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Unit Root Tests: Common Pitfalls and Best Practices

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Abstract

Since the seminal paper by Granger and Newbold (1974) on spurious regressions, applied econometricians have become aware of the consequences of unit roots in empirical analysis with time series data. Yet one can still find many published papers with unit root tests implemented in an inappropriate way. The objective of this Technical Note is to highlight the common pitfalls and best practices when testing for unit roots. In addition to the theoretical discussion, we provide examples using price data from Kenya, Mali, Togo, and South Africa to illustrate the procedures we think are worth following.

Résumé

Depuis l'article fondateur de Granger et Newbold (1974) sur les régressions fallacieuses, les économètres appliqués sont conscients des conséquences de la présence de racines unitaires dans l'analyse empirique avec des données chronologiques. Pourtant, on peut encore trouver de nombreux articles publiés avec des tests de racine unitaire mis en œuvre de manière inappropriée. L'objectif de cette note technique est de mettre en évidence les pièges courants et les meilleures pratiques lorsqu’on effectue des tests de racines unitaires. En plus de la discussion théorique, nous fournissons des exemples utilisant des données de prix du Kenya, du Mali, du Togo, et de l'Afrique du Sud pour illustrer les procédures que nous jugeons utiles de suivre.

1. Introduction

Since the seminal work of Granger & Newbold (1974), econometricians can no longer ignore the time series properties of the variables with which they are concerned. After the 1980s, time series analysis underwent many developments. These were aimed, on the one hand, at questioning the fundamentals of the study of time series, and, on the other hand, at proposing more general and more efficient alternatives (Granger & Newbold (1974), Cuddy & Della Valle (1978), Nelson and Plosser (1982)). To this end, the problem of unit root was widespread. Indeed, Standard asymptotic distribution theory often does not apply to regressions involving such variables presenting this fact, and inference can go astray if the presence of unit roots is ignored (Campbell & Perron, 1991).

However, the early literature of unit roots focuses on the problem of spurious regression pointed out by Granger & Newbold (1974). This refers to a situation in which more unrelated and not all stationary series can show a significant relationship through the application of linear regression. Most practical works in time series analysis propose tools for estimating these relationships and testing hypotheses (cointegration tests, causality tests).

Nelson and Plosser (1982) were the first to point out Difference stationary (DS) and Trend stationary (TS) processes and to investigate whether macroeconomic time series are better characterized as stationary fluctuations around a deterministic trend or as non-stationary processes that have no tendency to return to a deterministic path. They used 14 long annual historical macroeconomic time series for the United States. With the sole exception of the unemployment rate, all US macroeconomic series are derived from DS processes, not TS.

The understanding of the common pitfalls and best practices when performing unit root tests is important for the unwary applied researchers. Firstly, this technical note aims to develop an understanding about unit roots. Secondly, we present the common pitfalls in developing unit root tests, and lastly, we suggest the best practices to consider along with some practical examples using price data from Kenya, Mali, Togo and South Africa that illustrate the best practices when performing univariate unit root/stationary tests. It is important to note that this document does not cover panel unit root/stationary tests. These tests will be the object of a forthcoming note.

2. What should we understand about unit roots?

In principle, when time series are stationary, the Box and Jenkins methodology is directly applied, and the best model among the set of stationary processes is chosen. However, when time series are not stationary, it is necessary to determine the nature of the non-stationarity (TS or DS). As noted by Granger and Newbold (1974), the econometrician should bear in mind the time series properties of the variables with which they are concerned.

2.1 Definition and process types

2.1.1 Definition

The stationarity of a time series refers to a principle of temporal invariance of its own order moments. This temporal invariance of the order moments, referred to as strong stationarity, is restricted to a notion of weak stationarity at moments of order equal to or down to two, also called second-order stationarity, which is the most used in applied econometrics. Theoretically, it is defined as follows: A process (x_t, t ∈ ℤ) is said to be stationary in the weak sense if it satisfies the following three conditions:

$$\forall\, t \in \mathbb{Z} : E({x_t}^2) < \infty \qquad (1)$$

$$\forall\, t \in \mathbb{Z} : E(x_t) = \mu \qquad (2)$$

$$\forall\, (t,h) \in \mathbb{Z} * \mathbb{Z}: Cov(x_t, x_{t+h}) = E[(x_{t+h} - \mu) * (x_t - \mu)] = \gamma(h) \qquad (3)$$

2.1.2 Process types

There are two types of processes according to Nelson and Plosser (1982). These are mainly the TS process associated with a deterministic non-stationarity and the DS process corresponding to stochastic non-stationarity.

- TS (Trend Stationary) process

A TS process is a process that can be written as a sum of a deterministic function of time and a stationary stochastic process. Technically (x_t, t ∈ ℤ) is a TS process if it can be written in the following form:

$$x_t = f(t) + \varepsilon_t \qquad (4)$$

f(t) is a deterministic function of time, ε_t is a stationary stochastic process.

The fundamental property of these processes is the non-persistence of shocks, also called the absence of hysteresis. This means that the long-term trajectory of the process is not affected by the short-term fluctuations.

- DS (differency stationary) process

In contrast to TS processes, DS processes have a non-deterministic component, also known as the stochastic component. Technically, (x_t, t∈ ℤ), a non-stationary process, is a DS process of order d if $(1 - L)^d x_t$ is stationary. The fundamental property of these processes is the persistence of shocks (hysteresis effect). That is, shocks have a permanent effect on the process under consideration.

2.2 Common pitfalls and their consequences

Many pitfalls are present when performing unit root tests in applied econometrics (Campbell & Perron, 1991). The applied econometrician should be aware of these pitfalls and be cautious in his testing procedure.

Three main pitfalls are found in the literature: these are the wrong trend specification, the nonlinearity, and the heterogeneity in the processes. However, before presenting these pitfalls, we first highlight the statistical consequences of the presence of unit roots.

