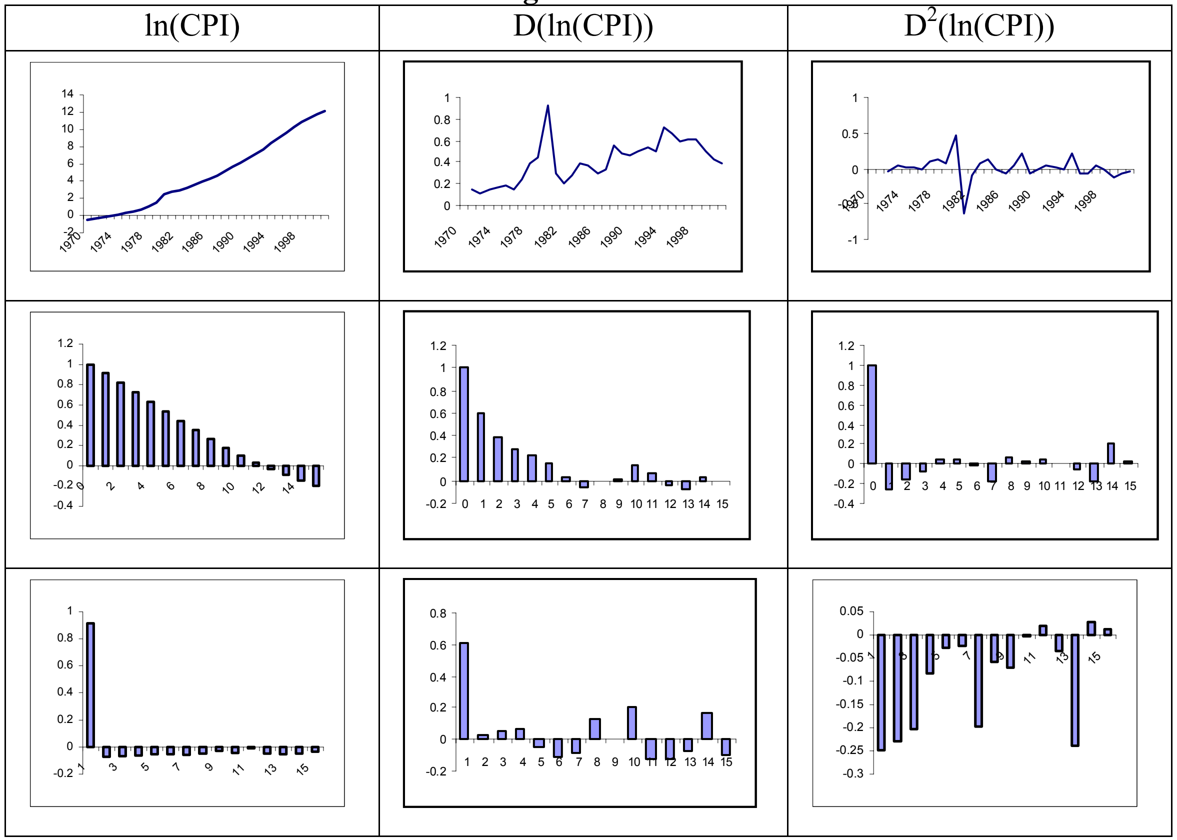
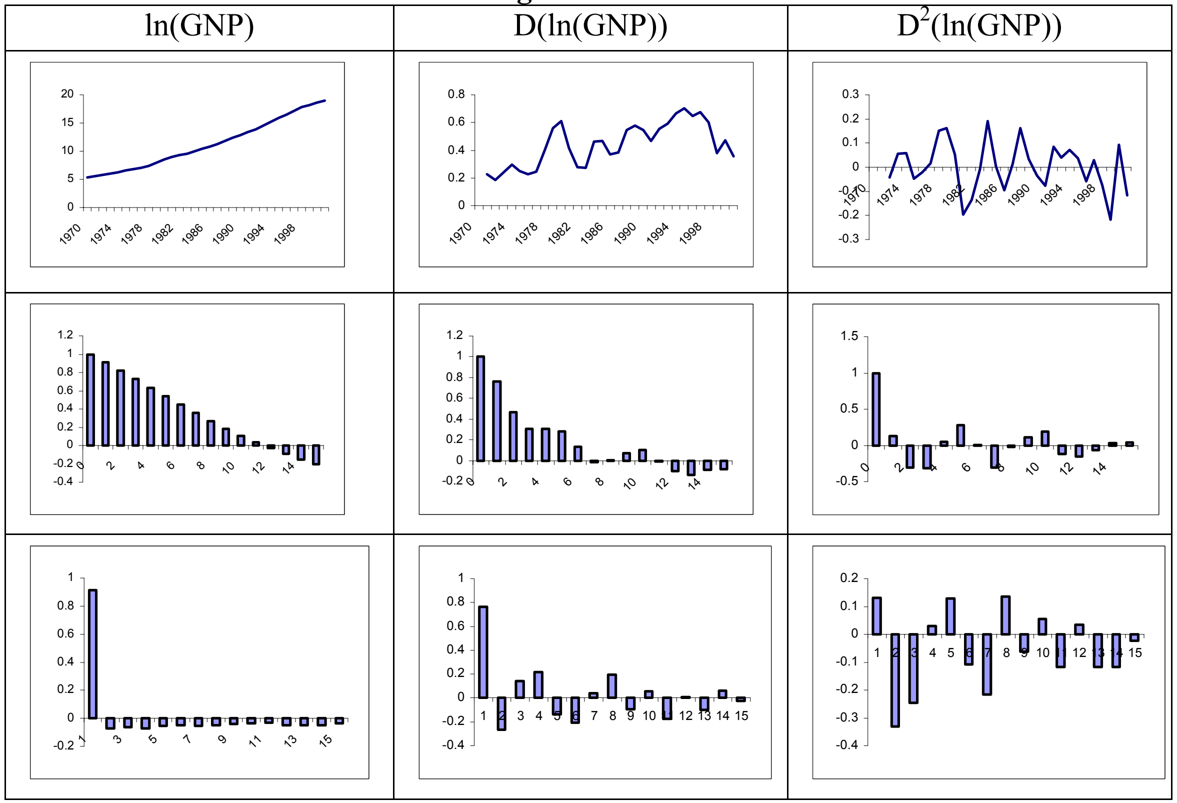