2.2.1 Statistical consequences of the presence of a unit root

Despite the work of Ganger and Newbold (1974) and warnings in textbooks on econometric methodology, applied works still contain partial estimations. Time series regressions with a high degree of fit[1] but with a very low Durbin Watson statistic and highly autocorrelated errors, is very common to see reported in applied econometric work. These errors can yield three main consequences:

- Inefficient estimates
- Sub-optimal forecasts
- Invalid significance tests

Furthermore, Ganger and Newbold (1974) illustrated the so-called spurious regression, finding significant relations between two independent random walk variables using usual significance tests. One of the main signs of these spurious regressions was a high R-squared and a low Durbin-Watson statistic.

2.2.2 Wrong trend specification

There are two main common misspecifications in the analysis of trending time series. First, if the series is DS (difference-stationary), extracting a linear time trend introduces spurious cyclicality**.** As noted by Chan, Hayya, and Ord (1977), removing a linear trend from a random walk artificially creates strong positive autocorrelation of the residuals in the early lags**.** Nelson and Kang (1981) continue by showing that the inappropriate detrending of time series produces apparent evidence of periodicity which is not in any meaningful sense a propriety of the underlying system. **Second, if the time series is TS (trend-stationary), taking the first difference will** eliminate the deterministic trend component, but creates an artificial perturbation (autocorrelation). These results prove the consequences of making mistake in time series differentiation when necessary.

It is worth noting that the consequences of differencing when not needed to achieve stationarity are less costly in the present context than in those ailing to difference when it is appropriate (Plosser and Schwert, 1977, 1978). There is no econometric problem when **first difference is performed in stationary time series.** However, extracting a linear trend in a stationary time series creates autocorrelation.

In economic terms, considering a TS process in the place of a DS process leads to the observation of a transitory effect of shocks instead of a permanent effect. Until the end of the 1980s, proprieties of macroeconomic time series have not been considered much. However, macroeconomists used to

[1] Coefficient of multiple correlation R^2 or adjusted R^2 coefficient

decompose macroeconomic time series by eliminating a deterministic trend. This decomposition is questioned by the break in the pace of growth of Western economies after the crisis of the 1970s. This leads to a break in the trend and calls into question the validity of the trend/ cycle decomposition method.

Unit root/stationary testing procedure depend mostly on their respective null hypotheses. And the nonstandard and nonnormal asymptotic distributions fall under the respective null hypotheses. Indeed, the limiting distributions of the test statistics are affected by the inclusion or not of the ***deterministic terms*** (intercept, trend, or both) in the regressions. This distinction is crucial because the misspecification of the deterministic terms (intercept, trend, or both) may lead the researcher to wrongly reject the unit root hypothesis. Special care is needed to specify the different processes generating the data and the different regression models.

2.2.3 Nonlinearity: Perron (1989) and extensions

It is also well noted that macroeconomic time series may experience structural breaks due to shocks arising from crises, institutional changes, or radical policy changes. Perron (1989) noted that if the true data generating process is subject to structural changes, common tests (Dickey and Fuller, Philips and Perron) are not powerful and fail to reject the null hypothesis of unit roots. Perron suggested that it may be necessary to isolate some unique economic events and consider them as structural break(s) in the data generating processes. This led Perron (1989) to question Nelson and Plosser (1982)'s conclusions by determining exogenous breaks points. However, the identification of structural break points exogenously was amended by Zivot and Andrews (1992) and Banerjee et al. (1992) as an extension and improvement of Perron (1989)'s conclusions.

3. Best practices

The applied econometrician can no longer ignore the common pitfalls previously noted in unit root tests. It is worth noting that there is no one-size-fits-all practice to detect and test the presence of unit roots. The analyst needs to select a combination of elements (e.g. graphic representation, back to theory and empirical results, nature of data and variables under consideration) to diagnose and test the presence of a unit root.

3.1 First diagnostic: graphic representation (Auto-correlogram)

Correlograms are usual informal tools to diagnose the presence of a unit root. Indeed, the correlogram can be useful in checking the randomness of the data-generating process, and very useful for visual inspection (periodicity, seasonality, trend, outliers…). If the correlogram of the data-generating process degrades slowly, this might suggest the presence of a unit root or a trend, while with a stationary process the decay is faster. For non-stationary processes, the correlogram does not die out and high autocorrelation remains for large values of lags.

3.2 The testing procedure of Dolado et al (1990) and Enders (1995)

There are several unit root testing strategies in the literature (Dickey and Fuller (1976, 1981), Dickey, Bell et Miller (1986), Perron (1988), Dolado, Jenkinson, and Sosvilla-Rivero (1990), Enders (1995), and Ayat and Burridge (2000). We present the procedure proposed by Enders (1995) based on previous works by Dolado et al. (1990).

The main idea here is that we are including the appropriate deterministic regressors (constant and trend). Yet the distribution of the test statistics depends on the presence of deterministic regressors and the distribution of the test statistics of the presence of deterministic regressors depend on the presence of unit roots. This creates a complex circular reasoning which is not easy to handle. Fortunately, a powerful result was provided by Park and Phillips (1988) who show that the non-standard distribution (Wiener process) dominates only when the DGP has no drift or trend. Therefore, if the true DGP contains a drift or a trend, the t-statistics for ρ converges to a normal distribution and the test can be done using standard normal tables.

The applied econometrician should start with the general structure including a constant and a trend and test down as highlighted in Figure 1.

This process is defined as follows:

$$\Delta \boldsymbol{y_t} = \boldsymbol{\beta_0} + \boldsymbol{\beta_1 t} + \boldsymbol{\rho y_{t-1}} + \sum_{i=1}^{p} \boldsymbol{\alpha_i}\, \Delta \boldsymbol{y_{t-i}} + \boldsymbol{u_t}; \boldsymbol{u_t} \sim \boldsymbol{i.i.d}(\boldsymbol{0}, \boldsymbol{\sigma_u}^{\boldsymbol{2}}) \qquad \textit{(Model 1) (5)}$$

The testing strategy can be described in four main sequential steps (See Figure 1).

Step 1. If the null hypothesis $\rho = 0$ is rejected by performing a Dickey and Fuller test, y_t is a stationary process and it is possible to test the linear trend by performing standard tests.

Step 2. If the null hypothesis $\rho = 0$ is not rejected, one should test the significance of the linear trend by considering the (same) following model.

$$\Delta \boldsymbol{y_t} = \boldsymbol{\beta_0} + \boldsymbol{\beta_1 t} + \boldsymbol{\rho y_{t-1}} + \sum_{i=1}^{p} \boldsymbol{\alpha_i}\, \Delta \boldsymbol{y_{t-i}} + \boldsymbol{u_t}; \boldsymbol{u_t} \sim \boldsymbol{i.i.d}(\boldsymbol{0}, \boldsymbol{\sigma_u}^{\boldsymbol{2}}) \qquad \textit{(Model 2) (6)}$$

With this model the next step of the procedure consists of testing $H_0: \beta_1 = 0 \; vs \; H_a: \beta_1 \neq 0$.

Step 3. If $\beta_1 = 0$ is rejected, one can test $\rho = 0$ in the model with trend and intercept by using standard tests (student test or normal tests) because the deterministic trend dominates the stochastic one.

Step 4. If $\beta_1 = 0$ cannot be rejected, they propose to test again the null hypotheses $\rho = 0$ by using the model with no deterministic trend as follows:

$$\Delta \boldsymbol{y_t} = \boldsymbol{\beta_0} + \boldsymbol{\rho y_{t-1}} + \sum_{i=1}^{p} \boldsymbol{\alpha_i}\, \Delta \boldsymbol{y_{t-i}} + \boldsymbol{u_t}; \boldsymbol{u_t} \sim \boldsymbol{i.i.d}(\boldsymbol{0}, \boldsymbol{\sigma_u}^{\boldsymbol{2}}) \qquad \textit{(Model 3) (7)}$$

Step 5. If the null hypothesis $\rho = 0$ is rejected by performing a Dickey and Fuller test, y_t is a stationary process with a drift.

Step 6. If the null hypothesis $\rho = 0$ is not rejected, one should test the significance of the constant.

Step 7. If $\beta_0 = 0$ is rejected, one can test $\rho = 0$ in the model with the intercept by using standard tests (student test or normal tests) because the deterministic trend dominates the stochastic one.

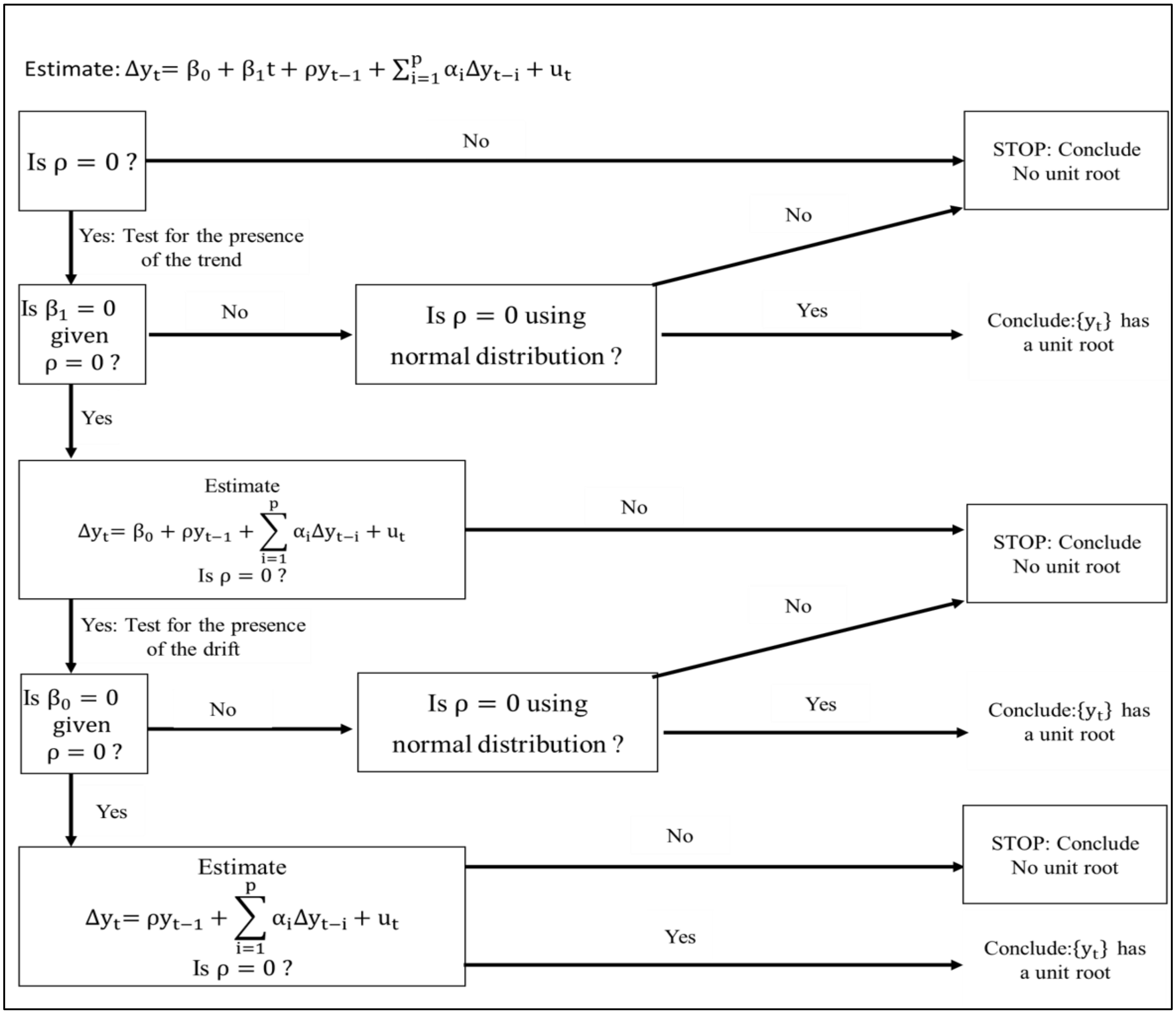
Step 8. If $\beta_0 = 0$ is not rejected, it is possible to test again the unit root test by performing standard Dickey-fuller type tests by using the model with no intercept as follows:

$$\Delta \boldsymbol{y_t} = \boldsymbol{\rho y_{t-1}} + \sum_{\boldsymbol{i=1}}^{\boldsymbol{p}} \boldsymbol{\alpha_i} \Delta \boldsymbol{y_{t-i}} + \boldsymbol{u_t}; \boldsymbol{u_t} \sim \boldsymbol{i.i.d}(\boldsymbol{0}, \boldsymbol{\sigma_u}^{\boldsymbol{2}}) \qquad \textit{(Model 3) (8)}$$

Step 9. If $\rho = 0$ is not rejected, y_t follows a random walk process without a drift.

To sum up, the main advantage of the Dolado et al (1990) and Enders (1995) approaches is that they provide a general and coherent framework for the testing procedure. Such a framework was lacking in the literature. However, at the end of the testing procedure, one may still obtain conflicting results, particularly when the form of the data-generating process is completely unknown. In that case it is important to get back to theory and to some empirical results.

Figure 1: Dolado et al (1990) and Enders (1995)



Source: Enders (1995)

3.3 Back to theory and to empirical results

There is a strong link between time series properties and economic theories studying these phenomena and establishing the relation between the two is important. Theorical considerations and empirical results might suggest the appropriate specification of the data generating process. Here we point out some economic theories related to business cycles, hysteresis and purchasing power parity.

3.3.1 Business cycles

In their research, Nelson and Plosser (1982) warned against the common belief that the economy fluctuates around a deterministic trend (business cycle). This is the main characteristic of the TS processes. Referring to monetary theories of business cycles, monetary shocks are the main source of fluctuations but have a temporary effect. In accordance with this theory, they are the combination of a deterministic trend (secular component) and a stationary short-run fluctuation around the trend (cyclical component). However, when the process is a DS type, the effects of shocks are persistent. These processes are in accordance with the RBC (Real Business Cycles) models (Kydland and Prescott, 1982). The RBC models rely on the fact that long run relationships are mainly guided by real factors and innovations (technological changes) are one of the main sources of economic fluctuations. They are characterized by persistent movements, with a non-stationary growth component plus a stationary cyclical component.

3.3.2 Hysteresis

Hysteresis is a tendency of an event to sustain even if the factors that led to that event have been removed or have otherwise ran their course. Time series results have played a key role in the controversy over the natural rate and hysteresis hypothesis (Darned and Diebolt, 2005). They noted that the high and persistent levels of unemployment experienced by European countries since the mid-1970s have led to a major reconsideration of the natural rate paradigm of Phelps (1961, 1968) and Friedman (1968). The hysteresis theory in employment considers that the policy interventions or shocks which change the unemployment rate tend to persist in the long run. This fact has challenged the fluctuations in unemployment rate around the natural rate, i.e., the non-accelerating inflation rate of unemployment (NAIRU). Considering this latter assumption leads to temporal effects of shocks on unemployment. Also, allowing structural breaks in the natural unemployment rate may support the permanent change due to occasional shocks. Therefore, the natural unemployment rate is stationary around a process with structural breaks. Camarero et al. (2006), were able to reject the hysteresis effect in unemployment by using conventional univariate and panel stationary/unit root tests allowing structural breaks. Similar studies found evidence against unemployment hysteresis when structural breaks are allowed. Therefore, special care is needed to be considered when unit-root/stationarity tests are performed.

3.3.3 Purchasing power parity

PPPs appear in international trade theory in the context of equilibrium exchange rates where they are defined as the underlying rates of exchange towards which actual exchange rates will converge to in the long term. Based on the law of one price (LOOP), PPP asserts that relative prices of goods are not affected by exchange rates changes. Also, the exchange rate changes will be proportional to relative inflation. Indeed, the purchasing power parity states that once converted to a common currency, the real exchange rate, national price levels should be equal**.** The real exchange rate is defined as the nominal exchange rate deflated by a ratio of foreign and domestic price levels $e_{r,t} = \frac{e_{n,t} p_t}{p_t^*}$ with $e_{r,t}$the real exchange rate, $e_{n,t}$ the nominal exchange rate (the home-currency price per unit of foreign currency), p_t the home price and p_t^* the foreign price. The logarithm transformation is defined as follow: $log(e_{r,t}) = log(e_{n,t}) + log(p_t) -$

$log(p_t^*)$. If the hypothesis of PPP holds, the logarithm of the real exchange rate should be stationary. A sufficient condition to reject the hypothesis of PPP is the presence of unit root test in real exchange rate. The challenge to analyze the hypothesis of PPP relies on the consideration of the various exchange rate regimes. Baum et al. (1999) show that for the hypothesis of PPP to hold in the long run (real exchange rate stationary around a constant mean) one should consider the existence of structural breaks in the real exchange rates.