Figure 5: GNP



Hence, the determination of the correct number of unit roots gains importance for detecting the order of autoregressive models as well. A similar discussion is also valid for WPI, CPI and the GNP series in Figures 3-5 respectively.

5. Conclusion

This paper attempted to prove that the ADF-type unit root testing and the autocorrelation and partial autocorrelation functions are not robust in the determination of I(2)-ness of the series. Using annual data for the period of 1970-2001 for Turkey, empirical evidence for the Dickey and Pantula (1987) sequential unit root testing is presented when the underlying series are integrated of order two. Sequential unit root testing procedure is applied to Turkish macroeconomic aggregates; namely, broad money (M2), GNP, CPI and WPI. The data are found to be second order integrated time series, whereas their autocorrelation and partial autocorrelation functions provide contrary evidences. This study shows, for example, that while Turkish macroeconomic series have generally been modeled as I(1) based on the conventional tests mentioned above, they must indeed be modeled as I(2) since the past shocks to the variables have not only a lasting but ever-increasing effects. Based on these results, we suggest that particular attention should be given to examining the possibility of the existence of double unit roots in macroeconomic series. The preferred testing strategy is due to Dickey and Pantula (1987), in the form of testing I(2) against I(1) prior to testing I(1) against I(0).

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Özet

I(2) olan Serilerde Birim Kök Testlerinin Performansı

Bu çalışma, ikinci derece farkları alındığında durağan olan, I(2), makroekonomik zaman serilerine uygulanacak birim kök testlerinden hangisinin en uygun olduğunu araştırmaktadır. Çalışmada önce, sayısal simulasyon yolu ile, ne geliştirilmiş Dickey Fuller testinin ne de otokorelasyon ve kısmî otokorelasyon fonksiyonlarinin I(2) serileri için uygun birim kök testi olmadığı gösterilmiştir. Makalenin uygulama kısmında, ilk olarak Türk tüketici fiyat endeksinin geliştirilmiş Dickey Fuller testi, otokorelasyon ve kısmî otokorelasyon fonksiyonlari ile I(1) bulunmuş daha sonra aynı serinin I(2) olduğu Dickey ve Pantula tarafından geliştirilmiş ardışık birim kök yöntemi kullanılarak gösterilmiştir. Bu bulguya dayanılarak makalenin sonuç kısmında, serilerin I(2) olma özelliğinin makroekonometrik modellemelerde ciddi şekilde ele alınması gereği tartışılmıştır.