3.4 Balance between approaches

There is no straightforward way to test for stationarity/unit roots. It is important to combine various stationary/unit root tests. Indeed, stationary/unit root tests have one main shortcoming which is their low power (Cochrane, 1991; Blough, 1992). The various tests which consider the null hypothesis of stationarity against the alternative of non-stationarity tend to favor the null hypothesis. Therefore, it is a good practice as a robustness check to use a test whose null hypothesis is stationarity. One should combine unit root tests of Dickey and Fuller (1976, 1981), Perron (1988) types with the KPSS (1992) for instance.

In the presence of a structural break, various unit root/ stationary tests have been performed. Perron (1989) developed a univariate time series unit root test allowing the presence of structural breaks both in the null and the alternative hypothesis while Zivot and Andrews (1992) performed a unit root test allowing structural breaks in the alternative hypothesis.

Practitioners must consider all these tools at their disposal and be aware of their limitations. The combination of these tools is always useful because it allows the user to have an overview of the possibilities that exist. It is worth noting that the choice of the right tools depends on the set up of the problem which is of interest to the researcher and the underlying theory. It is always necessary to recognize the strength and weakness of these tools to discriminate between two contradictory results.

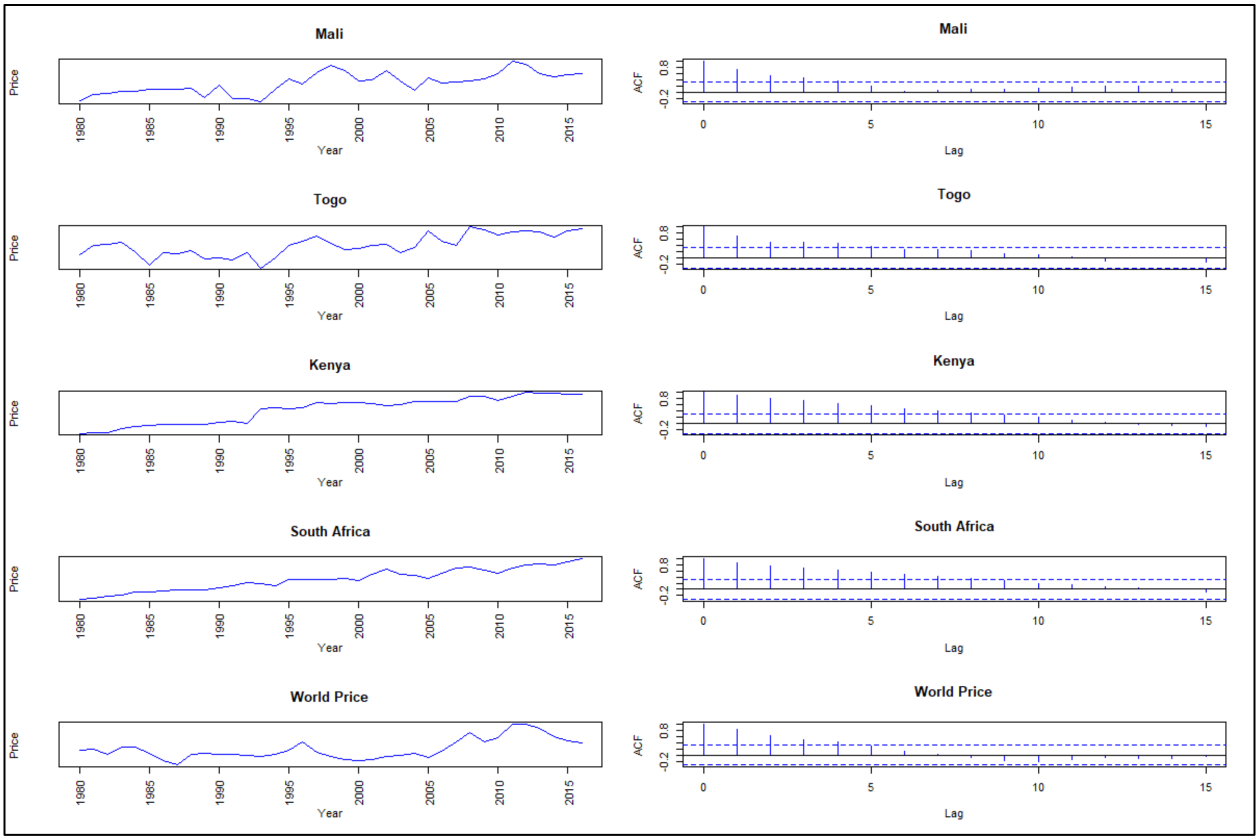
4. Applications

4.1 Data

In this technical note, we focus on the maize producer’s price of Togo, Kenya and South Africa to perform the unit root tests, described above. Referring to FAOSTAT definition, the producer's price is the amount receivable by the producer from the purchaser for a unit of a good or service produced as output minus any VAT, or similar deductible tax, invoiced to the purchaser; it excludes any transport charges invoiced separately by the producer. It refers to prices received by farmers, i.e., prices determined **“at the farm gate”** or at the first point of sale when farmers participate in their capacity as sellers of their own products. Annual producer’s price from 1980 to 2016 are provided by FAOSTAT. Moreover, the world price of maize[2] from the IMF[3] is also considered from 1980 to 2016. All the price series are taken in logarithm so that first differences represent growth rates.

Figure 2 clearly shows that most of the times, series, except the case of Mali, are affected by a trend and the ACF decay is very slow and does not wash out quickly. Therefore, shocks do not die out right away. It is not straightforward from the visual inspection to identify the nature of the processes (TS, DS or mixed process). At this point, unit root/stationary test will help to identify the nature of the processes.

Figure 2: Trend and Partial autocorrelation of maize producer's price



Source: Author's calculation

4.2 Univariate unit root/non-stationary tests

Common unit root tests (Dickey and Fuller (1976, 1981), Philips-Perron (1988), and KPSS (1992)) have low power to reject the null hypothesis and are affected by the presence of the structural break. Enders (1995) noted that if Dickey Fuller test reject the null hypothesis of unit root test, there is no need to proceed. Besides, Perron (1989) noted that if true data generating process is subject to structural changes, these tests are not powerful and do not reject the null hypothesis of unit root. However, we are going to develop at

[2]Maize (corn), U.S. No.2 Yellow, FOB Gulf of Mexico, U.S. price, US$ per metric ton

[3] https://www.imf.org/en/Research/commodity-prices

first, the testing procedure of Enders (1995) and at second, the unit root test of Zivot and Andrews (1992) to consider structural breaks.

4.2.1 Unit root tests using the testing procedure of Enders (1995)

The testing procedure of Enders (1995) points out the fact that the unit root test of Dickey and Fuller have low power to reject the null hypothesis of the presence of unit root. Indeed, if the null hypothesis of unit root is rejected, there is no need to proceed. However, if the null hypothesis of unit root test is not rejected; special care needs are to be taken into account by focusing on the presence or not of the deterministic regressors. Enders (1995) noted that in the presence of deterministic regressors (trend or drift), the asymptotic distribution considered by Dickey and Fuller favor to not reject the null hypothesis. That is the reason why if the null hypothesis of unit root is rejected in the case of a presence of deterministic regressors (trend or drift), there is no need to continue the process and the presence of unit root is straightforward rejected. However, if the presence of unit root is not rejected, Enders (1995) proposes to test the significance of the deterministic regressor (trend or drift). In this case, if the deterministic regressor is significant, hence it's important to retest the model by using the standardized normal distribution. The process is presented in figure 1, and based on it, we perform in the tables 1 and 2 the unit root tests of the maize producer prices of Mali, Togo, Kenya, South Africa, and the world.

As noted in the Tables 1 and 2, the testing procedure of Enders (1995) is a consistent approach to deal with the fact that Dickey and Fuller tests tend to fail in rejecting the null hypothesis if the deterministic regressors (trend or intercept) are not properly included. It is crucial to choose the best asymptotic distribution under the null hypothesis. Indeed, in the null hypothesis of unit root, the distribution of the coefficients doesn't follow the standard normal distribution. Their significance or not is important in the testing procedure of Enders (1995). The Tables 1 and 2, below, help understand better the testing procedure of Enders (1995).

Table 1 presents Enders (1995)' approach of unit root tests of maize producer price in Togo and in South Africa. Both tests reject the unit root presence and support that both series are trend stationary. As noted by Enders (1995), if the null hypothesis of unit root is rejected at the first step, there is no need to pursue.

Table 1: Togo and South Africa: Unit root tests of maize producer's price using the testing procedure of Enders (1995)

Countries	**Togo**	**South Africa**
Models	**Model 1**	**Model 1**
Dependent variable	$\Delta \mathbf{P_t}$	$\Delta \mathbf{P_t}$
	Estimate	**Estimate**
Constant	6.936***	5.594***
	(1.94)	(0.896)
Trend	0.019***	0.092***
	(0.006)	(0.015)
$\boldsymbol{P_{t-1}}$	-0.636***	-1.156***
	(0.177)	(0.187)
$\Delta \boldsymbol{P_{t-1}}$	0.145	0.552***
	(0.17)	(0.153)
Obs	35	35
R2	0.324	0.551
F	4.954***	12.706***
T-statistic	Critical value of DF at 5% in ()	
$t_{\widehat{\beta_0}}$ [4]	3.57** (3.59)	6.24** (3.59)
$t_{\widehat{\beta_1}}$ [5]	3.16 (3.25)	6.10** (3.25)
$t_{\widehat{\rho}}$ [6]	-3.60** (-3.5)	-6.16** (-3.5)

Notes: Signif. codes: '***' means p-value < 0.1; '**' p- value < 0.05; '*' means p- value < 0.1
Note: P_t *is* the logarithm of the maize producer's price
Source: Author's calculation

Table 2 illustrates the procedure for Mali, Kenya and World maize producer prices. For Mali, for the first model we cannot reject the null hypothesis of a unit root. Therefore, we test the significance of the trend. The t-statistic associated with the trend (2.24) must be compared to the critical values tabulated by Dickey and Fuller (1981). Since 2.24 is lower than 3.25, we conclude that the trend is not significant and move to model 2. We then test the null hypothesis of a unit root, which we cannot reject since the t-statistic (-2.0) is higher than the critical value (-2.93). We next test the significance of the constant and since the t-statistic (2.02) is less than the critical value, we conclude that the constant is not significant and move to model 3. For that case, we cannot reject the null as well and conclude that the series contains a unit root without a drift. The same results hold for both Kenya and the world price.

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[4] This statistic represents the t-statistic corresponding to the intercept β_0 in the Enders (1995) testing procedure.
[5] This statistic represents the t-statistic corresponding to the trend coefficient β_1 in the Enders (1995) testing procedure.
[6] This statistic represents the t-statistic corresponding to the unit root coefficient ρ in the Enders (1995) testing procedure.

Table 2: Mali, Kenya and World: Unit root tests of maize producer's price using the testing procedure of Enders (1995)

Countries	**Mali**			**Kenya**			**World price**		
Models	**Model 1**	**Model 2**	**Model 3**	**Model 1**	**Model 2**	**Model 3**	**Model 1**	**Model 2**	**Model 3**
Dependent variable	ΔP_t	ΔP_t	ΔP_t	ΔP_t	ΔP_t	ΔP_t	ΔP_t	ΔP_t	ΔP_t
	Estimate	**Estimate**	**Estimate**	**Estimate**	**Estimate**	**Estimate**	**Estimate**	**Estimate**	**Estimate**
Constant	5.845***	2.754*		2.308**	0.650*		1.445**	0.911*	
	(1.884)	(1.359)		(1.012)	(0.363)		(0.528)	(0.471)	
trend	0.015**			0.028*			0.007*		
	(0.007)			(0.016)			(0.004)		
P_{t-1}	-0.548***	-0.244*	0.002	-0.310**	-0.06	0.011**	-0.328***	-0.187*	0.0001
	(0.178)	(0.122)	(0.004)	(0.148)	(0.04)	(0.005)	(0.118)	(0.097)	(0.007)
ΔP_{t-1}	0.114	-0.05	-0.157	0.011	-0.134	-0.121	0.271	0.224	0.126
	(0.178)	(0.172)	(0.171)	(0.184)	(0.169)	(0.175)	(0.169)	(0.174)	(0.173)
Obs	35	35	35	35	35	35	35	35	35
R2	0.254	0.134	0.03	0.165	0.082	0.115	0.215	0.118	0.016
F	3.527**	2.477*	0.506	2.038	1.438	2.138	2.832*	2.141	0.265
T-statistic	Critical value of DF at 5% in ()								
$t_{\widehat{\beta_0}}$ [7]	3.10 (3.59)	2.02 (2.97)		2.27 (3.59)	1.79 (2.97)		2.74 (3.59)	1.93 (2.97)	
$t_{\widehat{\beta_1}}$ [8]	2.24 (3.25)			1.74 (3.25)			1.96 (3.25)		
$t_{\widehat{\rho}}$ [9]	-3.1 (-3.5)	-2.0(-2.93)	0.5 (-1.95)	-2.1 (-3.5)	-1.5(-2.93)	2.1(-1.95)	-2.9 (-3.5)	-1.9(-2.93)	0.01(-1.95)

Notes: Signif. codes: '***' means p-value < 0.1; '**' p- value < 0.05; '*' means p- value < 0.1
Note:P_t *is* the logarithm of the maize producer's price
Source: Author's calculation

[7] This statistic represents the t-statistic corresponding to the intercept β_0 in the Enders (1995) testing procedure.
[8] This statistic represents the t-statistic corresponding to the trend coefficient β_1 in the Enders (1995) testing procedure.
[9] This statistic represents the t-statistic corresponding to the unit root coefficient ρ in the Enders (1995) testing procedure.

In conclusion, the Enders (1995) approach is an interesting one as it avoids making biased inferences as one can see in many studies. Two (Togo and South Africa) out of the five maize producer price times series are trend stationary and the testing procedure by Enders (1995) fails to reject the null hypothesis of unit root of the other three maize producer prices (Mali, Kenya, World). However, the results from this approach may still fail in the presence of structural breaks.

4.2.2 Common univariate unit root/non-stationary tests considering structural breaks

Zivot and Andrews (1992) approach tests the null hypothesis ($\Delta y_{it} = \beta_0 + \varepsilon_t$) of unit root against the alternative hypothesis of trend stationarity with break (in trend or intercept, or both). They performed a testing procedure based on three models, allowing a break in the alternative hypothesis of stationarity. Table 3 describes the results of the unit root test by Zivot and Andrews (1992), allowing structural break in the alternative hypothesis. Results from Table 3 show that maize producer prices are stationary in trend with a break except for Mali and the World prices. The Zivot and Andrews (1992) test supports the results of Enders (1995)' testing procedure in the case of Mali and World prices by failing to reject the null hypothesis and reject the null hypothesis of unit root in the case of Kenya. Besides, the Zivot and Andrews unit root test rejects the null hypothesis of unit root in the case of Togo and South Africa like the results of Enders (1995)' testing procedure while supporting the structural break.

Table 3: Unit root test with structural breaks

Countries	Mali	Togo	Kenya	South Africa	World price
Dependent variable	ΔP_t	ΔP_t	ΔP_t	ΔP_t	ΔP_t
	Estimate	**Estimate**	**Estimate**	**Estimate**	**Estimate**
Constant	7.635***	12.213***	6.517***	7.019***	2.606***
	(1.936)	(2.271)	(0.834)	(0.884)	(0.577)
trend	0.004	-0.049**	0.056***	0.131***	-0.002
	(0.008)	(0.018)	(0.010)	(0.017)	(0.004)
P_{t-1}	-0.711***	-1.060***	-0.918***	-1.486***	-0.552***
	(0.182)	(0.197)	(0.121)	(0.190)	(0.123)
ΔP_{t-1}	0.099	0.343**	0.171	0.711***	0.329**
	(0.167)	(0.156)	(0.113)	(0.141)	(0.148)
Break	0.403**	-0.763**	0.948***	-0.340***	0.383***
	(0.177)	(0.292)	(0.128)	(0.101)	(0.116)
trend:Break		0.083***			
		(0.023)			
Period of break	1995	1994	1993	2005	2006
Observations	35	35	35	35	35
R2	0.364	0.551	0.705	0.674	0.425
F	4.292***	7.124***	17.965***	15.531***	5.553***
T-statistic	-3.91	-5.38**	-7.56***	-7.83***	-4.5
$t_{\widehat{\beta_0}}$ [10]	3.94** (2.97)	5.37** (2.97)	7.81** (2.97)	7.93** (2.97)	4.51** (2.97)
$t_{\hat{\rho}}$ [11]	-3.91 (-4.8)	-5.38**(-5.08)	-7.56**(-4.8)	-7.83** (-4.8)	-4.5 (-4.8)

Notes: Signif. codes: '***' means p-value < 0.1; '**' p- value < 0.05; '*' means p- value < 0.1
Note:P_t is the logarithm of the maize producer's price
Source: Author's calculation

[10] This statistic represents the t-statistic corresponding to the intercept β_0 in the testing procedure of Zivot and Andrews (1995).
[11] This statistic represents the minimum t-statistic of the break point corresponding to the unit root coefficient ρ in the testing procedure of Zivot and Andrews (1995).

5. Conclusion

One of the best practices in unit root/stationary tests is to understand the common pitfalls and the best practices in their application. Indeed, the most cited common pitfalls in unit root testing are the misspecification in the process definition (TS,DS, or mixed), the failure when considering deterministic terms in the unit root/stationary test, the absence of consideration of structural break(s) due to shocks from crises, institutional changes, or radical policy changes.

Facing the common pitfalls in unit root/stationary tests, practitioners need to develop good practices. The most commonly used best practices are graphic presentation (correlogram), the adoption of the testing procedures such as Dolado et. al. (1990) and Enders (1995)' approaches, going back to theory and empirical results, and the balance between several approaches such as combining unit root and stationary tests, and also the consideration of structural breaks. In conclusion, the econometrician should bear in mind that there is no one-size-fits-all best practice to detect and test for unit root/stationarity.

References

Ayat, L & Burridge, P. (2000). Unit root tests in the presence of uncertainty about the non-stochastic trend. *Journal of Econometrics, vol. 95, no. 1,* 71-96. Récupéré sur http://ideas.repec.org/a/eee/econom/v95y2000i1p71-96.html

Bai, J. and S. Ng. (2004). A Panic Attack on Unit Roots and Cointegration. *Econometrica, 72,* 1127-1177.

Banerjee, A., R. L. Lumsdaine, and J. H. Stock. (1992). Recursive and Sequential Tests of the Unit Root and Trend Break Hypothesis. *Journal of Business and Economie Statistics 10,* 271-287.

Blough, S. R. (1992), The Relationship Between Power and Level for Generic Unit Root Tests in Finite Samples, *Journal of Applied Econometrics*, 7, 295-308.

Campbell, J. Y. and P. Perron (1991). Pitfalls and Opportunities: What Macroeconomists Should Know about Unit Roots. *Vol. 6*, NBER Macroeconomics Annual.

Chan K. H., J. C. Hayya, and J. K. Ord (1977). A note on trend removal methods: the case of polynomial regression versus variate differencing. *Econometrica, 45,* 737-744.

Cochrane, J. H. (1991), A Critique of the Application of Unit Root Tests, J*ournal of Economic Dynamics and Control*, 15, 275-284.

Cuddy, J. D. A. and P. A. Della Valle. (1978). Measuring the Instability of Time Series Data. *Oxford Bulletin of Economics and Statistics 40 (1),* 79-85.

Darné, O. and C. Diebolt (s.d.). Non-stationarity Tests in Macroeconomic Time Series. *2005*.

Dickey, D. A. and W.A. Fuller (1981). Distributions of estimators for autoregressive time series with a unit root. *Journal of the American Statistical Association*, 74, 427-31.

Dickey, D. A. (1976). Estimation and Hypothesis Testing for Non Stationary Time Series.

Dickey, D. A., W. R. Bell, and R. B. Miller (1986). Unit Roots in Time Series Models : Tests and Implications. *The American Statistician, 40,* 12-26.

Dolado, J. J., T. Jenkinson, and S. Sosvilla-Rivero (1990). Cointegration and unit roots. Journal of Economic Surveys 4(3). 249-273.

Enders, W. 1995 (1995). Applied econometric time series. *New York, John Wiley*.

Engle, R. F, and C. W. J. Granger (1987). Co-integration and error correction: Representation, estimation and testing. *Econometrica, 55,* 251-276.

Friedman M. (1968). The role of monetary policy. *American Economic Review 58,* 1-17.

Granger, C. W. J. and P. Newbold (1974). Spurious regressions in econometrics. Journal of Econometrics 2. 111-120.

Johnson, P. A. (2006). Is it really the Fisher effect? *Applied Economics Letters*.

Kwiatkowski, D., P. C. B. Phillips, P. Schmidt, and Y. Shin (1992). Testing the null hypothesis of stationarity against the alternative of a unit root. *Journal of Econometrics*, 54, 159-78.

Lumsdaine, R. L. and D. H. Papell (1997). Multiple trend breaks and the unit-root hypothesis. *Review of Economics and Statistics 79(2)*, 212–218.

Nelson, C. R. and C. I. Plosser (1982). Trends and random walks in macroeconomic time series. *Journal of Monetary Economics* , 10, 139-62.

Nelson, C.R. and H. Kang (1981). Spurious periodicity in inappropriately detrended time series. *Econometrica 49*, 741-751.

Ouliaris, S., J. Y. Park, and P. C. B. Phillips (1989). Testing for a Unit Root in the Présence of a Maintained Trend. (B. R. Dordrecht, Éd.) *Econometrics and Modelling*.

Park, J. Y., and P. C. B. Phillips (1988). Statistical Inference in Regressions with Integrated Processes: Part F, *Econometric Theory,* 4: 468-97.

Perron, P. (1988). Trends and Random Walk in Macroeconomic Time Series : Further Evidence from a New Approach. *Journal of Economic Dynamics and Control, 12*, 297-332.

Perron, P. (1989). The Great Crash, the oil price shock and the unit root hypothesis. *Econometrica, 57*, 1361-401.

Phelps, E. (1967). Phillips curves, expectations of in°ation and optimal unemployment over time. *Economica 34*, 254-281.

Phelps, E. (1968). Money wage dynamics and labor market equilibrium. *Journal of Political Economy 76*, 678-711.

Plosser, C. I. and G. W. Schwert. (1978). Money, income and sunspots: Measuring economic relationships and the effects of differencing. *Journal of Monetary Economics, 4*, 637-660.

Plosser, C. I. and G. W. Schwert. (1977). Estimation of a noninvertible moving average process: The case of overdifferencing. *Journal of Econometrics, 6*, 199-224.

Quah, D. (1994). One business cycle and one trend from (many,) many dissagregates. *European Economic Review, 38,* 605-613.

Zivot, E. and D. W. K. Andrews (1992). Further evidence on the Great Crash, the oil-price shock, and the unitroot hypothesis, *Journal of Business and Economic Statistics, 10*, 251-70.